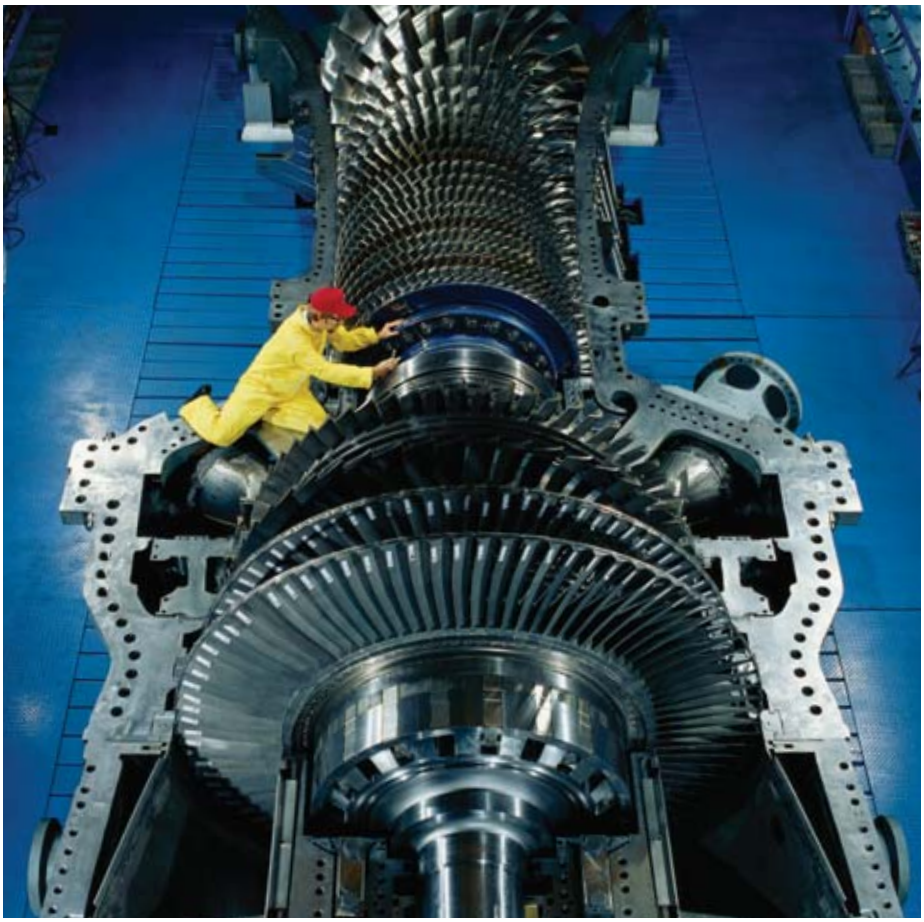
Improving economic and operational efficiency through on-site application of advanced surface coatings

Manufacturers and operators of power generation equipment routinely rely on surface coatings to improve engine life and efficiency. Cold section coatings protect airfoil sections against corrosion and wear, limit compressor fouling and help to prevent failure in sensitive and vulnerable engine areas. In the hot section, coatings are used to reduce the effects of hot corrosion and oxidation, and in some cases to act as a thermal barrier. Failure of unprotected components can trigger a chain reaction within the turbine that could result in catastrophic failure.

Traditionally, components have been shipped to an off-site facility for coating. In the traditional off-site method, servicing and coating engine components can be a time-consuming process. Components must be de-stacked, shipped, coated, reshipped and re-stacked. Disassembling alone can involve hundreds of individual parts.

Large industrial turbine components and assemblies such as compressor rotors, stators, bladed disks and cases can now be coated on-site, at your power plant. Praxair's Axxess™ on-site coating services can help:

- Shorten outage time
- Reduce damage risk
- Increase turbine efficiency



On-site surface coating of power generation components—in both the cold and hot sections—can shorten outage time, reduce damage risk and increase turbine efficiency.

