



U.S. Department of Energy

International Conference on Innovation in Energy Technologies

The Innovation of Complex Energy Technologies: The Case of the Advanced Turbine System Program

By

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Policy and International Affairs



Advanced Turbine Systems

Siemens - Westinghouse
501G



375 MW, 58% Efficiency

General Electric
H System



480 MW, 60% Efficiency



ATS Overview

- Technology Performance Characteristics
 - 60% efficiency
 - Less than 10 ppm NOx emissions
 - 10% lower operating costs
- DOE ATS Program
 - \$755 million cost-shared program
 - Public-private partnership between industry-universities-government
 - Phased Approach Using Cost-shared Agreements



Objective of the Study

- Examines the innovation of a complex, energy technology
- Seeks to understand how the OEMs acquired knowledge and capabilities needed for innovation under conditions of uncertainty
- Illuminates our understanding of innovation of complex energy technologies within a public-private partnership

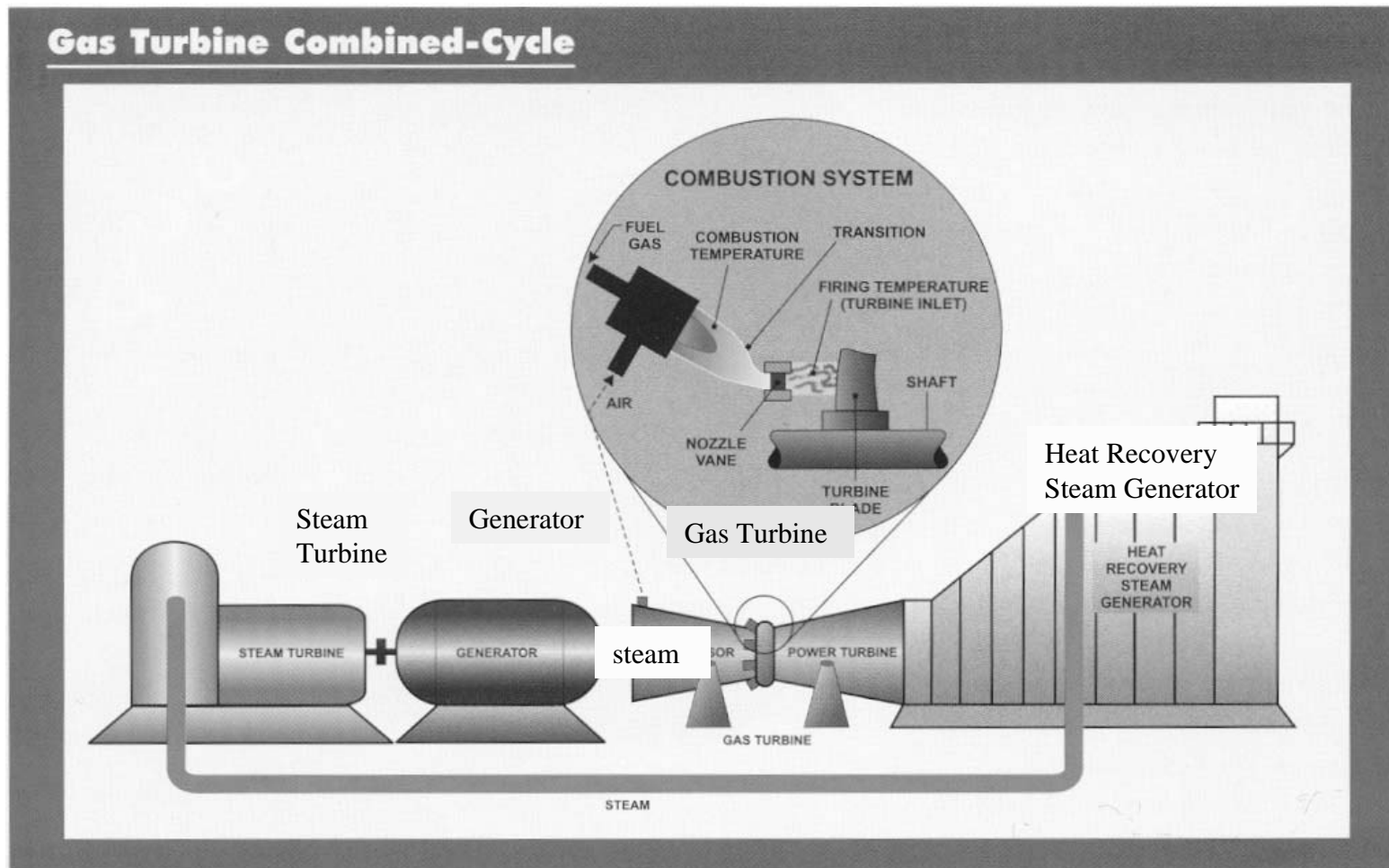


It's An Ideal Subject Because..

