WASTE HEAT RECOVERY FOR

Commercial and Industrial Facilities

A Technical Overview of Particulate-Laden Exhaust Air

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May 2026
Revision 1.1

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ABSTRACT

Many commercial and industrial facilities discharge heated exhaust air to atmosphere while simultaneously consuming purchased energy for process heating, facility heating, or potable hot water generation. In thermal-process environments, these exhaust streams often contain substantial recoverable thermal energy.

Historically, heat recovery in particulate-laden exhaust air has been limited by fouling, pressure drop, maintenance burden, and declining thermal performance over time. Traditional heat exchanger designs optimized for clean-air applications often become impractical in exhaust streams containing particulate matter, moisture, and other airborne contaminants or process byproducts.

Engineered heat recovery systems designed specifically for polluted exhaust air now enable reliable heat recovery in applications previously considered impractical. By combining particulate-tolerant heat exchanger geometry, closed-loop thermal delivery, and performance monitoring, these systems allow facilities to convert waste exhaust heat into usable thermal power. Recovered thermal energy can then be delivered where needed and utilized across multiple downstream heating applications while maintaining separation between contaminated and clean-air systems.

This paper provides a technical overview of exhaust heat recovery principles, historical limitations, engineered design approaches, and practical applications for particulate-laden exhaust environments. It also examines how recovered exhaust heat can be measured and treated as a quantifiable thermal energy asset within commercial and industrial facilities.

For facilities with particulate-laden exhaust, the question is no longer whether heat recovery is possible.

The question is how much recoverable thermal value is currently leaving the building unused.

Thermal Energy Recovery Fundamentals

Commercial and industrial facilities continuously discharge heated exhaust air to atmosphere from thermal-process equipment such as dryers, ovens, kilns, furnaces, and other industrial systems. This exhaust air often contains substantial thermal energy that has already been purchased through facility energy consumption.

A significant portion of industrial energy demand is associated with process heating and steam generation. Studies indicate that approximately 40% of fossil fuels used in U.S. manufacturing are consumed in these thermal applications, underscoring both the scale of industrial heating demand and the magnitude of energy often rejected through exhaust systems. Much of this demand occurs in low- and medium-temperature applications where exhaust air systems represent a meaningful source of recoverable thermal energy.

Inside Installation

The most common method of recovering this energy is through a heat exchanger, which transfers thermal energy from one medium to another while maintaining physical separation between the two streams. In exhaust heat recovery applications, thermal energy is recovered from heated exhaust air and either delivered directly to another air stream or converted into thermal power within a liquid transfer loop for delivery elsewhere in the facility.

Piping with Measurement

The effectiveness of any heat recovery system depends on heat exchanger selection, thermal design, pressure-drop management, and the characteristics of the exhaust air stream. While the thermodynamic principles of heat recovery are straightforward, practical implementation becomes more complex when the exhaust stream contains particulate matter, moisture, and other airborne contaminants or process byproducts.

Recovered exhaust heat is a measurable, quantifiable thermal energy asset—not wasted energy.
It can be delivered where needed and utilized in the applications that provide the greatest value.

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How Engineered Heat Recovery Systems Work

Engineered heat recovery systems function through three primary steps: converting exhaust heat into usable thermal power, delivering that thermal power where needed, and utilizing it within downstream heating applications.


Rooftop Installation

The process begins at the exhaust-side heat exchanger, where thermal energy is recovered from heated exhaust air and delivered into either another air stream or a closed-loop liquid circuit. In indirect systems, the liquid loop acts as the thermal delivery medium, allowing recovered energy to be transported to a different location within the facility.

Once delivered, recovered thermal energy can be utilized across a range of downstream heating applications, including gases and liquids for either process or facility requirements.


Supply Air Intake Coil

Closed-loop heat recovery architectures provide important advantages in commercial and industrial applications. They maintain physical separation between contaminated exhaust air and the receiving medium while enabling recovered thermal energy to be delivered across the facility to where it provides the greatest value.

