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DIFHEMI

DIFHEMI INDUCTION HEATERS | BRASCOELMA TECHNOLOGY

Potential Engineering and Technical Sales Brascoelma Cooperation

Executive Engineering Review
Induction Heating vs. Conventional Resistance Heating

Application: High-Temperature Heating of NG + CO_2 Process Gas for Syngas-Oriented Petrochemical Service

Project / Client	For Petrochemical Project
Reference	DIFHEMI 01
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Technical basis: preliminary CFD-style thermal screening, heat-transfer comparison, carbon fouling risk screening and creep-life perspective.

Public technical edition: client and EPC identities have been intentionally omitted. The process basis is presented only to demonstrate the engineering capability of the DIFHEMI / Brascoelma induction-heating platform for demanding petrochemical gas service.

1. Executive Summary

DIFHEMI Induction Heaters, developed for high-performance industrial fluid heating, provide direct electromagnetic heating of the metallic tube wall of coil. This report presents a preliminary engineering comparison between the DIFHEMI induction concept and a conventional shell-and-rod electrical resistance heater under the same process basis.

The review uses process information and drawings associated with a major international petrochemical project application and the DIFHEMI / Brascoelma induction-heater platform. The purpose is to clarify the principal differences in thermal

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behaviour, heat-flux distribution, thermal stress, carbon fouling tendency, transient response, maintenance implications and long-term equipment integrity.

The comparison basis considers an NG + CO_2 process stream heated from approximately 73°C to 600°C, at 25–52 bar, using Inconel 601 and a multi-tube serpentine geometry. Under the preliminary model assumptions, the induction concept maintains the tube wall close to process temperature, while the conventional resistance concept requires substantially hotter local heating surfaces.

The preliminary simulations indicate radial temperature gradients of approximately 15–30°C for the induction case. The resistance case shows localized hot-surface temperatures in the 800–900°C range and radial gradients above 200°C. These results are important because local temperature peaks strongly influence **carbon fouling**, creep, thermal fatigue, ATEX temperature-class considerations and maintenance requirements.

KEY ENGINEERING MESSAGE

The principal advantage of DIFHEMI is not simply heat generation efficiency; it is the ability to generate heat directly in the tube wall with a more uniform thermal field and without localized high-temperature resistance elements. The fluid's residence time within the Inconel 601 coil is extremely short, ensuring minimal contact duration. This high velocity, combined with an exceptionally low thermal gradient between the process fluid and the coil wall, drastically prevents carbon fouling. In sharp contrast, conventional electrical resistance systems force the fluid to reach significantly higher local temperatures with an extended contact time, inevitably triggering localized hot-spots and severe carbon deposition.

2. HIGH-TEMPERATURE PROCESS HEATING AT 600ºC AND 52 BAR

Heating a process stream to approximately 600–620°C at a design pressure of 52 bar in a classified petrochemical area is a demanding thermal duty. The heater must combine high heat flux with controlled metal temperatures, pressure integrity, fast protective shutdown, reliable power modulation and a hazardous-area design that prevents accessible equipment surfaces from exceeding the permitted temperature class.

Three principal technologies can be considered for this service: electrical resistance heating, fired heating and electromagnetic induction heating. DIFHEMI induction technology differs fundamentally from the alternatives because electrical energy is converted into heat directly in the metallic process-tube circuit by induced current and Joule heating. This eliminates the need for a separate immersed resistance element or an open-flame combustion chamber at the heater.

2.1 Design Basis Considered

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Parameter	Design / Project Basis
Process outlet temperature	600°C nominal; up to approximately 620°C considered
Heater duty	900 kW per heater module 1800 KW Total
Design pressure	52 bar
Process tube material	Inconel 601, subject to final mechanical design verification
Piping / process design basis	ASME B31.3 where specified by the project
Hazardous-area requirement	ATEX; Zone 2 / IIB / T2 where specified
Functional safety	SIL 2 safety-function architecture required
Power control	Solid-state SCR / thyristor control
Electrical-to-thermal performance	Approximately 98% stated design efficiency/yield for the DIFHEMI system

3.0 TECHNOLOGY ALTERNATIVE

3.1 Electrical Resistance Heaters — Immersion or Circulation Type

Resistance heaters are a mature and widely used technology. Heat is generated in electrically resistive elements and then transferred through the element sheath and surrounding metal to the process fluid.