- Manufacturers Overcame Presumptive Technological Limits
 - Higher Temperatures Needed for Efficiency
 - But Higher Temps Can Mean High NOx Emissions
 - Problems with “Lean” Fuel-Air Mixtures
 - Exceed Material Tolerances
- Technological Change Occurred During Period of Uncertainty
- Public-private Partnership Used to Spur Innovation



Combined-cycle Gas Turbine System



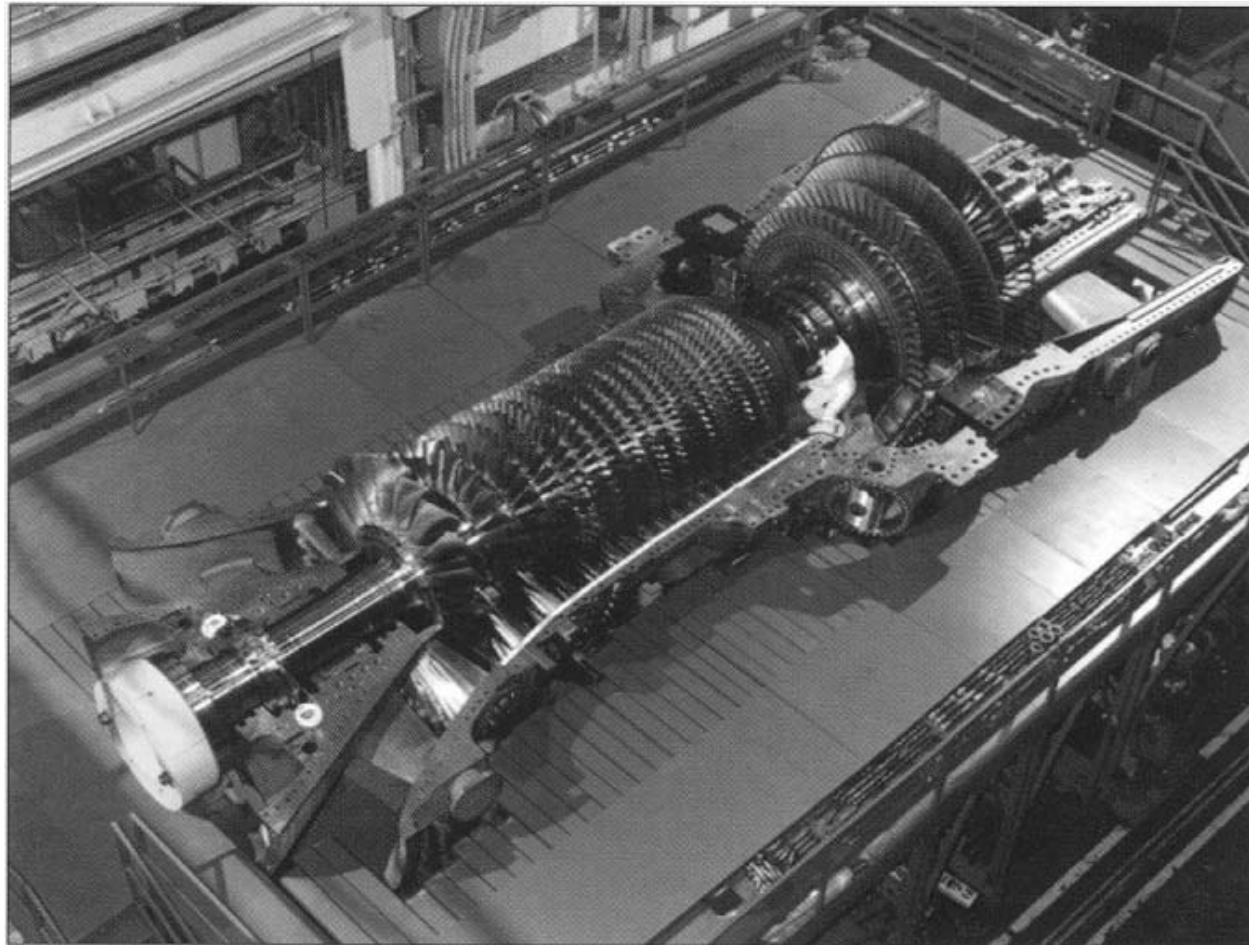


Key Subsystem Innovations

- **Closed-loop steam cooling:** Fundamentally changed the way turbine blades and vanes are cooled.
- **Single crystal fabrications:** First time application for utility-scale turbines.
- **Thermal barrier coatings:** Transferred from aircraft engine technology using ceramic coatings.
- **Lean pre-mix, dry low-NO_x combustors:** Improvements to existing technology to reduce NO_x emissions under “lean” conditions.



