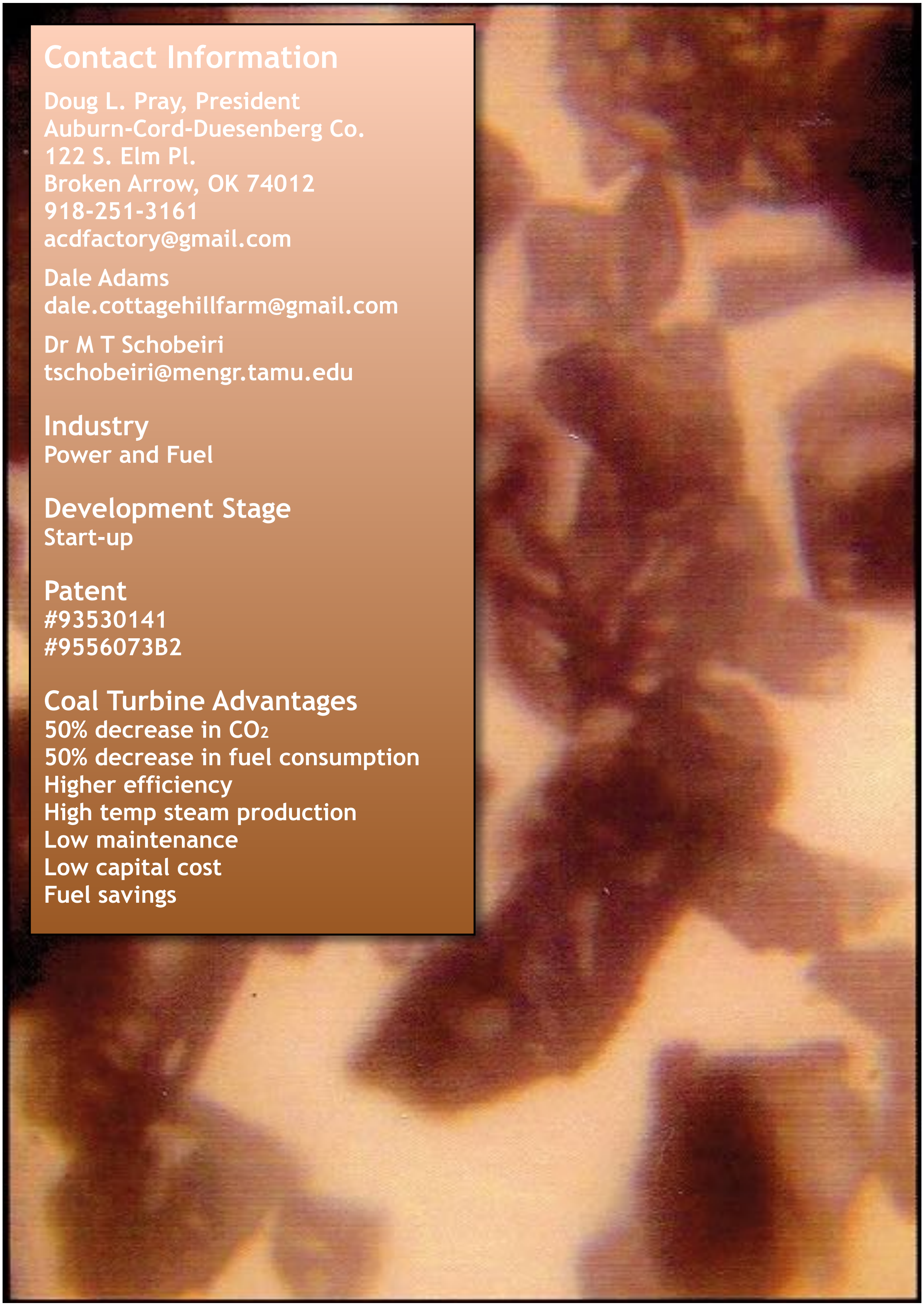
Coal-Fired Turbines for Combined Cycle Power Generation



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Industry
Power and Fuel

Development Stage
Start-up

Patent
#93530141
#9556073B2

Coal Turbine Advantages
50% decrease in CO_2
50% decrease in fuel consumption
Higher efficiency
High temp steam production
Low maintenance
Low capital cost
Fuel savings

THE PROBLEM

Current turbine technology is expensive to build, expensive to use, and expensive to maintain. Fuel sources for running current technology are depleting, as well as presenting major environmental issues. Newest technology developed by Dr. M.T. Schobeiri and Dale Adams makes possible far more efficient heat exchanges at higher temperatures than ever before, allowing coal to be used as an efficient low emission fuel. This technology consists of an advanced turbine design with thermal efficiency in excess of 40% and ceramic technology that allows for much higher turbine inlet temperatures and compression pressures in the hot section of power turbines, with a greater extraction of exhaust heat.

