Power Generation in the 21st Century:
Next Generation Gas Turbine Systems

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Slide 1: Next Generation Turbine Systems

Good afternoon. In my talk this afternoon, I will discuss three points:

- What does FETC see as potential market for gas turbines?
- What is the status of the current ATS program?
- What is the future of the DOE/FE portion of the turbine program — the NGTS Program.

I'd like to leave you with a sense of wonder and enthusiasm for the next generation of systems!

Slide 2: Cumulative New U.S. Generating Capacity, 1997-2020

Let me start with the potential market for gas turbines. Gas-fired, combustion turbines will meet the bulk of the demand for new capacity in the U.S. The reference case, the DOE Energy Information Administration (EIA) baseline scenario of 20 gigawatts (GW) per year agrees with John Siegel's scenario. We will need 380 GW between now and 2020: to meet a 1.4 percent per year growth in demand, and to replace retired units, primarily retiring nuclear and coal.

In the high-growth scenario, we will need 400 GW of new capacity. If we assume an average plant capacity of 300 MW, this is over 1,000 new plants! EIA projects that 87 percent of this new capacity will be combustion turbines, in simple or combined cycles.

To temper this very optimistic projection, EIA projections reflect regulations in effect as of July 1998. They do not address restructuring of the electric industry. With restructuring, the prospects for distributed generation — micro turbines, fuel cells, wind, etc. — could capture a significant fraction of the market by 2020.

Slide 3: Worldwide Generating Capacity Additions, 1997-2006

What happens internationally? This slide shows ***planned additions*** to worldwide generating capacity between 1997 and 2006, and is less optimistic than John Siegel's projection. Developing countries have a huge unmet demand for electricity. One third of the world's 6 billion inhabitants do not have access to electricity.

For the longer term, EIA predicts that natural gas will increasingly become the fuel of choice for new plants worldwide. John Siegel's demand scenario is approximately 100 GW per year, and two-thirds of this is turbine-based.

Slide 4: Power Generation Economics Favor Natural Gas

One reason for the dominance of turbines in the U.S. market is economics. Compared to other technology and fuel options, gas-fired, combustion turbines currently result in the lowest cost of electricity.

- The capital cost of turbo machinery is low. Technology has improved the efficiency and reliability, and reduced the cost.

- The fuel cost is low. Deregulation of the gas industry, and new technology to explore and produce natural gas, have reduced its price over the past two decades.

This slide shows data from Mobil. The cost of electricity (COE) from new gas plants is 3 cents per kilowatt hour compared to 5 cents for coal plants. Electricity from renewables costs more than conventional sources. However, renewable costs have declined dramatically, and are still being reduced.

The second reason for the dominance of turbines is environmental. Gas is cleaner than other fossil energy sources! Natural gas systems are virtually free of sulfur dioxide (SO_2), particulate, heavy metal, and toxic organic emissions. However, coal can be cleaned up to this level using technology, such as integrated gasification combined-cycle (IGCC), albeit at a higher capital cost.

Slide 5: Technology Can Reduce CO_2 Emissions From Fossil Energy Power Plants

Natural gas is the least carbon intensive of the fossil fuels. Existing coal-based power plants emit almost one ton of carbon dioxide (CO_2) for every MW-hr of electricity generated. Future coal-based plants could emit much less. But natural-gas combined-cycle systems emit even less CO_2 — 700 pounds per MW-hr.

This slide shows that CO_2 sequestration could enable ***all*** fossil-based systems to reduce CO_2 emissions by 90 percent or more. DOE has started a research and development (R&D) program to explore environmentally sound, cost-effective ways to sequester CO_2. But sequestration is the topic of another speech . . .

The middle bars are labeled Vision 21.

Slide 6: Vision 21 Plant

Let me define DOE's Vision 21 program. This is a new program that pushes efficiency and emission reduction to the limit, in fossil-based energy plants, at sizes larger than 30 MW. These plants can use coal, or gas, or any carbon-based feedstock. They can produce electricity, or fuels or chemicals, or combinations of these, plus steam and heat.

But they do so with absolutely the highest efficiency — harnessing the maximum amount of useful energy in the feedstocks to produce energy products. The fuel-to-electric efficiency for an electric-only Vision 21 plant is: 60 percent on coal, and 75 percent on gas.

Fuel and chemicals Vision 21 plants have equally challenging efficiency targets.

With the option of sequestration, Vision 21 plants can have near zero emissions — essentially, decoupling the use of fossil energy uses from its environmental implications.

Vision 21 uses a series of pre-engineered modules. One of these modules in an advanced gas turbine module. Thus, the successor program to the ATS program (which I will describe later) is a key part of Vision 21 plants.

Slide 7: Projected Natural Gas Consumption, 2000-2020

To serve the growing gas turbine market, demand for natural gas will increase. U.S. gas consumption will increase between now and 2020 for all sectors, but demand increases dramatically in the electric sector — almost tripling, growing from 3.5 trillion cubic feet (Tcf) in 2000 to 9 Tcf in 2020. Total annual gas demand will grow 50 percent by 2020, from 22 Tcf in 1997 to 32 Tcf in 2020, again under EIA's baseline case with no policy changes such as a Kyoto agreement.

Clearly, we are going to use much more natural gas. But under a carbon constrained scenario, we could use much, much more.

Slide 8: Enough Natural Gas to Meet Demand?

Do we have enough gas to meet this rising demand? DOE asked the National Petroleum Council to look at future U.S. gas supply. We expect their report in the near future. I don't want to anticipate what this report might say. However, my view is that we do have plenty of natural gas.

Experts place the total U.S. potential natural gas resource at 1,600 Tcf, about a 50 to 60 year supply, but as we use it up, we continue to discover more. If we consider methane hydrates, we have a mammoth resource. It is estimated at 320,000 Tcf, an almost unlimited gas supply if we can find a way to produce hydrates — safely and cost effectively.