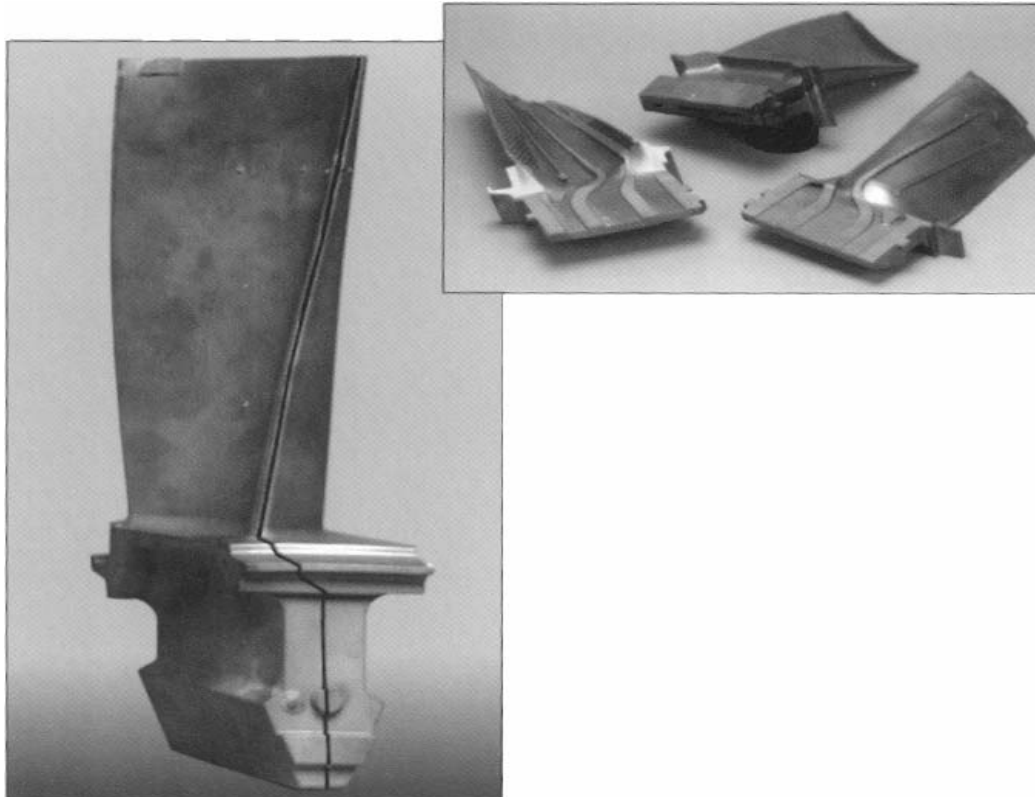
Closed-loop Steam Cooling



Source: Dept. of Energy, Office of Fossil Energy, National Energy Technology Laboratory.
Advanced Turbine Systems: Advancing the Gas Turbine Power Industry, November 2000.



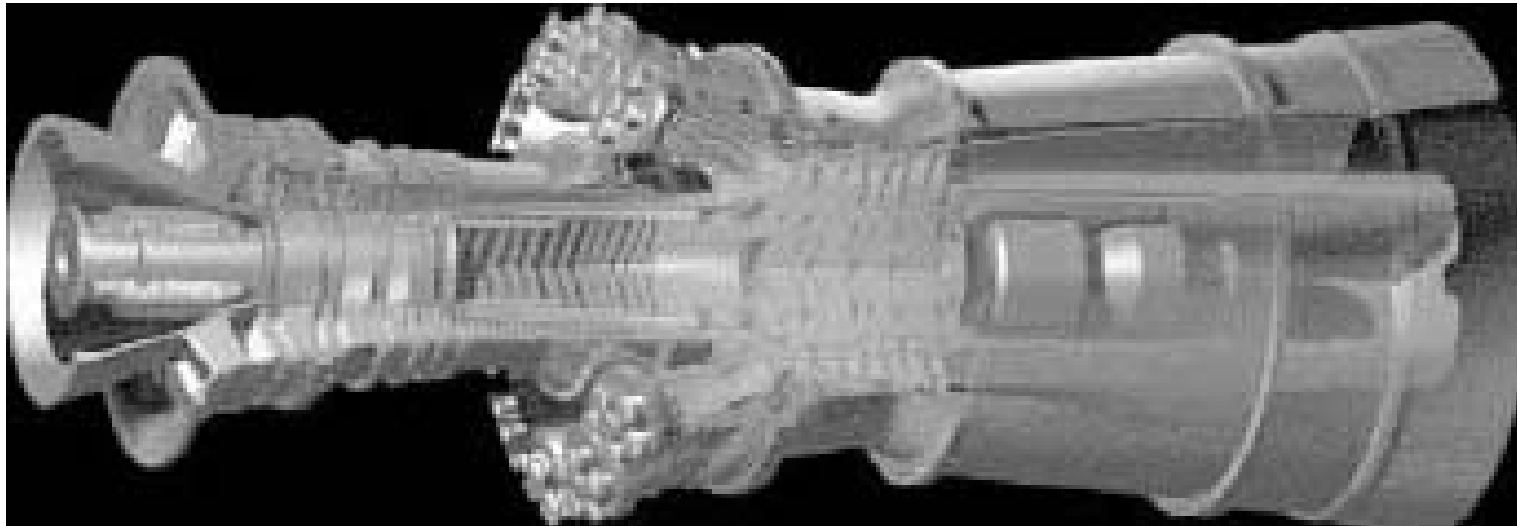
Single Crystal Blades



- Internal serpentine cooling passages
- 2-3 times larger than aircraft blades
- 5-10 times heavier than aircraft blades



Dry, Low-NO_x Combustors



Source: Proceedings of the 2000 Advanced Turbine Systems Annual Program Review Meeting, December 5, 2000, General Electric Power Systems