This is big news for coal. With this groundbreaking technology of coal combined cycle power generation, thermal efficiencies increase from the current rate of 35% to more than 70%. Not only does energy efficiency increase, capital expenditures sharply decrease, and can drop to only about $50 per KW. Emissions and fuel costs drop by 50%, making coal substantially cleaner and cheaper than other fuels.

With this new technology, coal-fired turbines are now possible as a clean efficient source of power. Coal-fired turbines have been tried in the past. However, high exhaust temperatures, along with sulfur and flyash, simply destroy the chromium-nickel alloy materials of the turbine blades. This seemingly insurmountable problem has been solved by the adaptation of Silicon Carbide turbine blades, rotors, and stators developed in Adams' work in the SiC sintering process.

THE SOLUTION

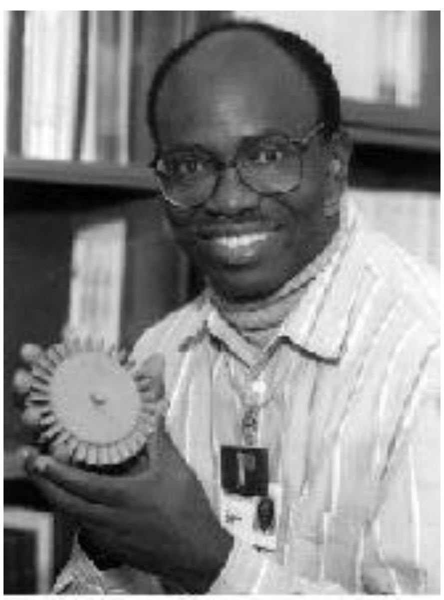
New technology to create turbine parts has been developed by Adams using a technical ceramic known as SiC (Carborundum). SiC is made by combining carbon and sand in the plasma of an electric arc. This process creates one of the hardest materials in existence. The high melting temperature 4892^{o}F (2700^{o}C) makes it supremely heat resistant and surpasses nearly all other materials. Engineers have been trying to adapt SiC to turbine blade manufacturing for years but, until now, have been unsuccessful because these ceramics are so hard they cannot be machined. In the early 90s, Oak Ridge National Lab developed a process to manufacture ceramics by gel casting, but SiC could not be sintered (fired to fuse the ceramic particles) as other ceramics can be. Adams developed a process of sintering in a molten liquid while applying pressure, ultrasonic vibration, and a high-frequency electrical current to solve the SiC sintering dilemma. In May of 2016, he was granted Patent #93530141 for this work.

Important facts comparing this new material's technology to currently used nickel-based alloys		
Ultimate Working Temperatures without losing properties:	Nickel-based alloys **SiC**	1800^{o}F (982^{o}C) **2912^{o}F (1600^{o}C)**
Sulfuric Acid Corrosion:	Chromium-Nickel-based alloys **SiC**	Yes **No**
Flyash Abrasion:	Chromium-Nickel-based alloys **SiC**	Yes **No**
Production Casting:	Chromium-Nickel-based alloys **SiC**	Lost wax (slow) **Multiple Mold - thousands per day**