Advantages: established technology, straightforward electrical architecture and broad industrial availability.

High-temperature consideration: the resistance-element and sheath temperatures must be above the process-fluid temperature to drive heat transfer. Local heat flux, flow maldistribution or loss of flow can therefore create elevated sheath temperatures and hot spots.

Maintenance consideration: elements and penetrations are discrete components exposed to repeated thermal cycling; service life depends strongly on heat flux, sheath temperature, flow, material selection and process chemistry.

Hazardous-area consideration: compliance depends on the complete certified assembly, surface-temperature control and independent protective functions—not merely on the heating principle.

3.2 Fired Heaters

Fired heaters are well established for large petrochemical heat duties and can achieve very high process temperatures. Their heat source is combustion, with energy transferred from flame and hot combustion gases to process tubes.

Advantages: proven for large thermal duties and high-temperature continuous service.

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Engineering considerations: stack losses, combustion-air management, burner systems, fuel trains, refractory, emissions control and combustion safeguarding add system complexity.

Hazardous-area and functional-safety requirements must address fuel isolation, flame supervision, purge sequences, burner management and safe shutdown.

Maintenance typically includes burner inspection, refractory and combustion-system maintenance, as well as tube-condition monitoring.

3.3 DIFHEMI Electromagnetic Induction Heating

DIFHEMI generates heat directly in the metallic tubular process circuit. Alternating current in the primary winding creates an electromagnetic field that induces high current in the closed secondary metallic circuit. The electrical resistance of the tube converts this induced current into thermal energy by the Joule effect (I^2R). The process fluid is therefore heated from the tube wall that simultaneously forms part of the pressure-containing flow path.

No burner, flame or combustion-gas circuit is required at the heater.

No conventional immersed resistance element is required in the process stream.

Solid-state power control enables rapid modulation of thermal input.

The distributed heating concept can be engineered to reduce localized thermal gradients and hot-spot severity.

The compact electrical heater can be located close to the point of process use, reducing the need for remote heat generation and long thermal-transfer circuits.

3.4 Critical Point: ATEX Zone 2, IIB, Temperature Class T2

For T2 equipment, the relevant maximum surface-temperature limit is 300°C. A process-fluid temperature of 600–620°C does not by itself make T2 impossible, but it creates an important design requirement: accessible external surfaces associated with the certified equipment must remain within the applicable temperature-class limit under the defined operating and fault conditions.

Accordingly, a high-temperature induction heater requires engineered thermal insulation, enclosure design, temperature monitoring and protective trips so that the hot process boundary can operate at the required temperature while the external classified-area surfaces satisfy the applicable ATEX certification basis. The induction

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principle is advantageous because power can be removed electrically and rapidly; however, ATEX compliance must be demonstrated for the complete certified assembly.

3.5 SIL 2 Functional-Safety Architecture

SIL 2 is not an intrinsic property of induction heating, resistance heating or fired heating. It is a performance requirement for a defined Safety Instrumented Function (SIF). For the DIFHEMI system, the heater's rapid electrical de-energization can be integrated effectively into an independent shutdown architecture.

Independent high-high process-temperature protection.

Tube / skin-temperature monitoring at critical locations.

Low-flow or loss-of-flow trip to prevent operation without adequate heat removal.

Pressure protection and process interlocks as defined by the HAZOP / LOPA.

Independent ESD command that removes heater power to a safe state.

Redundant or fault-tolerant sensing and logic where required by the SIL verification.

Final SIL 2 compliance must be demonstrated by SIF definition, failure-rate data, architecture, proof-test interval and SIL verification.

3.6 PED and Mechanical Integrity at 52 Bar

At 52 bar and 600–620°C, pressure containment is a primary design issue. Inconel 601 offers high-temperature oxidation resistance and useful elevated-temperature mechanical properties, but material selection alone does not establish PED compliance. Wall thickness, allowable stress, weld design, fatigue, creep, corrosion allowance, inspection, pressure testing and conformity assessment must all be verified for the final design.

Where ASME B31.3 is adopted as the process-piping design basis, the pressure-containing tubular circuit and welded connections should be engineered and documented accordingly, while the applicable PED conformity route is addressed separately for the European market.