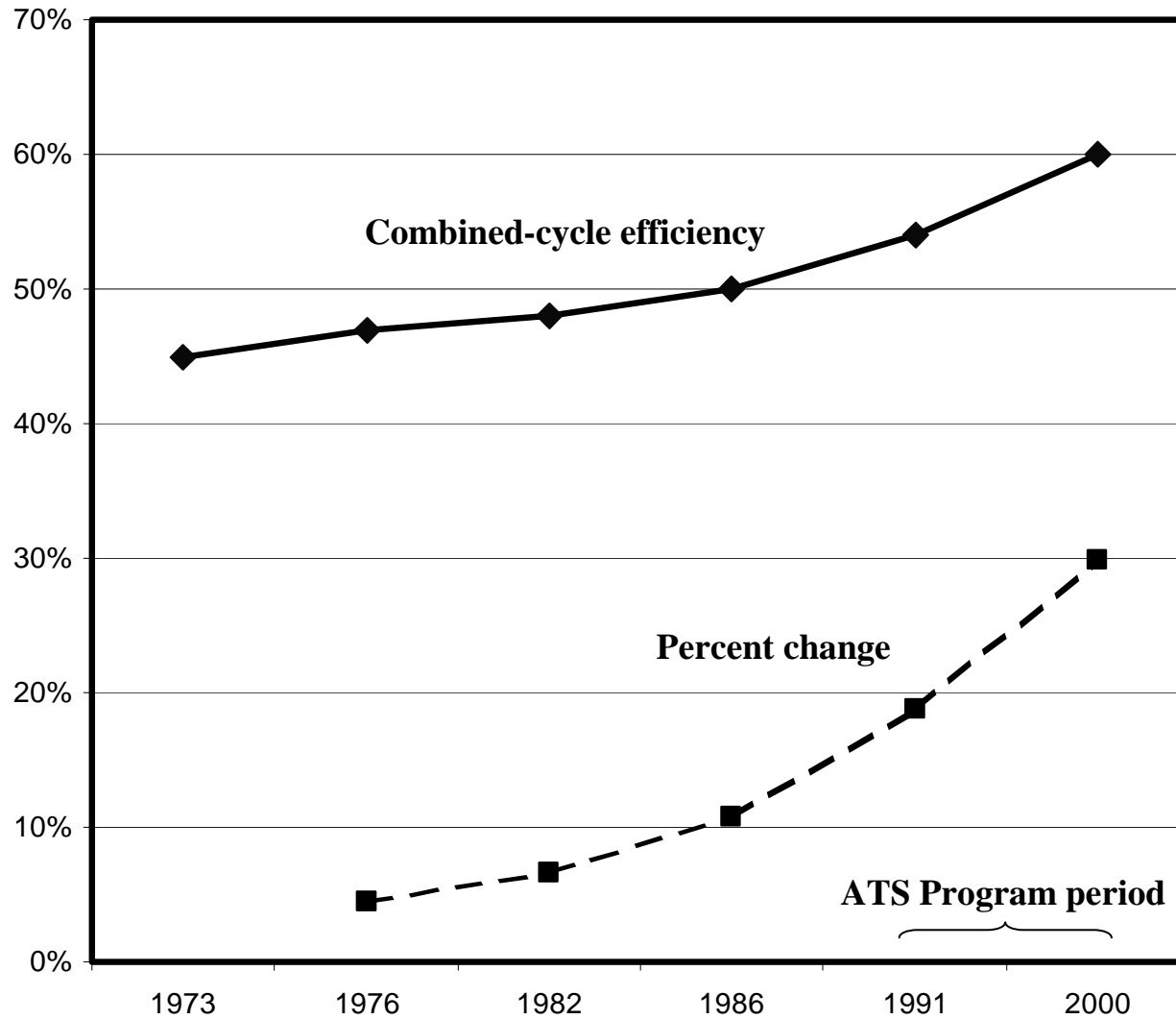


Framework For the Study

- Evolutionary theory of innovation
 - Selection environment
 - Trajectories
 - Path Dependency
- Organizational learning
 - Networks
 - Learning Processes
- Patterns of Innovation