One-piece SiC rotor

Current turbine blade

Heat Transfer:	**SiC**	**5x greater than Chromium-Nickel-based Alloys**



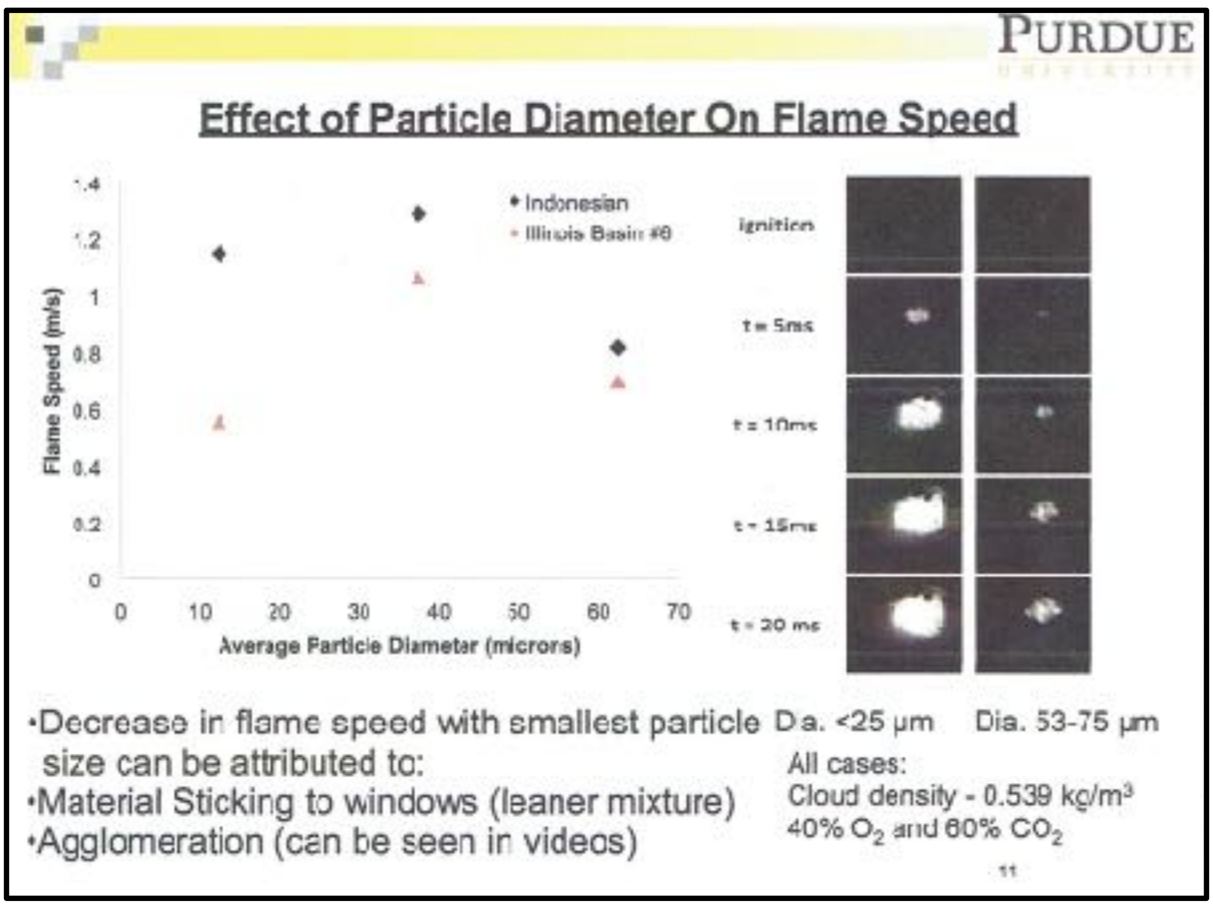
Ogbemi Omatete, of the Oak Ridge National Lab, shows a ceramic turbine rotor formed by gel casting