The real issue is ***what price*** will this gas be, particularly if we establish policies that preclude the use of coal and nuclear in existing or new power plants. Over the past 20 years, new technology for gas exploration and production (E&P), coupled with deregulation of the gas industry, worked together to keep gas prices low. As we moved toward more unconventional resources (tighter formations, deeper offshore wells), technology improvements offset the costs of the more challenging production environment.

DOE has a $15 million per year R&D program in gas E&P to continue this technology influx. We are also planning a 10-year methane hydrate program to better characterize this potential resource.

Let me talk about the current ATS program and what we have accomplished so far in the program.

Slide 9: ATS Program Objectives

The ATS program began in 1992 with clear objectives: to develop advanced turbines for utility and industrial applications that are ultra-high efficiency, super-clean, cheaper, and fuel-flexible. The objectives may seem tame today, but lest we forget, when they were established in 1990, they were very aggressive! They represented a leapfrog in turbine performance.

Slide 10: ATS Program Today

The structure of the ATS program has changed over its lifetime. It started with six turbine manufactures completing Phase I systems studies. We are now in Phase III, Technology Readiness testing. The DOE Office of Energy Efficiency and Renewable Energy (EE) is responsible for the industrial turbine portion, and the DOE Office of Fossil Energy (FE) is responsible for the utility portion. All of this has been supported by a tech-base research program, shared by FE and EE.

Let me give you a snapshot of the major FE projects in the program. Pat Hoffman will discuss the EE projects next.

Slide 11: General Electric Company

GE is developing an H-class, utility-scale combined-cycle (CC) system. GE's H-class turbines meet or exceed ATS goals for NO_X emissions, efficiency, and COE. The 60 Hz machine, which is formally part of the DOE program, is called the 7H. It is a 400-MW CC system.

The 50 Hz version (in the picture), the 9H, incorporates many ATS improvements. Full-speed, no load testing has been completed on the 9H, and it will be shipped to the United Kingdom for a demonstration next spring. The 7H will under go technology readiness and validation testing this year at Greenville, South Carolina. A pre-commercial demonstration will be conducted in 2001. You will hear more in a GE paper tomorrow. The discussion will include the siting of the 7 and 9H demonstration projects.

Slide 12: Siemens-Westinghouse Power Corporation

Siemens-Westinghouse is developing a 420-MW CC system. They have demonstrated ultra-low NO_X emissions, to about 4 or 5 parts per million, in component testing. They have installed a prototype ATS turbine, called the 501G, in Lakeland, Florida. (This is a picture of the turbine at Lakeland in shakedown.)

Siemens-Westinghouse plans a pre-commercial demo of the 501 ATS turbine in 2002. You will hear more in their paper today.

Slide 13: Industry/University Consortium

The third major piece of the DOE/FE program is the Industry/University Consortium, managed by the South Carolina Institute for Energy Studies (SCIES), which you can hear about in the film clip at the ATS display. We like to think of it as a virtual national lab composed of 95 universities and 8 industrial partners.

The program includes an R&D component, an educational component, and workshops/seminars. I encourage you to visit the poster session in the back of the room tomorrow and learn about the exciting results produced by this consortium.

Slide 14: Drivers for Continuing Government Investment in Advanced Gas Turbines

The ATS program is a success — read *Gas Turbine World.*

Much of the technology developed under the ATS Program is already being incorporated into existing products. The developers have surpassed the original goals of the program, proving that the sceptics back in 1990 were wrong!

And therein lies a problem! If the ATS Program is so successful, and if the market for gas turbines is so large, why does the government need to continue to fund turbine research? Why do we need a next generation program?

There are many drivers for continuing government investment. The market is large. Environmental regulations are continuing to ratchet downward. The public benefits are enormous if the very best, cleanest, and most cost effective power generation technology can be installed — a capital asset with a 50-year replacement cycle.

At the same time there is this great need, the restructured electric industry is becoming extremely competitive. Equipment costs have been driven down, making it difficult for equipment suppliers to invest in R&D.

In addition,

- The ATS program did not address mid-size gas turbine systems in the 30- to 150-MW size range.

- Nor did the ATS program include turbines for intermediate duty.

- Nor did the ATS program envision merchant plant owners when it started. Today, there is more emphasis on reducing life-cycle costs.

U.S. manufacturing jobs are a spinoff benefit for a government-funded program. If U.S. turbine manufacturers remain cutting-edge performers, they can compete in U.S. and world markets. This is too big a market for the U.S. to lose.

In their 1997 report, the President's Committee of Advisors on Science and Technology (PCAST) endorsed further gas turbine technologies R&D. Their rationale was the environmental driver.

Slide 15: Next Generation Turbine Systems

The Next Generation Turbine Systems (NGTS) program responds to these drivers.

We in FE hope we listened to you in designing this program. Many of you in this audience participated in several workshops we held to define the drivers and the technical performance targets for future turbine systems.

The next generation program has three components:

- Near-term systems with potential spinoffs in the 2000 to 2010 time frame.
- Long-term systems, which could impact the market in 2010 to 2015.
- Supporting R&D, to continue throughout the program.

Slide 16: Near-Term Next Generation Systems

During the Near-Term phase, DOE in partnership with industry, will develop by 2010:

- Flexible gas turbine systems (FGTS),
- Fuel-flexible, advanced turbine systems, and
- Hybrid turbine/fuel cell systems for distributed power. This is a shared DOE/FE - DOE/EE program. EE is responsible for the micro turbine development, and EE is responsible for the fuel cell and balance-of-plant (BOP) integration.

Slide 17: Near-Term Performance Targets

The near-term performance targets are aggressive.

- Flexible Gas Turbine Systems (FGTS) are:
  - Targeted for intermediate and peaking duty,
  - Simple cycle,
  - Mid-size range — 30 to 150 MW,
  - Suitable for distributed or central-station applications,
  - More efficient than current simple-cycle systems — a lower heating value (LHV) efficiency of 50 percent, and
  - Natural-gas based.

- Fuel-Flexible ATS:
  - Are targets for base-load combined-cycle in sizes greater than 50 MW for self-generation or central station markets,
  - Operate on coal-derived or other solid fuels, and
  - Operate an LHV efficiency of better than 45 percent in combined-cycle mode (still studying LHV efficiency of greater than 50 percent).