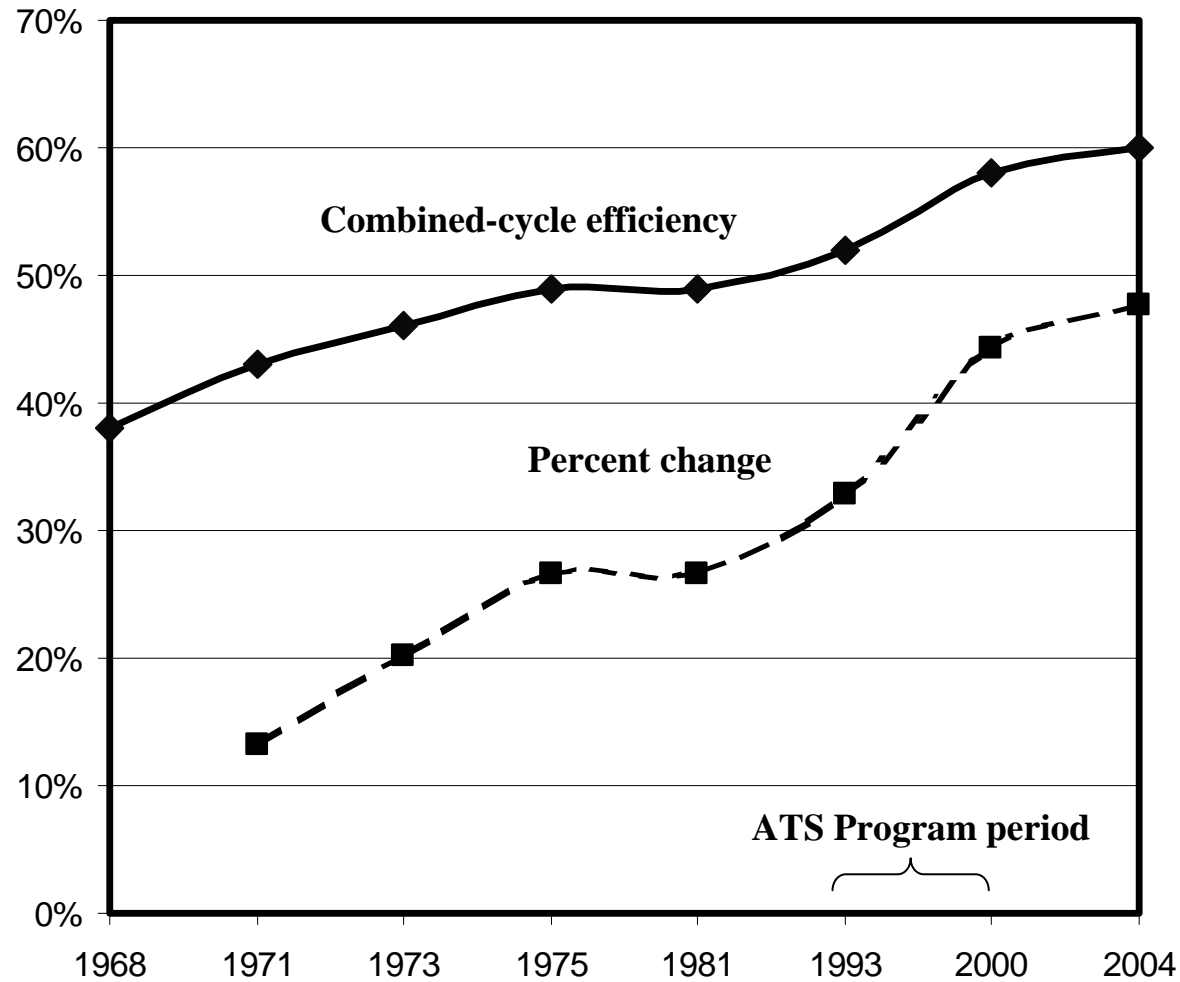


GEPS' Turbine Innovation Trajectory

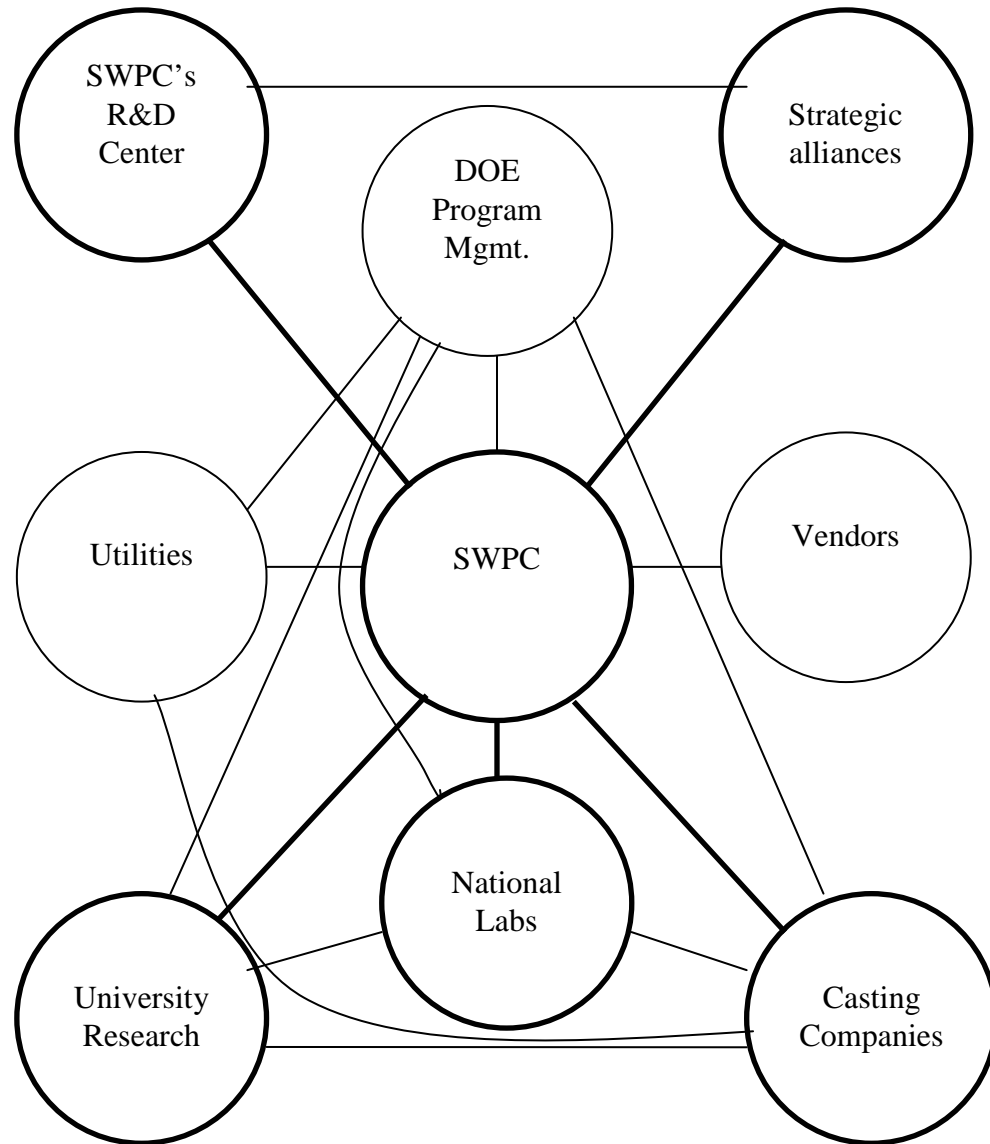




SWPC's Turbine Innovation Trajectory

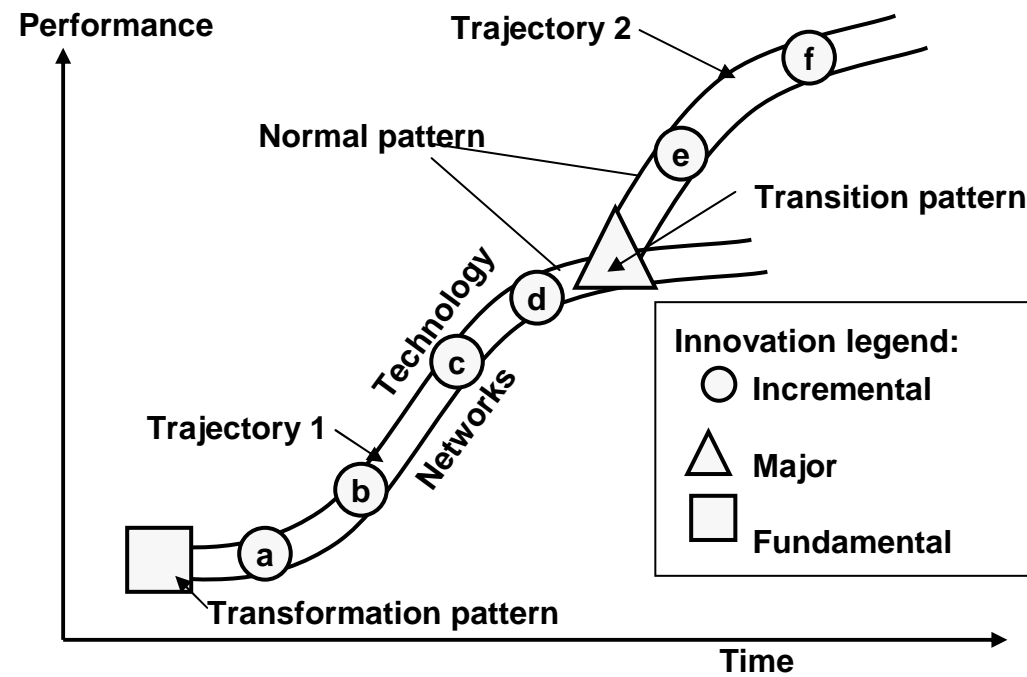


SWPC's Organizational Network





Patterns of Innovation



Source: Rycroft, Robert W., and Don E. Kash. *The Complexity Challenge -- Technological Innovation for the 21st Century*. London: Pinter, 1999, p.180.



ATS Technology in a Transition Pattern

- Significant improvements in efficiency and NO_x emissions
- Significant changes in design
 - Closed-loop steam cooling was fundamentally different than any previous technology
 - Single crystal components and thermal barrier coatings were a spin off from aircraft technology



Drivers for Innovation

- Gulf War 1990 and Concern for Energy Security
- Energy Policies of the 1990's favor energy efficiency to address energy and environmental concerns
- Energy Policy Act of 1992
- Deregulation of U.S. Retail Electric Markets
- Gas Turbine Markets in the 1990s
- Public Preference for Natural Gas-fired Power Plants over Coal or Nuclear
- Dept. of Energy's Advanced Turbine System Program



DOE Advanced Turbine System Program

- Begun in 1992, 8 yr. program
- 2 classes of turbines:
 - Industrial (< 20 MW)
 - Utility (>400 MW) Focus of Study
- Goals:
 - 60% efficiency (LHV)
 - < 10 ppm NO_x
 - 10% lower operating costs
 - Commercial systems in 2000
- University Research Program
- Cost-shared Phased Approach





SWPC's Learning Processes for Closed-Loop Steam Cooling

Innovation	Knowledge Source	Learning Approach	Knowledge Creation Process
Closed-loop Steam cooling	Internal - explicit	Learning by formalized inquiry	In-house studies for cooling medium and materials.
	External – tacit	Learning by interaction	Technological capabilities from alliances.
	External – explicit	Learning by Interaction	Licensing agreements from alliance partners.
	External – tacit	Learning by interaction	Testing from government labs and testing facilities. Building personal networks with university researchers and government laboratories.
	External – explicit	Learning by interaction	Reports from NASA and Wright – Patterson AFB research and testing.
	External – explicit	Learning from advances in science and technology	Research network through the AGTSR on rotating blade cooling and film cooling.