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3.8 Technical Comparison

Engineering Criterion	DIFHEMI Induction	Electrical Resistance	Fired Heater
Heat generation	Directly in metallic process-tube circuit by induced current and I^2R heating. Life span more than 25 years	In resistive element; heat crosses sheath and interfaces before reaching fluid, life span not more 4-5 years	Combustion produces radiant/convective heat transferred to process tubes.
Local hot-spot mechanism	Minimized through distributed electromagnetic and thermal design; tube wall still operates above fluid temperature at 20/30ºC as required for heat transfer.	Element/sheath surface temperature can substantially exceed bulk-fluid temperature, especially at high heat flux or reduced flow more than 200ºC.	Flame pattern and radiant heat flux can create high tube-metal temperatures if combustion or flow is non-uniform.
Power control	Fast solid-state SCR/thyristor modulation; rapid electrical de-energization.	Fast electrical control is possible; architecture depends on heater design.	Burner turndown and combustion control; shutdown includes fuel isolation and purge logic.
Pressure boundary	Heated tubular circuit can be designed as the pressure-containing process path.	Pressure boundary includes heater vessel plus element penetrations/sheaths depending on design.	Process tubes form pressure boundary within fired enclosure.
Hazardous-area design	No flame or fuel train at heater; external surface temperature still requires certified ATEX control.	No flame, but element/sheath and terminal temperatures require certified control.	Requires combustion and fuel-safety systems in addition to hazardous-area requirements.
Maintenance profile	Static electromagnetic heating principle; no maintenance concentrated on power electronics, instrumentation, insulation and process circuit.	Element inspection/replacement may be required depending on duty and thermal cycling.	Burners, refractory, fuel train, combustion controls and tube condition require maintenance.
Electrical-to-thermal efficiency	Approximately 98% stated for the project design, subject to defined system boundary and operating point.	Potentially high at heater terminals; overall performance depends on thermal losses and installation.	Overall efficiency depends on excess air, stack temperature, heat recovery and operating load.

3.9 Why DIFHEMI Is Particularly Attractive for This Duty

For a 900 kW, 600–620°C, 52 bar petrochemical heating duty, the strongest technical case for DIFHEMI is not based on a single claim but on the combination of direct tube-wall heating, absence of combustion, rapid solid-state power control, compact installation and the possibility of integrating the heater into a high-integrity ATEX / SIL safety architecture.

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Direct electromagnetic conversion of electrical energy into heat in the process-tube circuit.

No open flame, burner-management system or combustion exhaust at the heater.

Rapid reduction of heat input following a trip because electrical power can be removed immediately.

Potential for a more uniform axial and circumferential heat-input profile when the electromagnetic circuit is correctly engineered.

Robust high-temperature pressure circuit using a suitable nickel-alloy material such as Inconel 601, subject to final code calculations.

SCR-based continuous power modulation for precise process-temperature control.

Approximately 98% electrical-to-thermal efficiency stated for the DIFHEMI project design.

3.10 Engineering Positioning for a Major Petrochemical Application

The correct engineering comparison should avoid claiming that induction eliminates all high-temperature risks. At a 600–620°C process outlet, the tube wall must necessarily operate at a temperature sufficient to transfer heat to the flowing gas. The DIFHEMI advantage is that the heat source is integrated into the engineered metallic process circuit and can be distributed and controlled without a separate glowing resistance element or combustion flame.

This architecture provides a strong basis for precise temperature management, rapid shutdown response and compact high-temperature electrification. For critical petrochemical service, final acceptance should be supported by thermal analysis, pressure-design calculations, ATEX certification of the complete assembly, HAZOP/LOPA, SIL verification where applicable, and project-specific FAT/SAT procedures.

4. FEATURES OF THE BRASCOELMA INDUCTION HEATER

4.1 Safety - The Electrical Induction Heater offers several safety advantages due to its unique construction and operating principles:

✅ **Dry & Naturally Cooled Operation** – The system functions **without the need for external cooling**, ensuring **reliable performance** with minimal maintenance.

✅ **Flame-Free & Spark-Free** – Unlike traditional heating systems, the **Inductive Heater does not produce flames** or **spark-over**, making it an **ideal choice for hazardous environments**.

✅ **Zero Voltage on Heating Elements** – The entire **heating element remains at zero potential** relative to any external installation, enhancing safety during operation.