- Targets for hybrid combined turbine and fuel cell systems are:
  - Small size, less than 30 MW,
  - High efficiency, operating at a LHV efficiency of 70 percent on natural gas, and
  - Aimed at the distributed power market.

Slide 18: Long-Term Next Generation Systems

There are two classes of technology in the longer term portfolio: hybrid, turbine fuel cell systems for central stations; and revolutionary turbine cycles. Examples of revolutionary cycles include:

- Hydrogen turbines, no CO_2 production.
- Methane/oxygen/steam combustion turbines. The steam is used to control combustion temperature. The products are a concentrated stream of CO_2 and water.
- Ramjet engines — applying ramjet technology to turbo machinery. See the Ram Gen, Inc. web site.

Slide 19: Long-Term Performance Targets

This slide show the performance targets for the long-term systems. These systems are enabling technologies for Vision 21 plants at greater than 30 MW size. The hybrid turbine fuel cell systems have very high efficiencies on both natural gas and coal. The revolutionary turbine cycles also have aggressive efficiency targets.

Slide 20: Supporting Research and Development

The Supporting R&D component will continue throughout the NGTS program. Researchers will work to resolve remaining issues, for example: developing robust, zero emission combustion systems; creating more durable ceramics and alloys; using advanced computing to accelerate turbine design; developing technologies to reduce life-cycle cost; and developing better techniques for diagnostics, control, and monitoring.

Slide 21: Implementation

We have several competitive solicitations in the pipeline to implement the Next Generation program. A broad-based financial assistance solicitation was recently released as part of the Vision 21 program. We expect to release an FE-wide R&D broad-based solicitation this month.

We anticipate releasing several program research and development announcements (PRDAs) that target specific aspects of the next generation program. This year's PRDA is for the Flexible Gas Turbine System. The announcement in the *Commerce Business Daily* is on the street now, and the solicitation comes out this month.

As always, we welcome cooperative research and development agreements (CRADAs) with FETC's in-house researchers.

Slide 22: NGTS Program Philosophy

For the taxpayers to fund it, the Next Generation program must provide significant public benefit. Emission reduction is the primary benefit, and job maintenance and creation is an outcome. To achieve the public benefit of reducing emissions, the program must result in a product that the

private sector will commercialize. Therefore, the program has to overlap "public needs" with the needs of turbine developers and suppliers.

The structure of the NGTS program will differ from the ATS program. We envision multiple, smaller awards: more awards targeting specific, critical research needs. We expect broader teams of developers and suppliers to be involved. Since NGTS can have civilian and military use, we expect some aspects to be developed in cooperation with the National Aeronautical and Space Administration (NASA) and the Department of Defense (DoD).

To achieve next generation goals, industry, academia, and government partners will need to work together. We expect that the highly successful industry/university consortium formulated under the ATS Program will continue in some form.

But we also expect more consortiums to be developed. Some will be pre-competitive consortia — horizontal consortia cutting across the industry, sharing intellectual property. Some will be competitive consortia — retaining intellectual property, and including a turbine developer along with its supply chain. We expect full implementation in FY 2001. We received seed funding of $1 million in FY 1999 and 2000 to begin shaping the program.

Slide 23: What Does the Future Hold?

A few closing thoughts. The ATS Program has been highly successful. But U.S. industry has requested continued government involvement in combustion turbine R&D. DOE has responded with the Next Generation program that will meet:

- The taxpayer's need for a technology to produce lost-cost, clean, efficient electricity.

- The private sector's needs for systems with reduced life-cycle costs and improved fuel flexibility and reliability.

We invite your comments on the program. We invite your participation in the program.

Thank you.