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Shorten outage time

Every day a gas turbine is not generating power results in a loss of revenue. On-site coating eliminates shipping of parts and components. Components stay on-site, so equipment is ready for use as soon as possible, without long delays.

Reduce damage risk

Coating components on-site reduces the labor needed to package and reinstall parts and components. Axxess on-site coating, in some instances, can eliminate the need to de-stack and re-stack. On-site services can cure many blades in stacked condition. The entire process involves less teardown and reassembly. Together, these benefits reduce the risk of damage to components: There's no shifting around on aircraft or trucks and no risk of damage from being mishandled off-site.

On-site coating provides power generation operators with peace of mind. When coating occurs on-site, operators can monitor progress as it occurs to ensure coatings meet specifications. When parts ares shipped hundreds of miles away, the ability to inspect and adjust them is severely limited.

Increase turbine efficiency

Praxair's smooth-sealed aluminum-based coatings have been shown to improve the efficiency of power generation turbines by 1% to 1.7%*[1]. Evaluation of an axial compressor demonstrated a heat rate improvement of 0.58%. In one case, payback calculations were made using two Westinghouse 501F compressors; the review estimated the coating payback time was less than three months.

Advanced surface coatings are one of the most practical alternatives available to prevent and control fouling and corrosion of airfoils, compressors and other components, which lengthens the lifespan of components. Longer lifespans can help lower replacement part costs: Fewer parts require replacement, and the time between replacements can be extended. By extending the lifespan of components, operators also may be able to extend the time between service outages. Axxess on-site coating with one of Praxair's advanced surface coatings can pay for itself quickly.

*As measured by TSFC (thrust-specific fuel consumption)

An overview of on-site services and the benefits of in situ coating

Praxair's Axxess on-site coating services, featuring SermeTel® coatings, comprise qualified personnel and the equipment necessary to coat applicable components without leaving the power plant.

Furthermore, Axxess on-site coating can coat certain components in situ, which means they can be coated in the stacked position. This capability eliminates the time-consuming need to de-stack and re-stack components.

Axxess on-site coating can restore disks in many equipment configurations as well as coat compressor blades in the stacked position.

The ability to coat certain components in situ:

- **Eliminates transportation and shipping delays:** Components stay on-site and are ready for use without excessive delays.
- **Minimizes risk:** There's no risk of loss or damage in transit because there's no shipping and handling.
- **Provides quantifiable payback:** Payback comes in the form of increased power production, labor savings and lower replacement part costs.

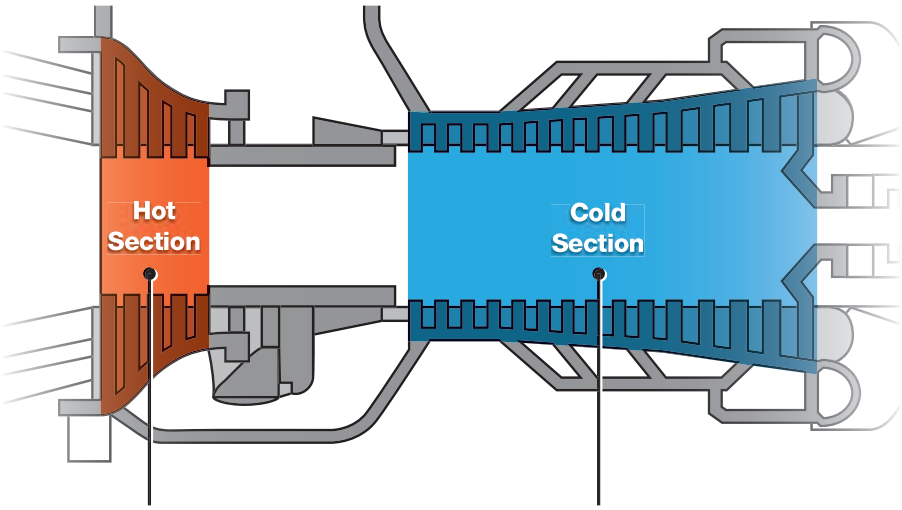
In situ coating also applies to **turbine disk restoration**. Turbine disk restoration successfully addresses "bucket rock," a condition often found in gas turbines used for standby or peaking service.