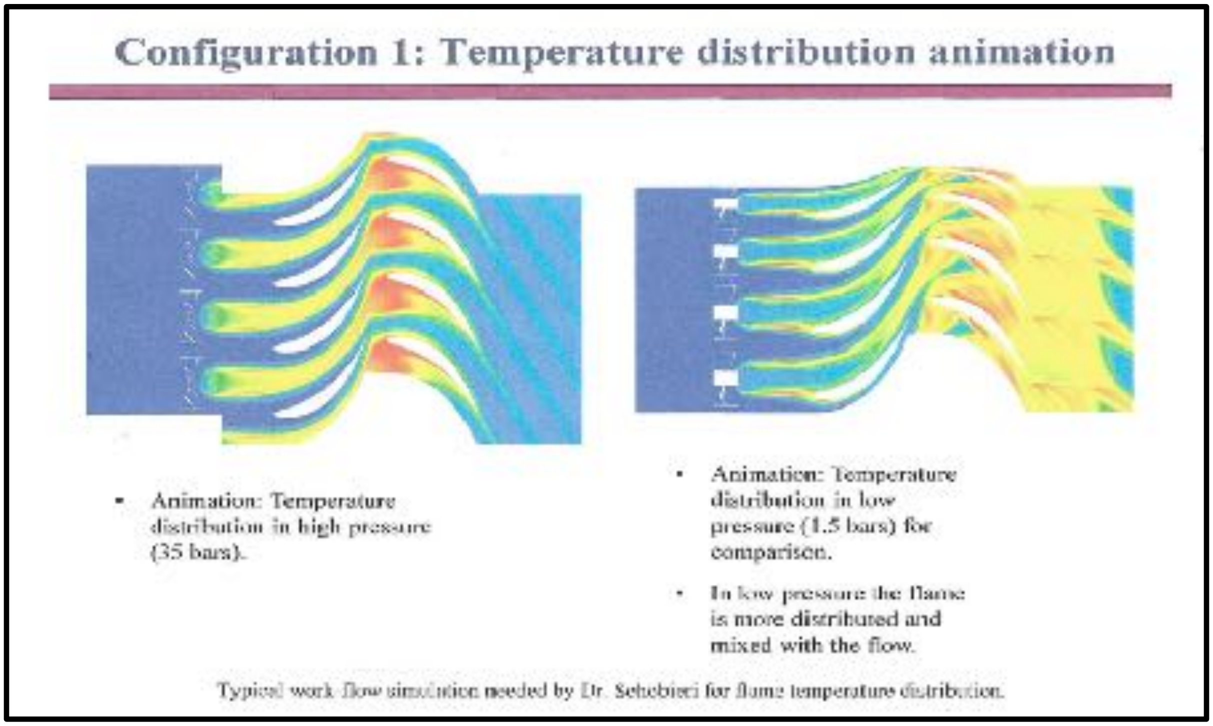
Current turbine construction is extremely complex and highly expensive. In standard turbine construction, turbine blades float in the turbine hub in exotic dovetails to allow for thermal expansion. This design is very expensive ($50,000 per blade) and made with difficult hollow-core casting methods necessary to supply cooling air to the blades so they won't melt in the exhaust heat. The heat treating process necessary to grow the proper grain structure is hard to achieve. SiC turbine parts are cast as one piece consisting of a shroud, blades, and a splined hub. Since there is no cooling necessary and no thermal expansion with SiC, manufacturing costs for an entire rotor and stator assembly is only a few hundred dollars.

This new patented sintering process, developed by Adams, allows for volume manufacturing of turbine components. For this process and mass production, multiple molds can be made inexpensively of metal, plastic, or wood. Prototype SiC castings can be made of simple 3D modeled molds.