Next Generation Gas Turbine Systems

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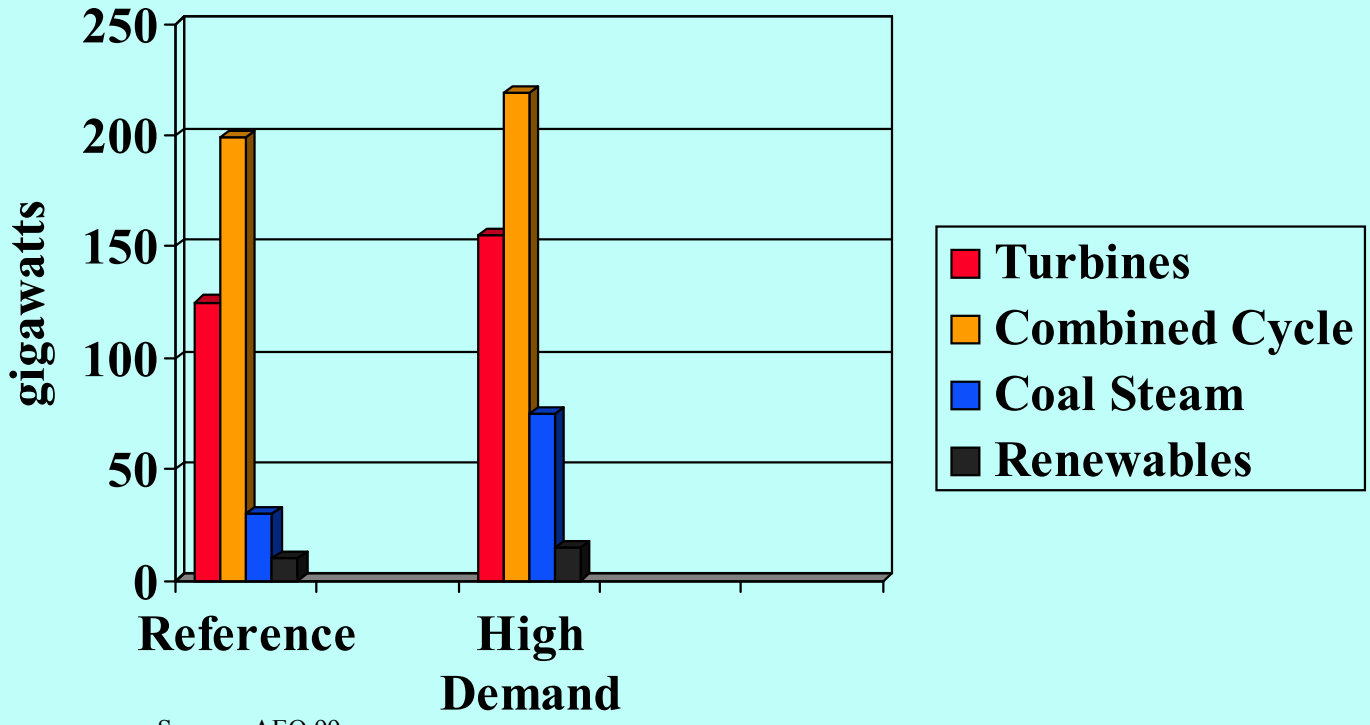
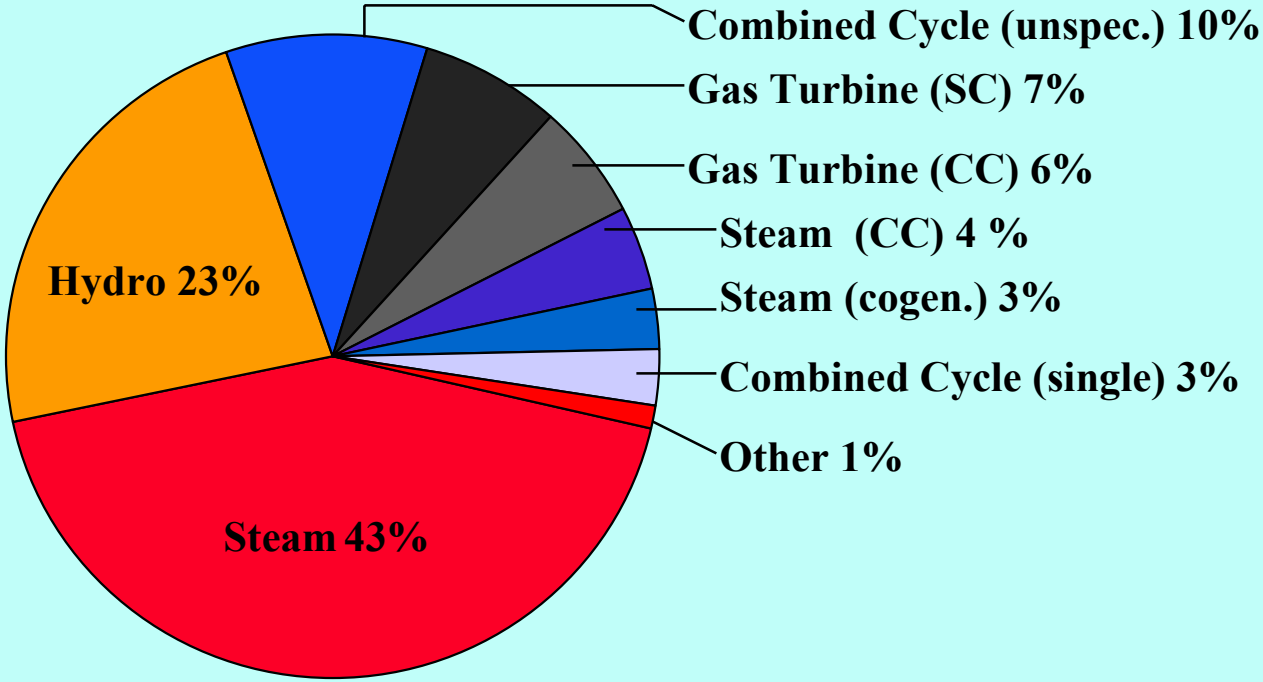
Cumulative New U.S. Generating Capacity 1997-2020



Source: AEO 99

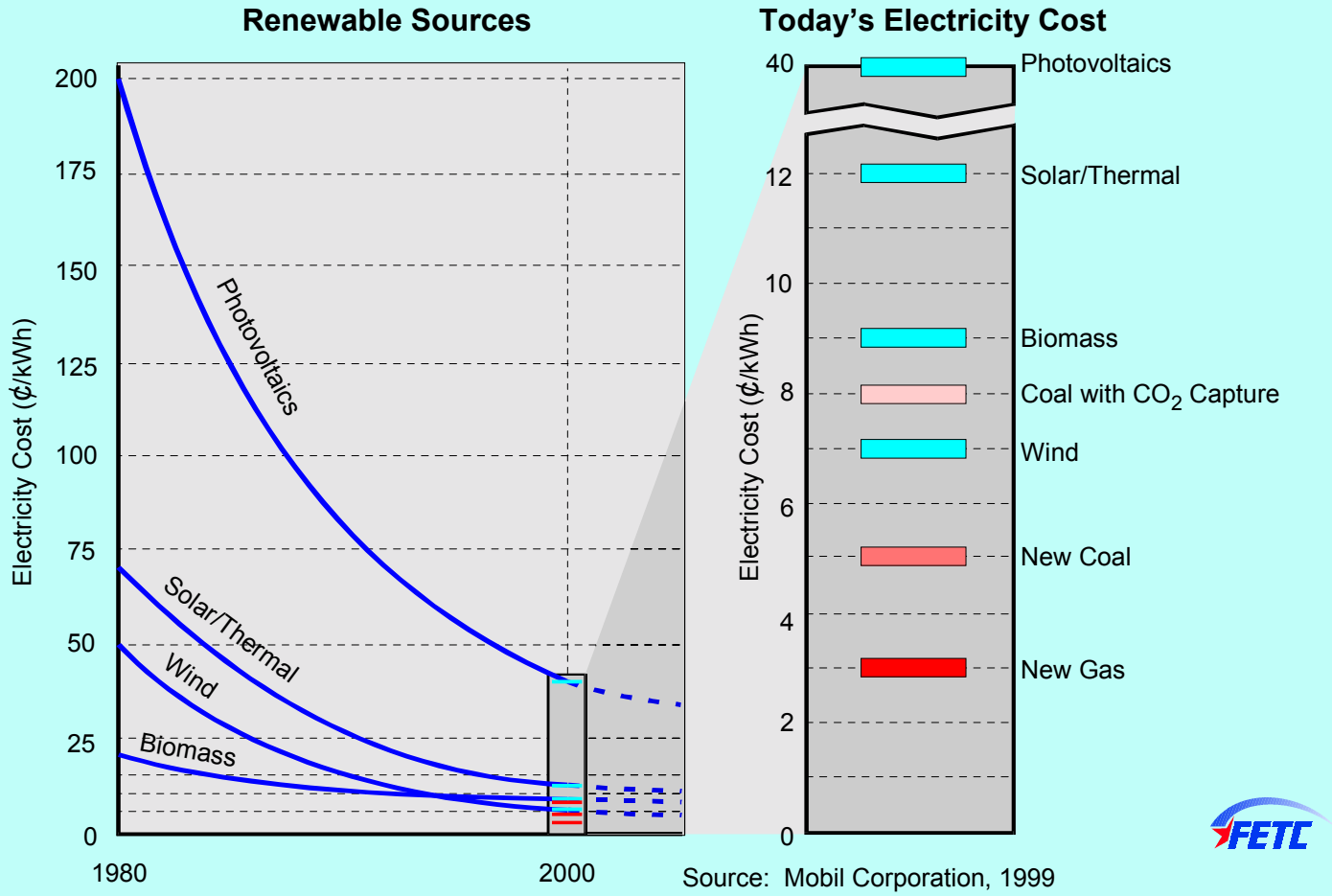
Worldwide Generating Additions, 1997-2006