Applying a customized surface coating to the "fir tree roots" section of the turbine disk improves both structural integrity and blade stability. The improved stability prevents "bucket rock," which is often found in gas turbines used for standby or peaking service.

On-site coating can eliminate the need to remove vanes or disks—there's no need to de-stack and later re-stack compressor blade disks. Instead, critical components stay on-site and are ready for use without shipping delays.

Coating services and benefits

Surface coatings on power generation equipment can extend engine life, protect valuable assets and ensure optimal performance. Traditionally, components have been shipped off-site for coating. Some components require off-site coating due to the nature of the coating, the part or the specifications. Many components, however, can be coated on-site, providing additional benefits such as shorter outages. This chart illustrates types of coatings used for various components and specifies those eligible for on-site vs. off-site coating.



Coat hot section components for asset protection.

Coat cold section components to improve efficiency.

Praxair Surface Technologies coating services

	Coating name	Components	Use and benefits	Technical specifications
On-site services	SermeTel® Process 5380DP	• Compressor rotors • Compressor cases w/stators	• Corrosion and erosion protection • Tight tolerances or dimensionally critical surfaces • Excellent surface finish	Abrasion resistance: > 300 liters/mil Heat resistance: up to 1200°F (650° C) Tensile bond strength: ≥8000 psi
	SermeTel® 2F-1	• Turbine rotors	• Cyclical corrosion and erosion resistance	Heat resistance: up to 1100°F (593°C) Abrasion resistance: >150 liters/mil Tensile bond strength: ≥8000 psi
	NiAl Thermal spray	• Turbine disks	• Restores fir tree clearances to address turbine blade/bucket "rock"	Tensile bond strength: >9100 psi Hardness: 55 – 80Rb
In-shop services	CrC coatings	• Transition ducts	• Wear resistance	Heat resistance: up to 1600°F (871°C)
	MCrAlY coatings	• Blade • Vane	• Type I and type II hot corrosion • Oxidation resistance	Corrosion to 1500°F (816°C) Oxidation resistance: 2000°F (1093°C)
	SermaLon®	• Centrifugal compressor • IGV • Turbine components exposed to corrosive steam	• Acid rain, deicing fluid, decontamination fluid, hydraulic fluid and lube oil resistance • Hydrocarbon fouling • Relative humidity to 100° and with continuous salt/mist in air	Heat resistance: up to 600°F (315°C)
	SermaLoy™	• Gas turbine hot section components; particularly those made of high-strength, low-chromium, nickel-base alloys	• High-temperature and low-temperature hot corrosion • Oxidation resistance	Heat resistance: up to 1835°F (1000°C)
	SermaWear®	• Compressor	• Solid particle erosion protection • Salt spray resistance	Tensile bond strength: >5700 psi Erosion resistance: >1000 liters/mil
	SermeTel® AFC7000	• Compressor	• Environmental compliance	Heat resistance: up to 1400°F (760°C)
	Zircoat™ yttria-stabilized zirconium	• Combustor liner • Turbine blade	• Extreme heat exposure • Solid particle erosion resistance	Hardness: ≥750 HV.3 Heat resistance: up to 2250°F
	MCrAlY + thermal barrier coating	• Blade • Vane • Shrouds • Transition ducts • Combustion liners	• High-temperature corrosion protection • Oxidation protection • Thermal protection	Dependent on component

Effects of fouling and corrosion on fuel efficiency

A variety of factors can rob an engine of fuel efficiency, but few more so than fouling. **Fouling** is any deposit on a surface that disrupts laminar flow. Fouling occurs through a variety of mechanisms, such as dissolved materials in air that condense on blade surfaces, or electrostatic forces that attract and hold fine particles to the blades.