When properly engineered, heat recovery systems become integrated components of a facility’s broader thermal energy infrastructure, allowing exhaust heat that would otherwise be wasted to be productively reused within the facility.

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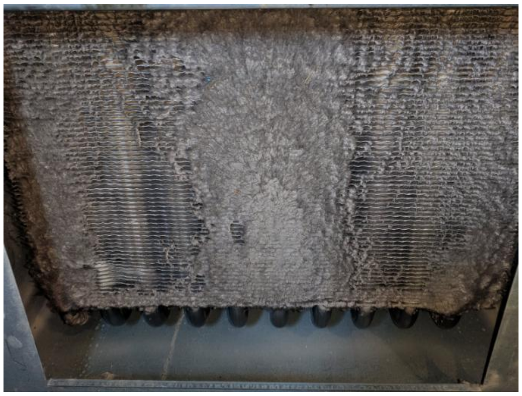
Exhaust Air Challenges in Industrial Heat Recovery

While the thermodynamics of heat recovery are straightforward, successful implementation in polluted exhaust air presents significant practical challenges. Historically, these challenges—not the availability of recoverable heat—have limited adoption in many commercial and industrial applications.

Clogged Unit



Traditional heat exchangers are typically designed to maximize thermal transfer by increasing surface area within a compact footprint. In clean-air environments, this design philosophy improves heat transfer performance. In polluted exhaust streams, however, narrow passages, and tightly spaced heat transfer surfaces can create particle-trapping zones that accelerate fouling.

Clog at Plate Level

As fouling accumulates, pressure drop increases, airflow resistance rises, maintenance requirements grow, and thermal recovery performance declines. In many thermal-process applications, excessive pressure drop can negatively impact upstream equipment performance or require increased fan energy to maintain design airflow.

For this reason, reliability, pressure-drop stability, and maintainability have historically been the primary barriers to exhaust heat recovery in applications containing particulate matter, moisture, and other airborne contaminants or process byproducts.

Particle Repellant Geometry (PRG): Why it Works

Effective heat recovery in polluted exhaust air requires a different design philosophy than traditional clean-air heat exchangers. Conventional heat exchanger designs are typically optimized to maximize thermal transfer efficiency within the smallest possible footprint. In particulate-laden exhaust applications, however, maximizing compact heat transfer surface area often increases fouling susceptibility.

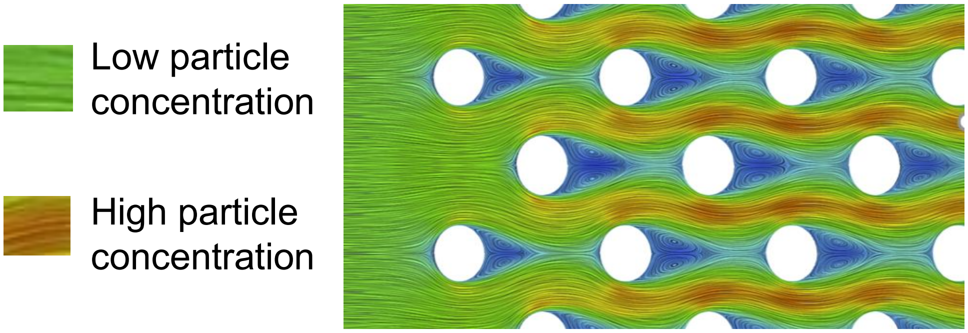
Particle Repellent Geometry (PRG) addresses this challenge by prioritizing particle management alongside thermal performance. Rather than relying on dense fin packs or tightly spaced compact surfaces, PRG utilizes staggered bare-tube geometry with open airflow paths and smooth tubular surfaces engineered to reduce particle adhesion and accumulation with no filtration.

As airflow approaches each tube in the Lepido heat recovery unit, aerodynamic effects cause the air stream to deflect and accelerate around the tube surface. This flow behavior creates repelling forces that encourage many airborne particles to remain in the airstream and pass through the heat exchanger rather than collide with the heat transfer surface.