642 GW Total Additions



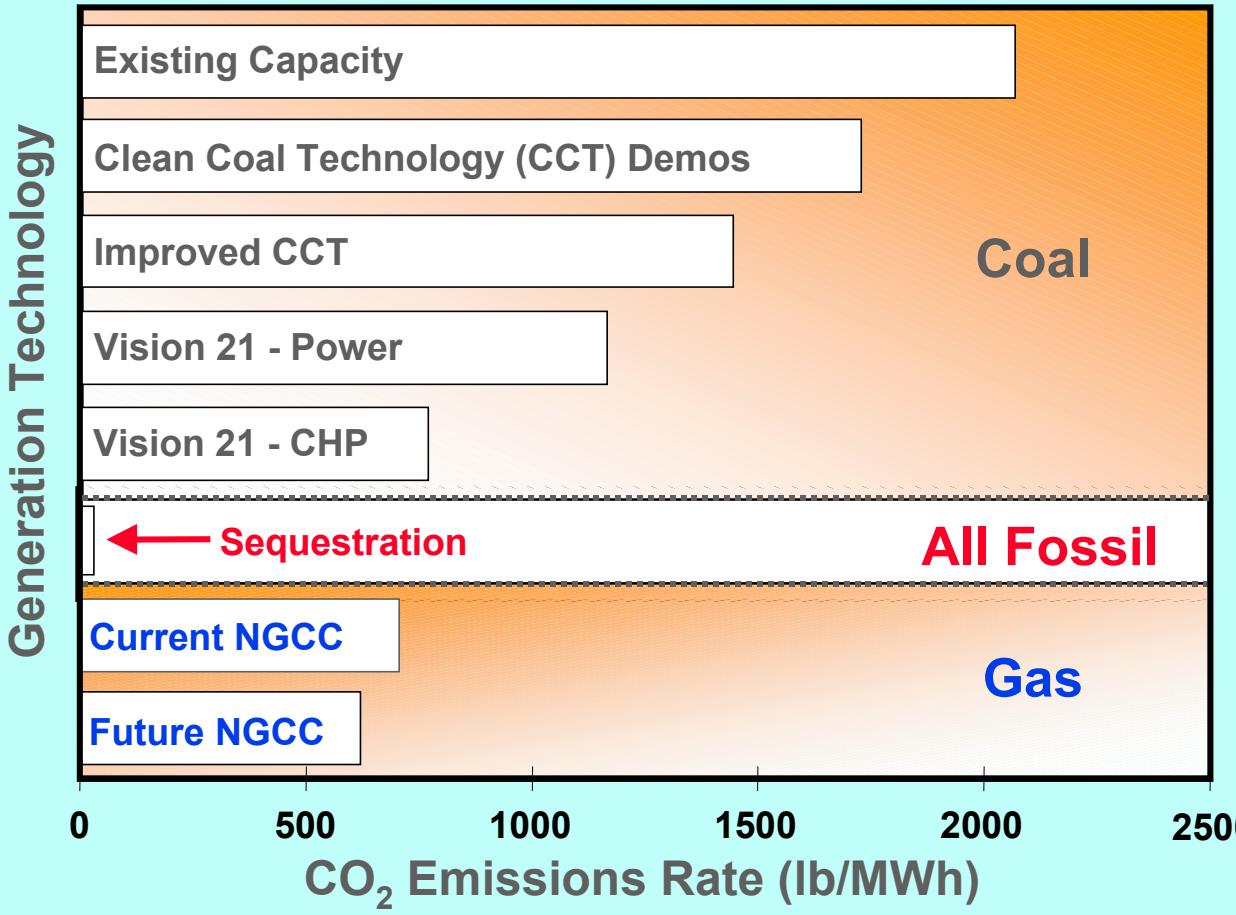
Source: TMI Handbook 1998

Power Generation Economics Favor Natural Gas



Source: Mobil Corporation, 1999

Technology Can Reduce CO_2 Emissions From Fossil Energy Power Plants