✅ **Efficient & Uniform Heating** – The **tubular heating elements** are heated by circulating currents within their walls, ensuring:

- **Constant surface heat flux** for steady and efficient fluid heating.
- **High convection heat transfer coefficient**, optimizing heat distribution.
- **Minimal temperature difference** between the heating surface and the flowing fluid, preventing overheating and improving overall safety.

With its **high efficiency, reliability, and enhanced safety features**, the **BRASCOELMA Induction Heater** is the **ideal solution** for a wide range of industrial fluid heating applications.

4.2 Efficiency of the BRASCOELMA Induction Heater

The **BRASCOELMA Induction Heater** delivers **exceptional efficiency** compared to conventional resistance heating, making it a **cost-effective and durable** solution for industrial heating applications.

4.3 Key Efficiency Advantages

✅ **High Heat Transfer Efficiency**

- The **tubular heating elements** enable **highly efficient heat exchange**, ensuring **minimal temperature differences** between the heating surface and the fluid.
- The fluid flows **at high speed through the pipes**, maximizing heat transfer and optimizing energy use.

✅ **Lower Wall Temperatures = Greater Durability**

- The **high heat exchange coefficient** keeps the **pipe wall temperature low**, reducing thermal stress and extending the lifespan of both the heater and the fluid.
- This feature is especially beneficial for heating **thermal fluids (mineral or synthetic oils) and ultra-viscous oils, as well as other fluids**.

✅ **98% Global Efficiency**

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- **Inductive heating achieves up to 98% efficiency**, significantly outperforming combustion-based heating systems.
- Traditional **fuel-based systems** suffer from **substantial energy losses**, making the **Induction Heater a more economical option in many applications**.

✅ **Energy & Cost Savings**

- Despite using **electrical energy**, the **high efficiency of inductive heating** often makes it **cheaper to operate** than **mineral oil or natural gas combustion systems**.
- The system's **fast response time** allows **precise temperature control**, further reducing energy waste.

✅ **Ideal for all kind of fluids**

- Among **countless industrial applications**, the **Induction Heater** has proven to be the **most efficient and safest solution** for heating **all kind of fluids**

With its **unmatched efficiency, durability, and cost-effectiveness**, the **BRASCOELMA Induction Heater** sets a new **standard for industrial heating technology**.

4.4 Minimal Maintenance Requirements - The BRASCOELMA Induction Heater is designed for long-term reliability with minimal maintenance, thanks to its unique construction:

✅ **No Moving Parts** – Eliminates mechanical wear and tear, reducing maintenance costs.
✅ **No Conventional Electric Resistances** – Avoids common failure points associated with resistance heaters, increasing system longevity.
✅ **Robust Construction** – Designed for **continuous industrial use** with high durability.

4.5 Temperature & Pressure Capabilities

The **operating limits** of the Induction Heater are determined **only by the type of fluid used**, making it an **extremely versatile** heating solution.

✅ **Works at High Temperatures & Pressures** – Can handle extreme operating conditions based on fluid properties.
✅ **Adaptable to Various Applications** – Suitable for industrial processes requiring **precise thermal control** at elevated pressures.

With its **low-maintenance design and superior temperature/pressure adaptability**, the **BRASCOELMA Induction Heater** is an **ideal choice for demanding industrial heating applications**.

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4.6 Immediate Availability, Modularity, and Compact Design

✓ Rapid Heating & Immediate Availability

Unlike conventional heating systems or boilers, the **BRASCOELMA Induction Heater** provides:

✅ **Instant Heating** – Due to its **low thermal inertia**, it quickly reaches the desired fluid temperature.

✅ **Fast Startup** – Immediately begins heating after being energized, optimizing process efficiency.

✅ **Consistent Performance** – Ensures precise temperature control with minimal delays.

✓ Modular Application & Flexible Integration

The **Induction Heater** is designed for **seamless integration** into existing industrial layouts:

✅ **Easy Installation** – Can be adapted to **existing infrastructure** without requiring major modifications.

✅ **Scalability** – Modular design allows **expansion per production sector or specific equipment**.

✅ **Interconnectivity** – Multiple modular units can be linked to **existing consumer equipment**, improving system efficiency.

✓ Compact & Space-Saving Design

Compared to traditional heating systems of equivalent power, the Induction Heater offers:

✅ Smaller Footprint – Maximizes available workspace.

✅ Easier Placement – Compact structure simplifies installation.

✅ Optimized Layout Usage – Efficient use of industrial space, ideal for restricted environments.