The geometry also influences where fouling occurs when particle deposition does happen. Since the highest thermal transfer occurs along the upper and lower (10:00 to 2:00 and 4:00 to 8:00) aerodynamic heat transfer zones of the tube surface, and these zones remain comparatively cleaner during operation, thermal performance degradation occurs much slower than in conventional designs.

The result is a heat exchanger architecture engineered to maintain useful thermal transfer, stable pressure drop, and practical cleaning intervals in exhaust streams that have historically challenged traditional heat recovery systems.

CFD Modeled AirFlow in Lepido



Lepido cutaway

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Engineered System Architecture and Measurement

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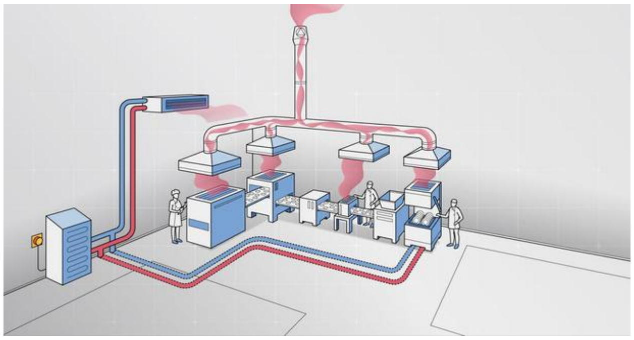
Successful exhaust heat recovery in polluted air applications requires more than a capable exhaust-side heat exchanger. Reliable long-term performance depends on integrating the heat exchanger into a complete engineered system that accounts for thermal delivery, controls, instrumentation, pressure-drop monitoring, maintenance access, and downstream heat utilization.

A typical engineered exhaust heat recovery system includes an exhaust-side heat exchanger, closed-loop thermal delivery circuit, pumps, supply-side heat exchanger(s), controls, and supporting instrumentation. This architecture allows recovered thermal power to be delivered where it provides the greatest operational and economic value while maintaining separation between contaminated exhaust air and downstream heating systems.

Instrumentation and monitoring provide an additional advantage beyond energy recovery alone. Exhaust systems are often among the least instrumented thermal assets within a facility despite representing significant thermal losses. By measuring temperatures, airflow, pressure drop, runtime, and recovered thermal energy, facilities gain visibility into a historically unmeasured portion of their thermal process infrastructure.

This measurement capability supports energy verification, utility incentive reporting, fouling trend analysis, maintenance planning, and ongoing optimization of system performance. It also allows recovered exhaust heat to be treated as a measurable thermal energy asset rather than an estimated efficiency improvement.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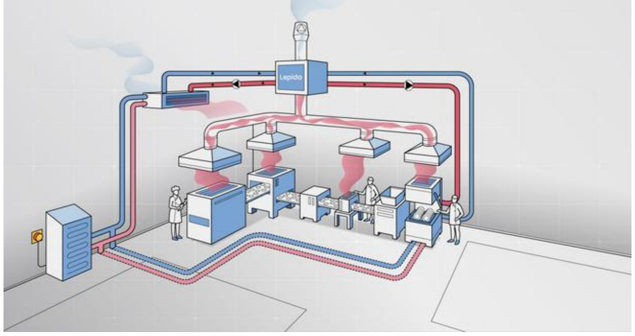
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Recovery Applications and Candidate Profiles

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Engineered exhaust heat recovery systems are most applicable in commercial and industrial facilities where heated exhaust air is discharged to the atmosphere, and a coincident heating load exists elsewhere in the facility.

The strongest candidates for exhaust heat recovery typically exhibit the following characteristics:

- Exhaust temperatures generally between 100°F and 450°F
- Minimum 50 operating hours per week
- Continuous or repeatable exhaust airflow profiles from 1,500-30,000+ CFM
- Available downstream heating demand
- Physical space for installation and maintenance
- Exhaust chemistry suitable for material compatibility upon engineering review

While many thermal-process applications can benefit from heat recovery, system feasibility is highly site-specific and is evaluated based on thermal performance, process integration, operating conditions, exhaust chemistry, and lifecycle economics.