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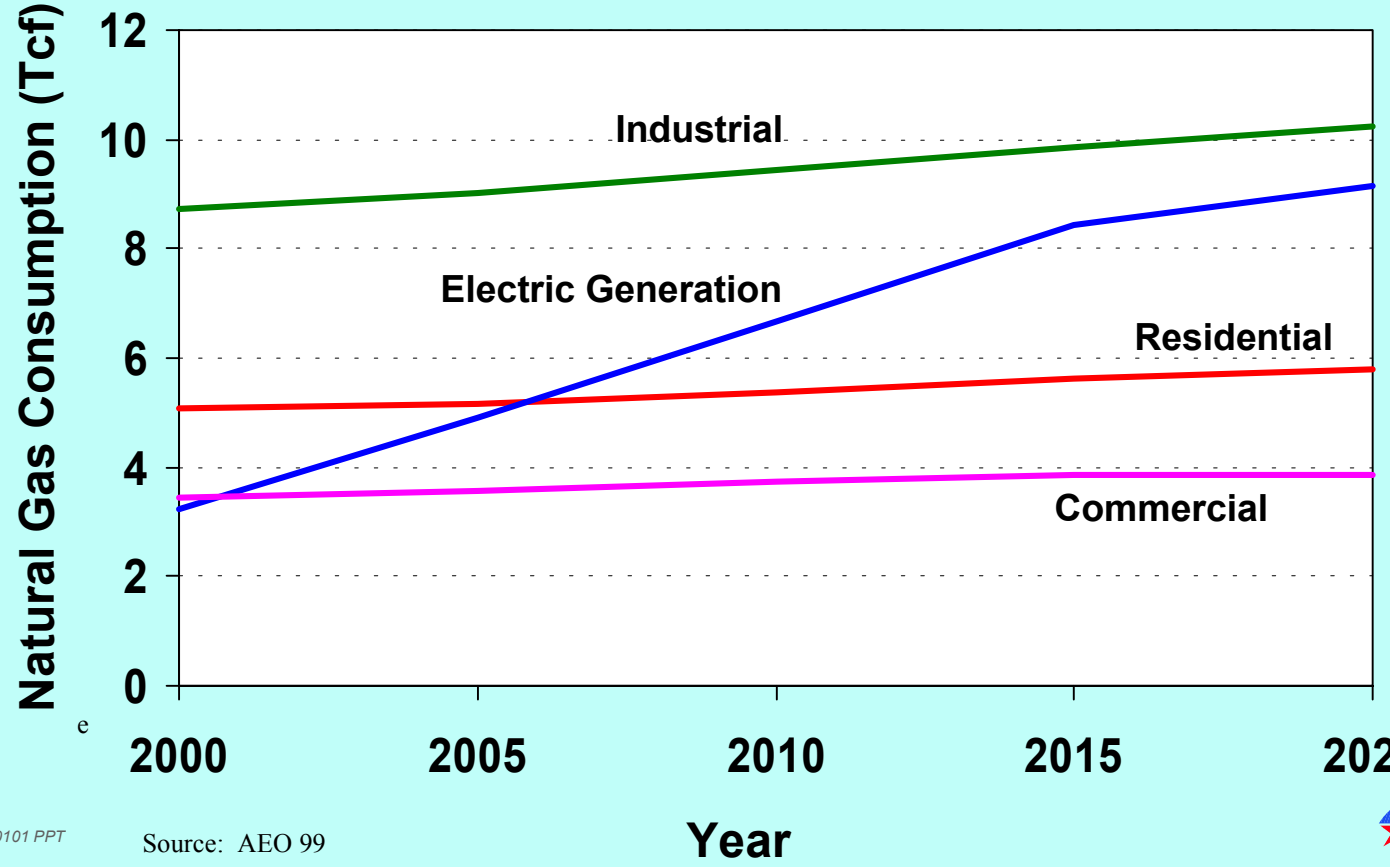
Vision 21 Plant

Projected Natural Gas Consumption 2000-2020



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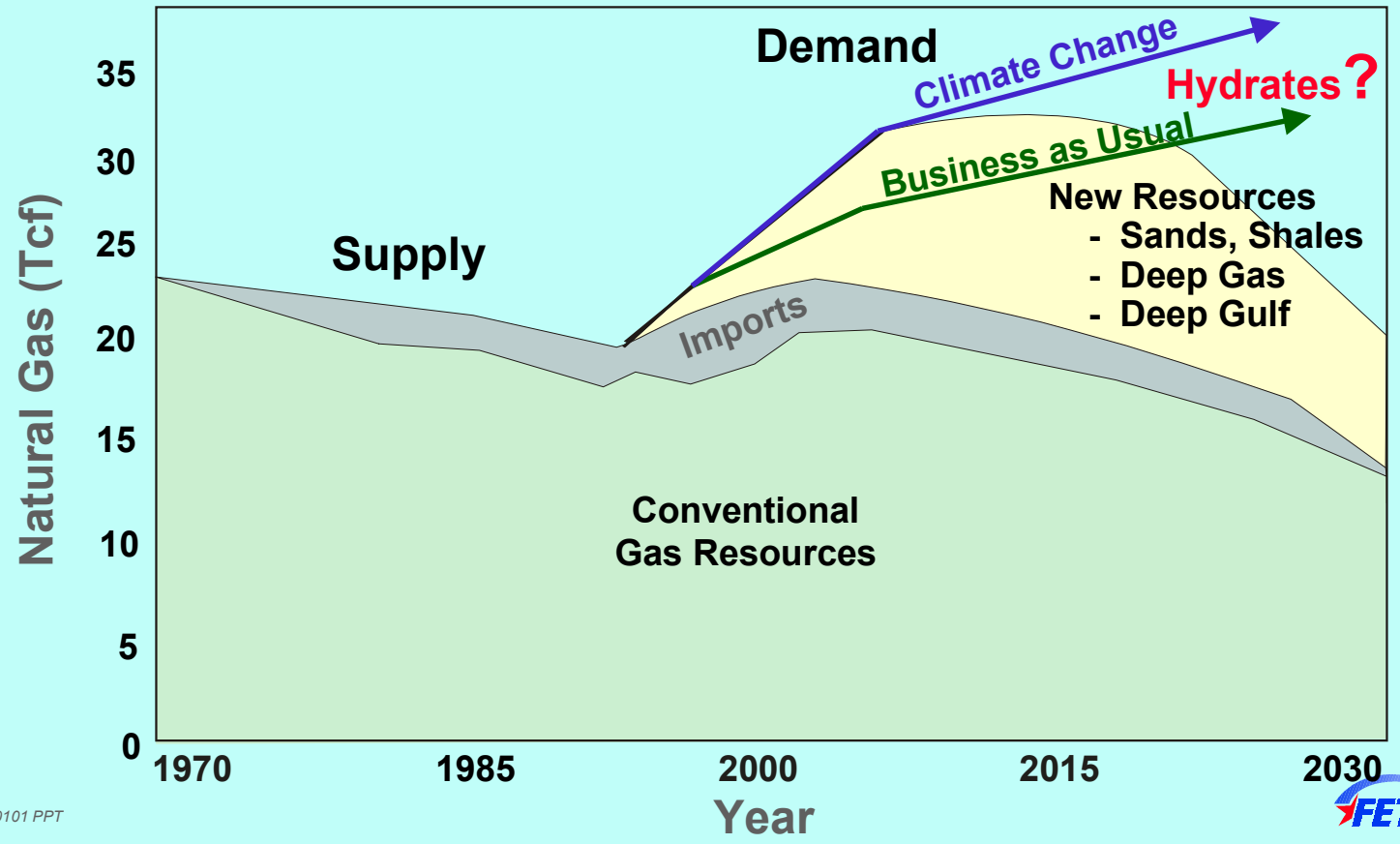
Source: AEO 99