4.7. Scope and Comparison Basis

The preliminary engineering review focuses on:

- Thermal behaviour and temperature uniformity
- Quantified heat-transfer and heat-flux comparison
- Transient response and residual heat after shutdown
- Fouling and carbon fouling risk screening
- Thermal stress, creeping and long-term integrity
- Maintenance, reliability and operational risk considerations

5. Initial Operating Parameters

Parameter	DIFHEMI Induction Heater	Resistance Shell & Rod
Heating surface / wall temperature	620–650°C	800–900°C rod surface
Fluid bulk temperature	600°C	600°C
ΔT to fluid	20–50°C	200–300°C
Heat flux	80–120 kW/m^2	150–250 kW/m^2 local peaks
Preliminary process efficiency	~96%	~86% statistical lower-limit case
Thermal field	Uniform / controlled	Localized hot spots possible

6. Thermal Performance and Energy Perspective

The source review identifies an electrical-to-thermal conversion of approximately 97–98% for the induction unit before overall process losses. The resistance element itself is treated as nominally 100% electrical conversion, but the report also identifies higher shell and radiation losses. On the preliminary basis used here, the compiled process-level figures are approximately 96% for induction and approximately 86% for resistance cases.

The induction heater also shows a more favourable shutdown response in the preliminary assessment: heat generation stops rapidly, residual heat is lower and the cool-down curve is faster. This can reduce prolonged exposure of the process fluid and metallic components to elevated temperatures.

Because the DIFHEMI concept heats the metallic tube wall directly by electromagnetic induction, the thermal field can be distributed along the heat-transfer surface rather than concentrated at discrete resistance elements. This distinction is central to the **carbon fouling** and thermal-stress comparison.

7.1. Carbon Fouling Risk Screening

A simplified Arrhenius-type screening approach was used in the source study to illustrate the strong sensitivity of hydrocarbon carbon fouling to film or hot-surface temperature. The screening used an activation-energy range of 150–220 kJ/mol and a mid-case value of 180 kJ/mol.

Case	Hot surface / film temperature	Relative carbon fouling rate screening
Induction – conservative	630°C	0.6×
Induction – baseline	650°C	1.0×
Resistance – moderate	800°C	~24× higher
Resistance – severe	850°C	~64× higher
Resistance – extreme	900°C	~155× higher

Within these assumptions, a conventional resistance shell-and-rod heater operating with local surfaces at 800–900°C may show a carbon fouling tendency roughly one to

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two orders of magnitude higher than the induction baseline. This is a screening comparison, not a substitute for a project-specific kinetic model.

8. The Strategic Context: Dry Reforming of Methane (DRM)

The objective of heating a natural-gas stream, composed primarily of methane (CH_4), together with carbon dioxide (CO_2) to elevated temperatures is consistent with the thermal requirements of Dry Reforming of Methane (DRM), an endothermic catalytic process that converts two carbon-containing gases into synthesis gas. From a strategic perspective, DRM is particularly attractive because it can utilize CO_2 as a reactive feedstock rather than treating it solely as an emission, while simultaneously converting methane into a versatile intermediate for downstream chemical production.

Reaction Output: Syngas Production

The principal products of DRM are carbon monoxide (CO) and hydrogen (H_2), collectively known as synthesis gas, or syngas. The ideal stoichiometric reaction is:

$CH_4 + CO_2 \rightarrow 2CO + 2H_2$

Under ideal stoichiometric conditions, DRM produces syngas with an H_2:CO molar ratio close to 1:1. This composition can be advantageous for selected downstream synthesis routes. In an industrial reactor, however, the actual product composition depends on catalyst formulation, temperature, pressure, feed ratio, residence time, and competing reactions such as the reverse water-gas shift reaction and carbon-forming reactions.

Why High-Temperature Heating Is Critical

Dry reforming is strongly endothermic and therefore requires substantial thermal energy to reach and maintain the reaction temperature. Consequently, controlled high-temperature preheating of the methane/CO_2 feed can be an important part of the overall process energy strategy. For critical petrochemical service, the heating system must combine high heat input with precise temperature control, mechanical integrity, rapid response, and reliable containment of the process stream.