Fouling increases aerodynamic drag in the compressor, which is related to the roughness of the airfoil surface. The rougher the surface becomes, the greater the drag. Any increase in surface roughness (such as fouling) decreases compressor efficiency and increases fuel consumption. Lower fuel efficiency increases operational costs. (By contrast, engines that operate more efficiently improve fuel consumption—and they generate fewer nitrogen oxide emissions, which can help meet environmental standards.) Aerodynamic losses in the compressor also may increase exhaust gas temperatures and increase wear and corrosion, further increasing costs and reducing time between overhauls and outages.

Another contributor to poor fuel efficiency is corrosion. **Corrosion** is the gradual attack of a metal or alloy by agents in the surrounding atmosphere. It causes disintegration of the surface and material loss. The rate of corrosion is controlled by several factors, such as the length of time a surface remains wet and the acidity or alkalinity of the solution on the surface. Corrosion also can lead to **pitting**, which compromises the mechanical integrity of compressor blades and valves. In severe cases, pitting can lead to catastrophic mechanical failure.

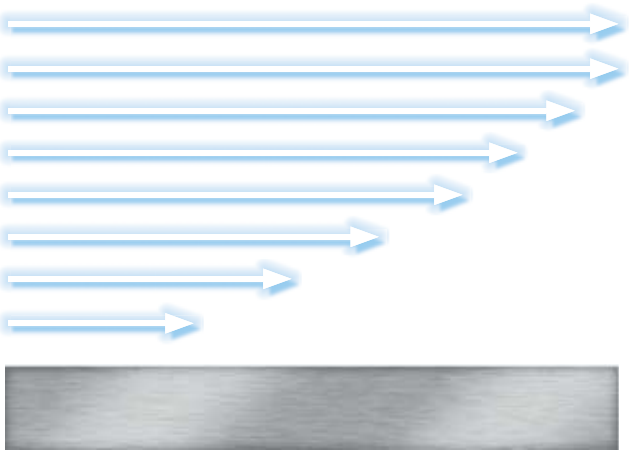
Factors affecting value of coatings

Beyond the protection they provide, surface coatings can contribute to a reduction in exhaust temperature and an increase in output performance. Values for specific coatings will vary according to a variety of factors, including:

- Type of engine
- Age of engine
- Type of coating
- Location of engine (remote or urban, humid or arid)
- Load factors (peak, intermediate, base)

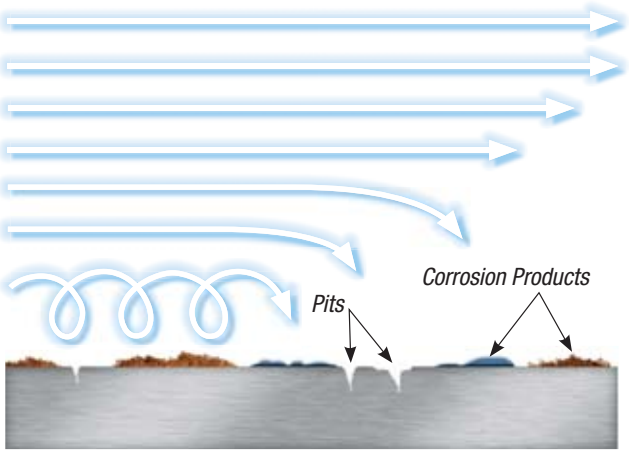
Effects of Fouling

Laminar Flow



When an airfoil surface is smooth and has minimal roughness, there is little aerodynamic drag, and the engine operates very efficiently. Studies have found that thermal barrier coatings can increase overall engine performance by protecting airfoil surfaces. One study determined that the addition of thermal barrier coatings would provide an increase of 5.5 megawatts in power at a cost of $140 per kW.[2] Another analysis concluded that coating compressor components improved compressor efficiency by 0.64%, resulted in a better heat rate of 0.58% and yielded 1.26% higher power output.