Enough Natural Gas to Meet Demand?



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ATS Program Objectives

By 2000, develop advanced turbines that are:

- **Ultra-high efficiency:** >60% for utility-scale systems
  15% improvement for industrial-scale systems
- **Super-clean:** NOx <10 ppm
- **Cost of electricity:** 10% less
- **Fuel-flexible:** gas is primary focus

Leapfrog in Turbine Performance

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ATS Program Today

System Studies (Phase I)

Concept Development (Phase II)

Technology Readiness Testing (Phase III)

UNITED TECHNOLOGIES TURBO POWER

ABB

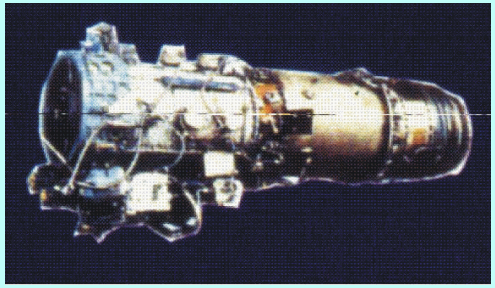
Allison

Solar® Turbines
A Caterpillar Company

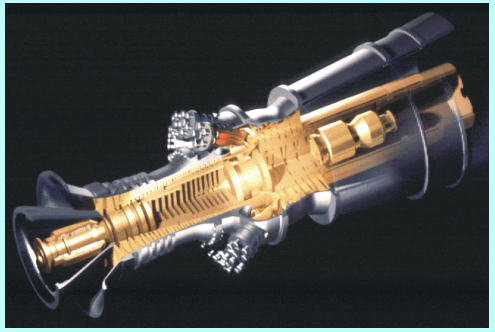
GE

Westinghouse

Manufacturer Full-Scale Testing/ Performance Validation



Industrial



Utility

Technology Base Research

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General Electric
Turbine System Development and Testing

- Completed full scale testing of 9H (50Hz) ATS, Greenville SC
- Complete 7H (60Hz) ATS testing in 2000, Greenville SC
- Conduct pre-commercial demonstration of 7H ATS in 2001

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Siemens-Westinghouse
Turbine System Development & Testing

- Continue field testing of catalytic combustion and steam cooled systems on 501G
- Develop steam cooled vanes and test on 501GS power plant in 2001
- Conduct pre-commercial demo of 501 ATS at customer site in 2002

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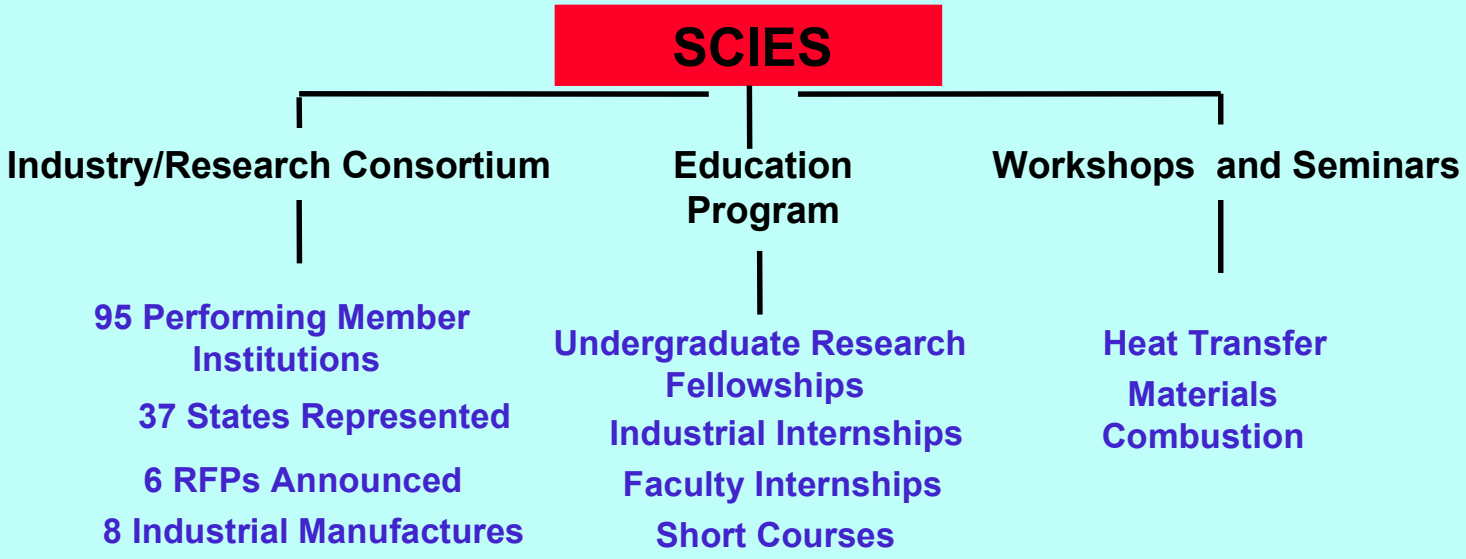
Industry/University Consortium