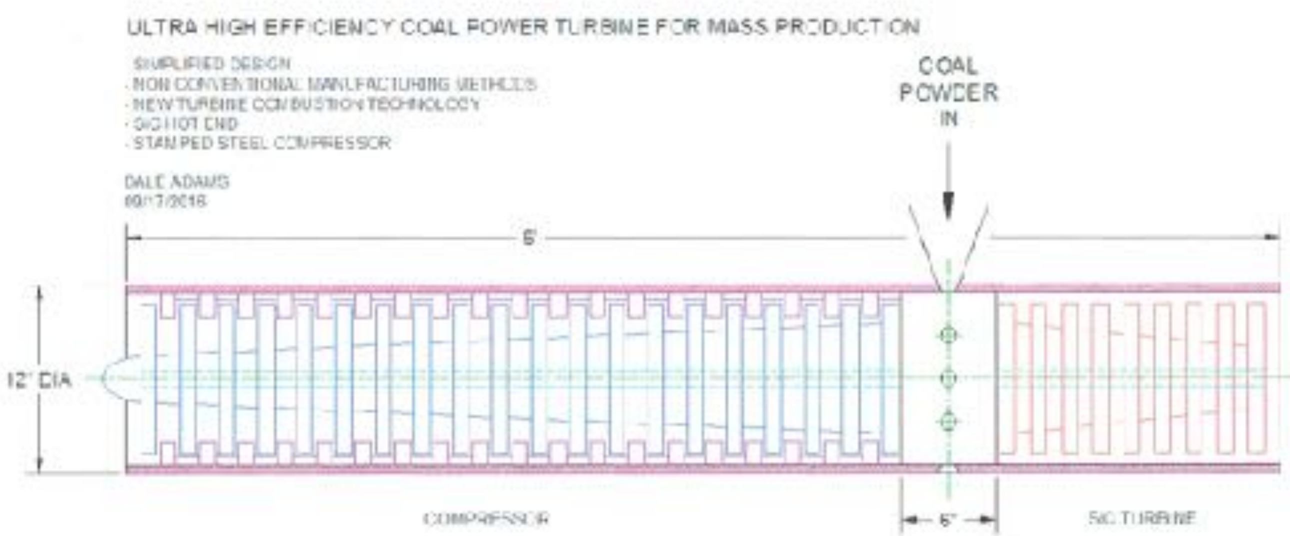
Until now, successful coal burning turbines have been impossible because of corrosion and abrasion of the working parts. With the combined efforts of Adams and Dr. Schobeiri — who literally wrote the book of the turbine design itself (*Turbomachinery Flow Physics and Dynamic Performance*) — new blade designs can be tried and tested. With extensive knowledge in turbine mechanics, Dr. Schobeiri is an expert developer and creator in the turbine energy field. His ingenuity and technical skill, combined with Adams' patented sintering process and extensive manufacturing experience make coal powered turbines possible and practical.

Another issue with current turbine technology is that coal particles are larger and burn slower than other fuels. A common coal particle is around 26 microns in diameter, thousands of times larger than the molecules of gas or diesel fuel. This requires changes in the design of the power turbine. Whereas jet fuel droplets or natural gas when burned are gone in a flash, coal lights and burns slowly due to its mass and high ignition temperature. Because the combustion of coal is slow, it requires two to three times more turbine sections than other fuels to capture shaft power. The new SiC turbine rotors and stators withstand heat and produce more heat downstream than current designs can support. More shaft energy is collected due to the multiple blade design — like more sails on a ship. Dr. Schobeiri is engineering the new technology for this UHECT (Ultra High Efficiency Coal Turbine) to handle the hot/slow flame speed of coal.