Turbulent Flow and Structural Damage



Aerodynamic drag in a compressor is related to the roughness of the airfoil surface. The rougher the surface, the greater the drag. Drag increases with fouling, which can occur through a variety of mechanisms. Materials in the air can condense and dry on blade surfaces. Fine particles in the air can be attracted and held by electrostatic forces. Turbulence occurs when deposits, cracks or other obstacles disrupt the smooth flow of the air. When corrosion or fouling damage the airfoil surface, aerodynamic drag increases, and the engine's overall efficiency and output decrease.

Customized coatings based on environmental conditions

The purpose of a turbine compressor coating is to maintain a smooth surface and reduce the effects of corrosion and fouling on airfoils. The problem is complicated because turbines operate in a variety of environments where they are exposed to:

- High or low humidity
- High salinity
- Severe acidity
- Alkaline pollution
- Sand ingestion

One of the main objectives of on-site coating is to return integral components to a like-new condition, protecting them from such threats as fouling, corrosion, extreme temperature and pressure. Praxair Surface Technologies provides this protection—and further improves operational efficiency—through customized coatings. Some surface coating providers follow a "one-size-fits-all" approach. But every site has different requirements. For example, engines in coastal environments are subject to different threats (such as salt fouling) than engines in hot, dry environments.

Praxair's Axxess on-site coating team develops a site-specific coatings approach for each customer's individual environment and needs. This approach may include adjusting the thickness of a coating or providing special materials needed for a coating. This approach also entails creating specific coatings and using specific applications for different areas of the engine.

Addressing site-specific problems and challenges contributes to better efficiency of the engine by optimizing coating characteristics to meet site-specific operating conditions. This customized protection helps to extend the life of the components and the engine itself.

Humidity | Salinity | Acidity | Alkaline Pollution | Sand

Every engine requires specific coating protection based on its environment, operating conditions and other factors. Praxair Surface Technologies provides customized on-site coatings for specific threats in specific environments.

Examples of corrosion

This is an example of a rotor with fouling from corrosion, which is disintegration caused by elements in the atmosphere or environment. Alkalinity or acidity of the elements on the surface are among the many factors that control the rate of corrosion. Any deposit on a surface—including condensation—that disrupts laminar flow is considered fouling.

This image shows airfoil blades that have been cleaned and blasted. Advanced surface coatings provide practical solutions for ensuring a smooth surface and reducing the effects of fouling and corrosion on airfoils and other engine components. Surface coatings also can decrease exhaust temperature and improve engine efficiency.

On-site coating process

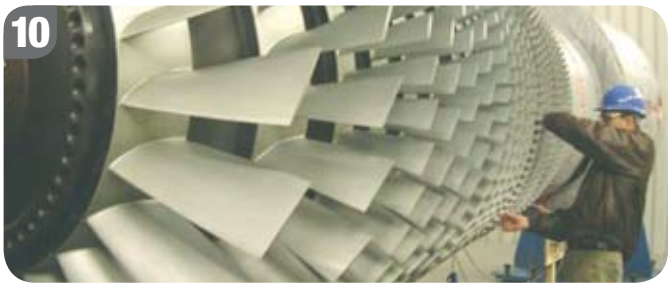
After more than 25 years, Praxair Surface Technologies continues to enhance its on-site coating services to maximize the benefits and minimize processing time. While some factors vary from project to project (such as oven size and surface preparation equipment), overall steps generally remain the same whether coating a rotor, bladed wheel, compressor case or turbine. Here is an overview of those steps:

1. Mobile unit setup. Praxair Surface Technologies ships complete mobile coating and restoration services to your site, including qualified personnel.
2. Inspect and clean surfaces. This includes inspecting airfoils for pits and other metallurgical concerns. Conduct NDT (non-destructive testing) on all components as needed.
3. Grit blast targeted surfaces to remove old coatings, oxidation and rust. Areas not to be coated (such as shafts, seals, internal surfaces of rotors) are masked.
4. Thermal de-greasing. Components are heated to a temperature slightly above the coating cure temperature to remove any residual oil, grease and other contaminants.
5. Mask as needed to protect parts and components that aren't scheduled for coating or servicing.
6. Apply base coat. All base coats use water as the only solvent. As such, humidity control in the spray booth area is essential for achieving smooth, uniform coatings.
7. Cure and burnish the base coat. The base coat is heated and dried at about 80°C (176°F), then cured at about 345°C (653°F). Total curing time depends upon mass, heat-up rate and part configuration. Burnishing may be done by impinging glass beads on the surface or by lightly abrading the coating surface with aluminum oxide grit.
8. Check for conductivity. A conductive coating is galvanically active and makes the coating sacrificial to all steels. The coating will preferentially corrode in hostile saline environments.
9. Apply top coat. The top coat creates a sealed, inert coating surface to resist all kinds of fouling, including corrosion.
10. Dry and cure the top coat. Top coats are dried and cured in the same manner as the base coat.
11. Final inspection. The component is inspected for thickness, surface finish and proper curing.

This mobile workshop is shipped and packaged as two independent containers. The workshop is useful for loose axial compressor diaphragms, bladed wheels and centrifugal compressor diaphragms. The units include an oven, a blasting/ burnishing cabinet and a spray booth area.

Grit blasting removes old coatings, rust and other fouling elements from the surface.

Humidity control is essential for applying a smooth, uniform base coat. Base coat materials are filled with atomized aluminum pigment, which creates rough, coarse overspray if applied at incorrect humidity values.



The top coat is heated and dried, then cured at about 345°C (653°F). Total curing time depends upon mass, heat-up rate and part configuration.

Summary

Today's power generators are sophisticated, precision machines. Each engine requires a significant investment of time, capital and effort to maintain optimal performance.

Advanced surface coatings provide a proven and reliable method for protecting such a significant investment and ensuring its operational efficiency.

Praxair Surface Technologies has pioneered coatings and processes that set benchmarks throughout the industry. These coatings and processes provide protection against corrosion, fouling and wear, thereby improving performance, decreasing energy consumption and extending the life of critical components.

Praxair Surface Technologies builds on its tradition of innovation by offering Axxess on-site coating services, which can:

- Shorten outage time
- Reduce damage risk
- Increase turbine efficiency

The on-site team has serviced more than 100 gas turbine rotors, hundreds of bladed wheels and stators, and disks, turbines and compressor cases throughout the world.

By coating sensitive and vulnerable engine areas with customized advanced coatings from Praxair Surface Technologies, plant operators can protect their investment, minimize risk and ensure optimal engine efficiency and performance.

Examples of components coated on-site using Axxess on-site coating services.

Additional information about on-site coating of turbomachinery:

Praxair Surface Technologies has spent more than two decades refining and mastering on-site coating services. The service team is qualified to coat most industrial gas turbines regardless of size, age, location, condition or environmental challenge. Axxess on-site coating services are available for these and other common industrial gas turbines:

- ABB Alstom (type 8, 9, 11, 13)
- GE Frame (3, 5, 6, 7, 9)
- Siemens/Westinghouse/MHI (W251, W501, W701)
- Siemens series (V94, V84, V64)

For more information, go to **www.praxairsurfacetechnologies.com/getmoreaxxess**

[1] McMordie, B. “Impact of Smooth Coatings on the Efficiency of Modern Turbomachinery.” Aerospace/Airline Plating & Metal Finishing Forum, Cincinnati, 27-9. March 2000.

[2] Phillips, J. and Levine, P. “Gas Turbine Performance Upgrade Options.” Fern Engineering. Accessed 8/19/11.<http://www.fernengineering.com/pdf/gt_upgrade_options.pdf>.

PRAXAIR
SURFACE TECHNOLOGIES

Printed in the United States of America
01-12
Printed on recycled paper
P-10443

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