95 universities, 8 industry partners



Drivers for Continuing Government Investment in Gas Turbines

- **Growing worldwide demand for electricity**
- **Tightening environmental requirements**
- **Declining R&D budgets in restructured U.S. electric industry**
- **Need flexible power generating technology:**
  - Mid size gas turbine systems
  - Satisfy intermediate load
  - Low operating costs
- **Increased competition from abroad**

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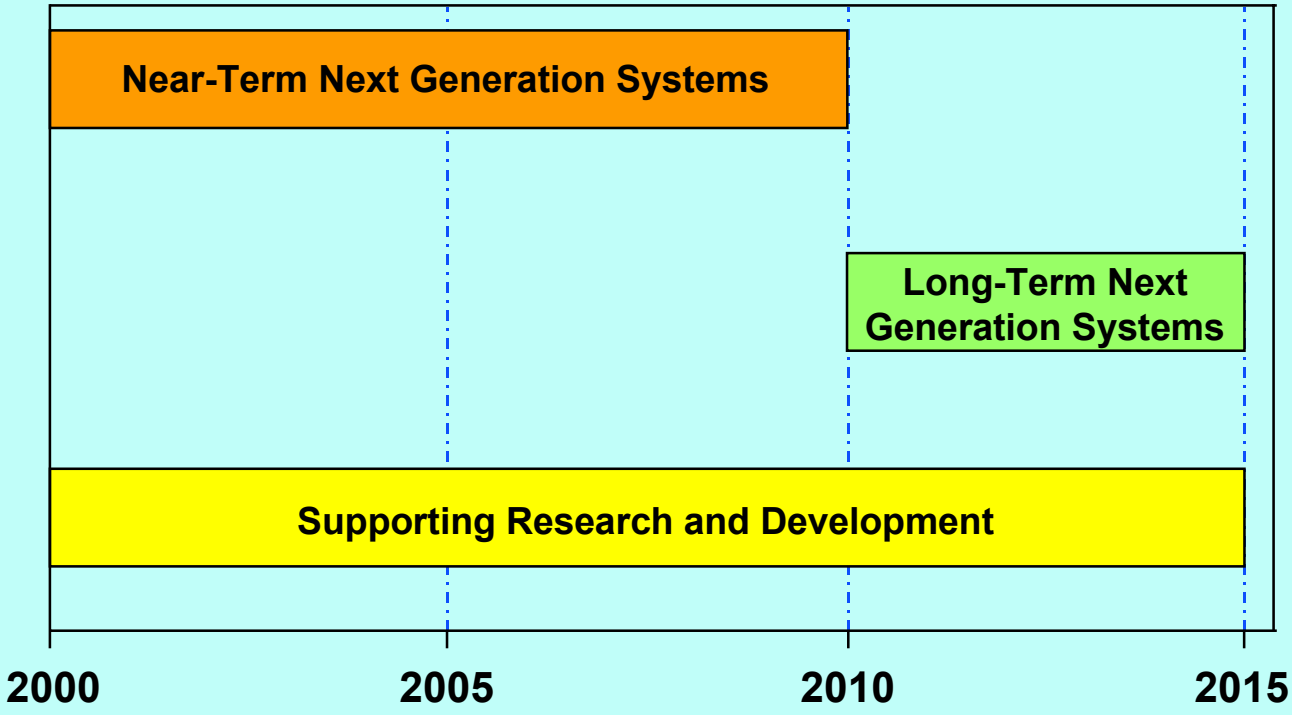
Next Generation Turbines Systems



Near-Term Next Generation Systems

- Flexible gas turbine systems
- Fuel-flexible advanced turbine systems
- Hybrid systems for distributed power

Near-Term Performance Targets

	FGTS	Fuel-Flexible ATS	Hybrids
Electrical Efficiency (LHV)	50% (simple cycle)	>45% (combined cycle)	70%
Power Rating (MW)	>30	>50	<30
Fuels	Natural Gas	Coal	Natural Gas
Power Markets	Distributed/ Central Station	Central Station/ Self-Generation	Distributed

These systems will be permittable under 2010 regulations; acceptable life cycle and cost of electricity.

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Long-Term Next Generation Systems

- **Hybrid fuel cell / turbine systems for central station power**
- **Revolutionary turbine cycles for central station power**
  - **Examples:**
    - Hydrogen turbines
    - Methane/oxygen/steam combustion turbines
    - Ramjet engines

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Long-Term Performance Targets

	Hybrids	Revolutionary Turbine Cycles
Electrical Efficiency (LHV, Gas Fueled)	75-80%	>65%
Electrical Efficiency (HHV, Coal Fueled)	>60%	60%
Power Rating (MW)	>30	>50
Power Markets	Vision 21	Vision 21

These systems will be permittable under 2015 regulations; acceptable life cycle and cost of electricity; zero emissions with carbon sequestration options.

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Supporting Research and Development

- Robust zero-emission combustion systems
- Materials: durable ceramics, advanced alloys
- Advanced computing
- Life-cycle cost maintenance
- Diagnostics, controls, and monitoring

Implementation

- **Broad-based financial assistance solicitations**
  - Vision 21 (released)
  - Fossil energy wide R&D (11/99)
- **Targeted next-generation program research & development announcements (PRDAs)**
  - FGTS is focus (11/99)
- **Cooperative research & development agreements (CRADAs)**

NGTS Program Philosophy

- Provide significant U.S. public benefits
- Focus on critical research needs
- Leverage DOE funding with DOD, NASA, and private R&D investments
- Use both pre-competitive and competitive consortiums
- Full implementation in FY 2001

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What Does the Future Hold?

- ATS commercialization providing significant public benefits
- DOE supporting federal R&D program to meet future need for low-cost, clean, efficient electricity
- U.S. turbine industry participating to reach goals of

  "next generation gas turbine program"

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