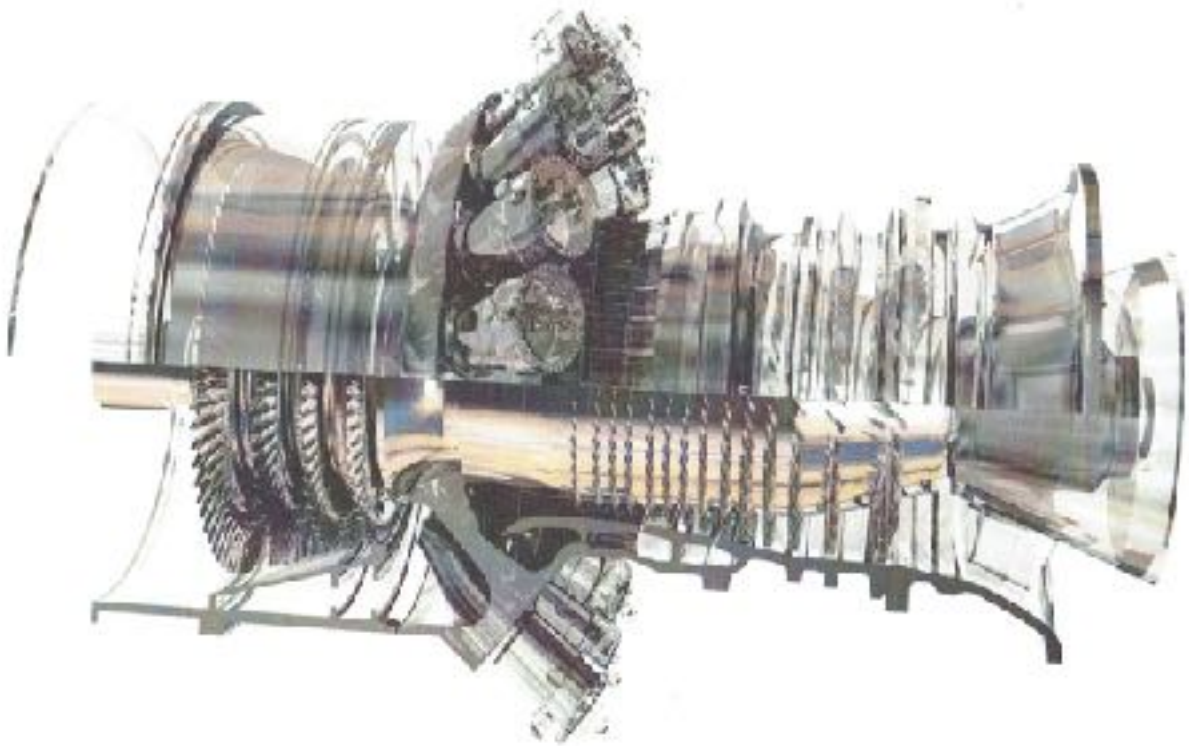




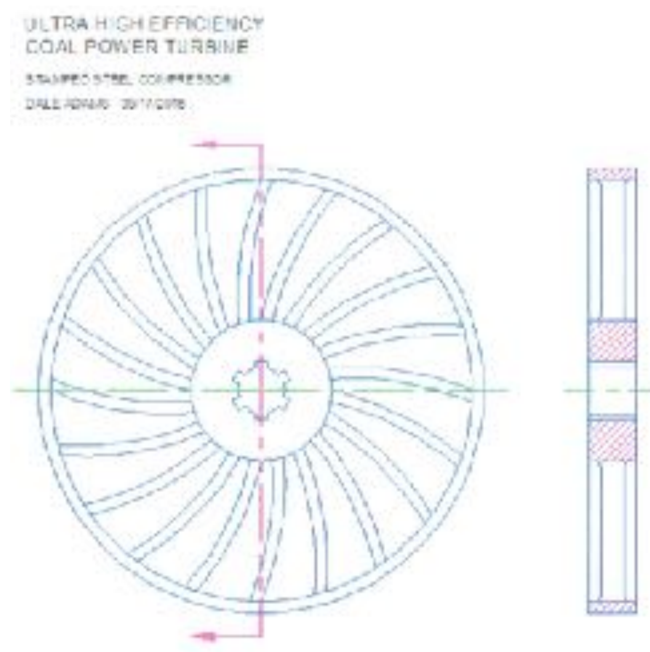
Unlike current turbine designs, with many working parts and possibilities for a breakdown, this new turbine technology will be much less vulnerable to breakdown, much less expensive to manufacture, and much more durable. Stators, rotors, shafts and bearings slide down inside a large tube to create the turbine design. The rotors and stators stack to complete the turbine, as shown in the diagram below.



Current GT (gas turbine) manufacturing (shown below) is well engineered and crafted, but will not work for coal — again, because of the high temperatures and dirty exhaust of coal-fired generators.



Dr. Schobeiri's development of his Ultra High-Efficiency Gas Turbine began while he was Chief Engineer at Brown Boveri and Cie Turbines in Switzerland. In simple concept, he eliminates the combustion chamber of a conventional GT and moves the combustion to the front of the first stator. He also dramatically raises the compression to an over 40 to 1 compression ratio (580 psi), which drives the power and efficiency up. All internal cooling on manifolds, turbine blades and housing are eliminated, making design and manufacturing much cheaper. Clever use of fuel injection devices allows combustion to begin right at the front of the turbine hot section.



By using multiple small turbines in a power generation installation, each with their own alternator and stator, there is no need to run the turbine at any speed other than optimum. They can be jetted to run at constant speed. Current gas turbines require 15 minutes for start-up. Nearly instant on and off capability of the Ultra High Efficiency Gas Turbine makes possible starting and stopping of the machines in seconds as loads rise and fall. The fuel mixture is more controllable in a turbine, therefore machines could always be adjusted to their cleanest and most efficient throttle position for 100% power and economy.

Heat recovery from the turbine exhaust is accomplished by SiC exhaust manifolds with hollow chambers cast in place for steam production. SiC's **temperature resistance and ability to conduct heat five times faster** than current materials greatly improves efficiency.