> **The strongest applications are those where recoverable exhaust energy can be consistently reclaimed, delivered, and utilized.**

Rooftop Exhaust with Lepido directly venting to atmosphere

Rooftop Exhaust with Lepido installed in existing duct prior to the filtration & scrubber

Financial and ROI Considerations

Performance is Site-Specific

The financial performance of an exhaust heat recovery system is highly site-specific and depends on several interrelated engineering and operating variables including exhaust temperature, airflow volume, moisture content, operating hours, local energy costs, installation complexity, and how effectively recovered thermal energy can be utilized within the facility.

REDUCE ENERGY COSTS

IMPROVE OPERATING MARGINS

Minimal Parasitic Losses

Once energy is recovered, these systems impose minimal parasitic energy losses, as the primary active components are limited to a circulation pump and, in some applications, mixing or control valves.

Engineered for Long-Term Reliability

The core heat recovery and heat utilization heat exchangers themselves are passive thermal components with no fans, motors, or moving mechanical assemblies. When properly engineered and maintained, primary system components commonly achieve service lives exceeding ten years.

TARGET PAYBACK OF 3 YEARS OR LESS

INCENTIVES IMPROVE ROI

Incentives Improve Economics

Available utility incentives, grants, or energy-efficiency rebate programs can further improve project economics by defraying upfront capital expenditures, in those cases materially reducing simple payback periods.

Strong ROI Potential

When properly engineered and applied, exhaust heat recovery systems can materially reduce purchased energy consumption, improve operating margins, and generate attractive financial returns. Properly selected applications often target simple payback periods of three years or less, depending on application, energy pricing, and available incentives.

The Barrier to Reliable Heat Recovery is Removed

Particulate-laden exhaust air has long been viewed as a difficult or impractical source of recoverable energy. In many facilities, that assumption was historically reasonable: traditional heat exchangers often fouled, created excessive pressure drop, required frequent maintenance, or failed to sustain performance in real operating conditions.

That barrier has now been materially removed through advancements in Particle Repellent Geometry and engineered heat recovery system design. By prioritizing particle management, stable airflow, closed-loop thermal delivery, and measured performance, engineered systems can now reliably recover energy from exhaust streams that were previously overlooked or dismissed.

Exhaust air that was once treated solely as an unavoidable waste stream can now be evaluated as a recoverable thermal resource. When properly engineered, recovered heat can be converted into usable thermal power, delivered through a closed-loop system, and utilized for make-up air, process air, water heating, facility heating, or other downstream heating loads.

The result is more than an efficiency upgrade. It is the conversion of a historically unmeasured exhaust stream into a measurable thermal energy asset—one that can reduce energy consumption and provide new operational insight into facility thermal performance.

For commercial and industrial facilities with particulate-laden exhaust, the question is no longer whether heat recovery is possible. The relevant question is whether the exhaust stream, operating profile, heat demand, and site conditions make the application a strong candidate for engineered recovery.

KEY VALUE DELIVERED

- RELIABLE IN PARTICULATE-LADEN EXHAUST
- PASSIVE THERMAL ARCHITECTURE WITH MINIMAL PARASITIC LOSS
- LONG-LIFE ENGINEERED SYSTEMS (10+ YEAR SERVICE LIFE)
- MEASURABLE THERMAL PERFORMANCE & ENERGY RECOVERY
- STRONG ROI POTENTIAL WITH 3-YEAR OR LESS TARGET PAYBACK

Exhaust streams once considered waste can now be engineered into measurable thermal energy assets that reduce purchased energy consumption and improve facility economics.

ABOUT THE AUTHOR

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Scott Preston has over 30 years of experience in industrial operations, supply chain, procurement, and manufacturing leadership across multiple process industries.

Scott is a Certified Energy Manager (CEM) through the Association of Energy Engineers and a repeat entrepreneur who has founded and operated industrial and service businesses. Through **Norrel™ Inc**. and the **ThermStar System™**, he focuses on assisting facilities to reduce their energy consumption, lower operating costs and decrease CO2 emissions by reclaiming thermal energy from exhaust streams.

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May 2026
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