Analysis of Learning Patterns

Subsystem innovations	General Electric Power Systems				Siemens Westinghouse Power Corp.			
	Internal		External		Internal		External	
	Tacit	Explicit	Tacit	Explicit	Tacit	Explicit	Tacit	Explicit
Closed-loop cooling	√ √ √	√ √ √ √	√	√	√	√	√ √ √	√ √ √ √
Single crystal castings		√ √	√	√	√	√	√	√ √
Combustors	√ √	√	√		√	√	√	√ √
Thermal barrier coatings	√ √	√	√	√		√ √	√	√ √



Casting Company's Learning Processes

Company	Knowledge Source	Learning Approach	Knowledge Creation Process
Howmet Corp.	Internal – tacit	Learning by doing	Trial-and-error experimentation with process improvements to casting development
	Internal – explicit	Learning from formalized inquiry	Work with ORNL on single crystal castings
	External – tacit	Learning by using	Network relationships with customers to identify long-term needs.
	External - explicit	Learning from advances in science and technology	University research was useful in casting development.



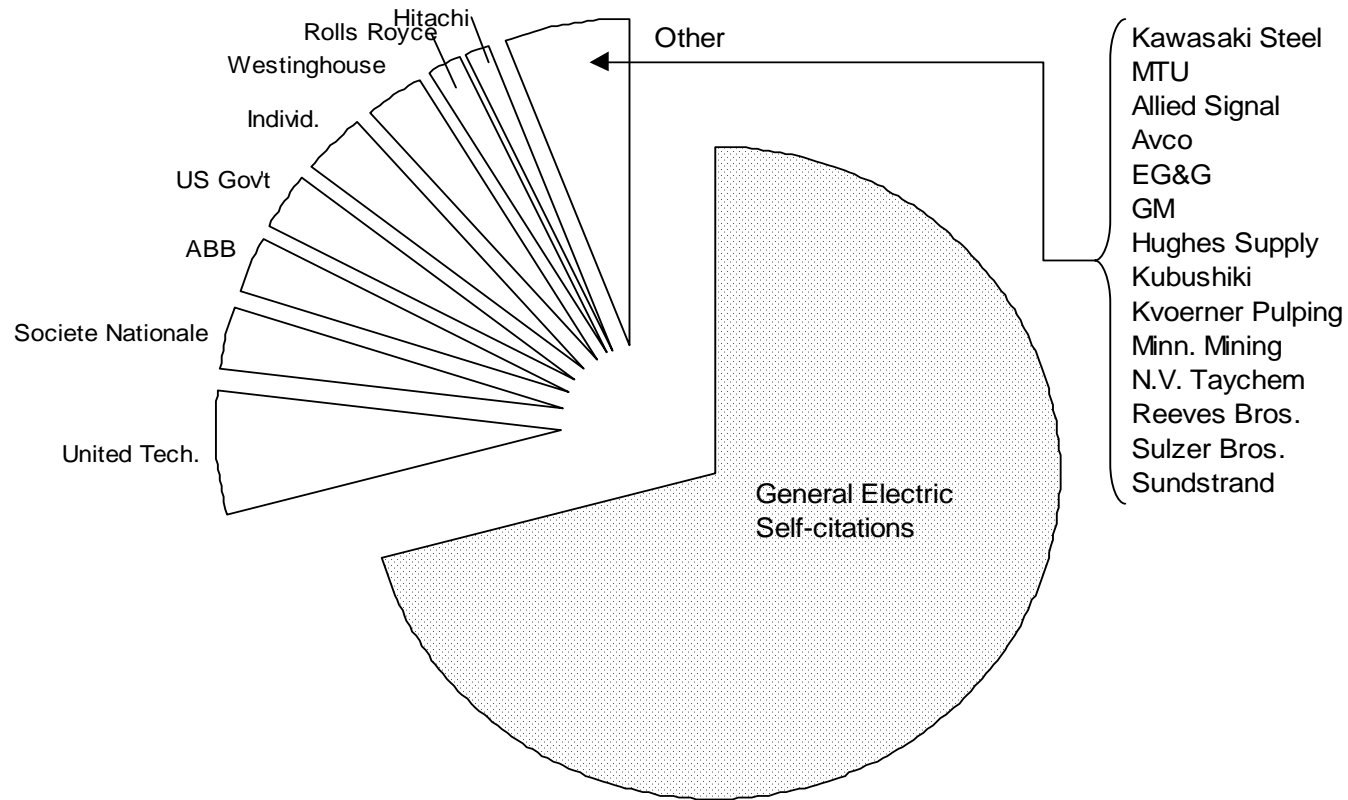
Patent and Citation Analysis

- Used as a proxy for the flow of explicit knowledge
- Measure of knowledge spillovers