Mass-producing this turbine will reduce manufacturing costs to only about $25,000 per unit, producing 500KW. Cost per KW is a fraction of current gas turbine generation. Adaptation of existing steam turbines is possible, thus bringing down the initial costs to bring coal-fired generating on-line.

RE-CAPPING COAL TURBINE ADVANTAGES

50% decrease in CO_2 output per KW
50% decrease in fuel consumption per KW
Higher efficiency, high temperature steam production
Low maintenance
Low capital cost per KW
Fuel savings quickly pays for new capital investment

Dr. Meinhard T. Schobeiri is an Oscar Wyatt Mechanical Engineering Professor and Director of the Turbomachinery Performance Laboratory of Texas A&M University. He was Chief of the Gas Turbine R&D Aero-Thermo Group at what is now Alstrom Power in Switzerland. He is the author of *Fluid Mechanics for Engineers*, a graduate textbook, and *Turbomachinery Flow Physics and Dynamic Performance*. He and his wife, Susan, reside in College Station, Texas.

Dale Adams has been President of Dale Adams Enterprises for more than 40 years. For 45 years, he has been in production machining and manufacturing of the mechanic's Bone Creeper (Bonecreeper.com), and in award-winning classic and antique auto restoration (DaleAdamsEnterprises.com), beginning his career at Auburn-Cord-Duesenberg Company in Tulsa, Oklahoma. Dale and his wife, Patti, reside at historic Cottage Hill Farm in Ravenna, Ohio, the former home of coal barons, the Hanna family.

Dr. Schobeiri and Dale Adams have been collaborating on this work for seven years — Dr. Schobeiri on turbine design and Adams on materials and manufacturing methods. They are now ready for commercial development. Their work will help save the coal industry by making coal substantially cleaner and less expensive. They are looking for private or government partners to make their work a reality.

Enclosures:
UHEGT article by Dr. MT Schobeiri
SiC Properties

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Silicon Carbide Material Properties

Mechanical	SI/Metric (Imperial)	SI/Metric	(Imperial)
Density	gm/cc (lb/ft^3)	3.1	(193.5)
Porosity	% (%)	0	(0)
Color	—	black	—
Flexural Strength	MPa (lb/in^{2}x10^3)	550	(80)
Elastic Modulus	GPa (lb/in^{2}x10^6)	410	(59.5)
Shear Modulus	GPa (lb/in^{2}x10^6)	—	—
Bulk Modulus	GPa (lb/in^{2}x10^6)	—	—
Poisson's Ratio	—	0.14	(0.14)
Compressive Strength	MPa (lb/in^{2}x10^3)	3900	(566)
Hardness	Kg/mm^2	2800	—
Fracture Toughness K_{IC}	MPa•m$^{1/2}$	4.6	—
Maximum Use Temperature (no load)	°C (°F)	1650	(3000)
Thermal			
Thermal Conductivity	W/m•°K (BTU•in/ft^2•hr•°F)	120	(830)
Coefficient of Thermal Expansion	10^{-6}/°C (10^{-6}/°F)	4.0	(2.2)
Specific Heat	J/Kg•°K (Btu/lb•°F)	750	(0.18)
Electrical			
Dielectric Strength	ac-kv/mm (volts/mil)	—	semiconductor
Dielectric Constant	—	—	—
Dissipation Factor	—	—	—
Loss Tangent	—	—	—
Volume Resistivity	ohm•cm	10^2–10^6	dopant dependent

*All properties are room temperature values except as noted.

ACCURATUS: *Latin* – careful, precise, accurate

BY DR. MEINHARD T. SCHOBEIRI

A breakthrough in gas turbine efficiency

CARNOTIZE THE BRAYTON CYCLE AND PERFORM COMBUSTION IN THE TURBINE STATOR

Turbine Inlet Temperature (TIT) is the major parameter for increasing the thermal efficiency (η_{th}) of power generation and aircraft gas turbines. To increase TIT, great efforts have been made in the past four decades to:

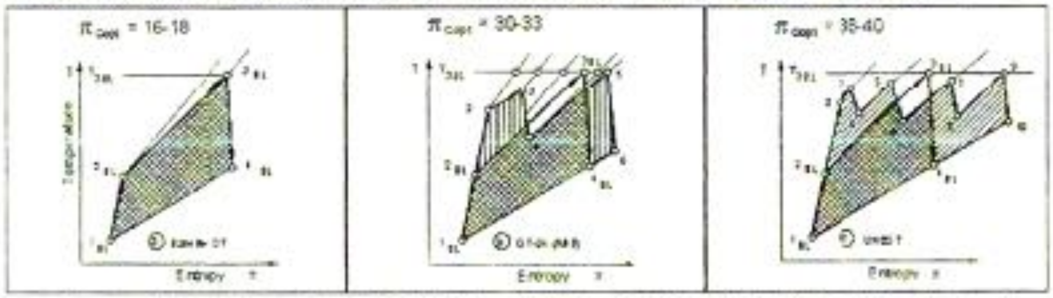
- Develop high-temperature resistant turbine blade material
- Improve turbine blade cooling technology

the η_{th} of its gas turbines. The company developed the GT-24/26 which had one reheat stage turbine followed by a second combustion chamber and a multi-stage turbine. The introduction of this technology increased η_{th} by more than 8% when the gas turbine is operating at full load.

Although the addition of a reheat turbine stage and a second combustion chamber

Using UHEGT in combined cycle power generation will boost the combined η_{th} from the current level of 60% to over 70%.

The UHEGT technology requires optimization of the compressor pressure ratio at 35 to 38 based on TIT. While this does not pose any challenge from a compressor aerodynamic design point of view, other challenging issues for design could be:



Process Comparison for (a) the Baseline GT, (b) the GT-24, (c) the Ultra High Efficiency Gas Turbine Technology (UHEGT) which has four stages with four integrated stator internal combustion

Using advanced cooling technologies and the conventional gas turbine process at high TIT, η_{th} close to 38% has been achieved. Continuous R&D in compressor and turbine aerodynamics has raised the efficiencies of the two components above 92%. But major investment will be needed to increase η_{th} further and even this increase will only be marginal. In the absence of new high-temperature turbine blade materials that can be reliably integrated into gas turbines, no major improvement in η_{th} can be expected.

But other new technologies can achieve significant improvements in thermal efficiencies. Though the underlying thermodynamics of these technologies have been known for several decades, they need visionary manufacturers for their implementation.

One of them is based on the well-known reheat principle — a classical method for thermal efficiency augmentation. Although this standard efficiency improvement method is routinely applied in steam turbine power generation, it did not find its way into gas turbine design.

The first company to take advantage of the reheat principle was ABB (formerly Brown Boveri & Cie and now Alstom) which felt a driving need to substantially improve

brought about a significant increase in thermal efficiency, it was found that a further increase in the number of combustion chambers will result only in its marginal improvement (1-1.5%). The cumulative total-pressure losses (12-15%) in three combustion chambers cancel the efficiency improvement due to the third chamber.

A significant increase in η_{th} at a consolidated TIT is achieved by the Ultra-High Efficiency Gas Turbine Technology (UHEGT).[1] This technology eliminates the combustion chambers altogether and places the combustion process inside the stator blade passages. The elimination of the combustion chambers reduces engine total-pressure losses. The UHEGT takes advantage of the strong turbulence and secondary flows within the turbine flow path to facilitate a complete combustion associated with much lower pollution. The substantial increase in thermal efficiency is achieved by "carnotizing the Brayton cycle" (shown in figure).

Detailed design, off-design, and transient calculations of a UHEGT shows that the process increases the thermal efficiency by 47%, pushing it far beyond the efficiencies of existing gas turbines including the GT-24/26.

- Placing the combustion process within a small space
- Cooling the stator blades where combustion takes place

These issues can be resolved with a reasonable R&D effort. The tremendous increase in efficiency justifies the R&D efforts that visionary manufacturers will need to make to develop this gas turbine.

[1] Schobeiri, M.T., 1999, "The Ultra-High Efficiency Gas Turbine Engine with Stator Internal Combustion," UHEGT, U.S. Patent Pending, 1389-TEES-99

Meinhard T. Schobeiri was the group leader of aero-thermodynamic design at Brown Boveri & Cie, Gas Turbine Division, Switzerland. He is now a professor of mechanical engineering and the director of the Turbine Performance and Flow Research Laboratory at Texas A&M University. Reach him at tschobeiri@mengr.tamu.edu.