Organization	Total
GE - ATS	23
SWPC – ATS *	28
Howmet	0
PCC Airfoils	0
DOE	2
Universities	2
Total	55

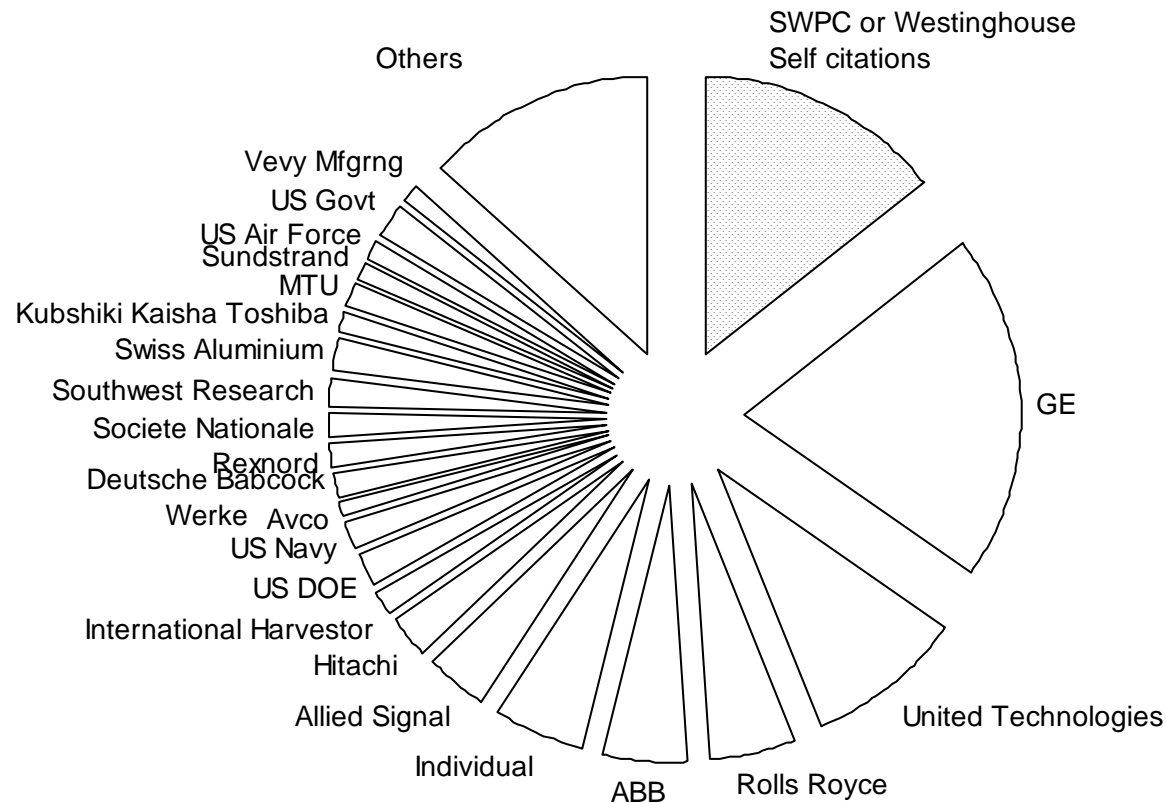


GE's Patent Citations





Siemens - Westinghouse's Patent Citations





Summary of GEPS Learning Processes

- Organizational networks consisted primarily of other GE business groups; GEAE, GE CRD
- Depth and breadth of capabilities reside within GE family of organizations
- Some external participants: Casting companies, professional networks
- Learning patterns are “path dependent”



Summary of SWPC's Learning Processes

- Organizational networks consisted internal and external organizations
- Depth and breadth of capabilities reside within as well as alliance partners, including Rolls Royce, Mitsubishi, and others
- Other external participants: Casting companies, national labs, universities
- Actively searched out new knowledge and capabilities



Innovation and Organizational Networks

- Organizational networks as resources of tacit and explicit knowledge
- GEPS' organizational network was one primarily made up of GE sister organizations
- SWPC's organizational network included both internal and external participants
- Howmet and PCC Airfoils (casting companies) were Critical Suppliers to Both GEPS and SWPC



Conclusions

- Organizational networks as resources of tacit and explicit knowledge
- Cost-shared public-private partnerships can act to spur organizational learning processes
- ATS Program
 - Filled a gap left by market failures
 - Created an industry-led program
 - Supported university research



Implications for Public Policy

- Enhance Organizational Learning
- Shape the Selection Environment
- Stimulating Innovation Processes Using Cost-shared public-private partnerships
- Technology development that addresses both energy and environmental concerns



Next Steps

- Evaluation of Benefits and Costs
- Use Framework developed by the National Academy of Science
- Benefits and costs will be evaluated for:
 - Economic
 - Environmental
 - Security