9. Downstream Industrial Applications of Syngas

9.1 Synthetic Fuels and E-Fuels

After appropriate conditioning of the H_2/CO ratio, syngas can be converted through Fischer-Tropsch and related synthesis routes into liquid hydrocarbons. Depending on the complete process configuration and carbon/energy sources, these products can include synthetic diesel, synthetic gasoline components and aviation-fuel-range hydrocarbons.

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9.2 Base Chemicals and Polymers

Syngas is an important platform feedstock for methanol and other oxygenated chemicals. Methanol is subsequently used in the production of formaldehyde, acetic acid, resins and numerous chemical intermediates. Through Methanol-to-Olefins (MTO) technology, methanol **can also be converted into light olefins such as ethylene and propylene, the principal building blocks for polyethylene and polypropylene.**

9.3 Aldehydes and Higher Alcohols

Carbon monoxide and hydrogen are also used in hydroformylation and related synthesis routes to manufacture aldehydes and alcohols that serve as intermediates for plasticizers, solvents, detergents and specialty chemicals.

9.4 Hydrogen Recovery and Further Processing

Where the process scheme requires it, hydrogen can be recovered and purified from conditioned syngas. High-purity H_2 is widely used for refinery hydrotreating and hydro processing. It is also a fundamental feedstock for ammonia synthesis after integration with a suitable nitrogen source.

9.5 Strategic Engineering Perspective

DRM therefore represents more than a conventional heating duty: it is a route for transforming methane and CO_2 into a flexible chemical intermediate. In such a service, the heater becomes a critical process component because stable and accurately controlled thermal input directly supports reactor-feed conditioning, process stability and downstream syngas quality.

The heating of **flammable fluids NG + CO_2 at 600/620°C and 52 Bar** represents one of the most critical challenges in process engineering. Traditional **"Shell & Tube"** resistance heaters (Immersion Heaters) are limited by the physical constraints of heat transfer through a sheath.

Brascoelma's **Magnetic Induction Technology** offers a **"Solid State"** alternative that prioritizes safety **(ATEX/SIL2),** mechanical integrity, and long-term profitability by transforming a traditional maintenance-heavy cost center into a high-uptime asset.

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9.6 Key Competitive Advantages of our heater (produced by Brascoelma)

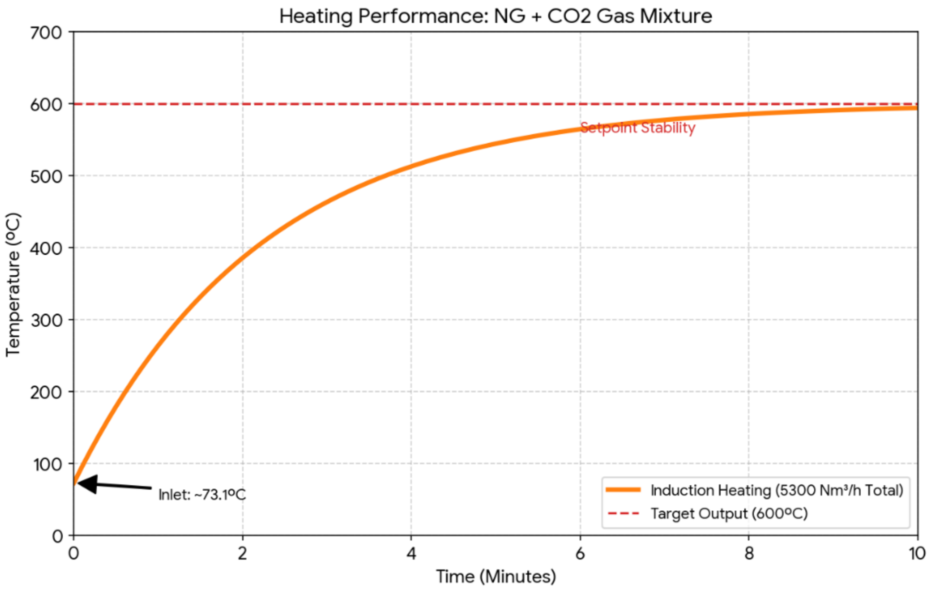
- **Certified 98% Energy Efficiency:** Our electromagnetic induction generators achieve a certified 98% efficiency rating, drastically reducing operational costs by ensuring nearly all power is converted into usable process heat.
- **Solid-State "Clean Tech" Design:** Built on an advanced solid-state induction platform, this technology eliminates combustion byproducts and mechanical wear, providing a sustainable and highly reliable industrial solution and no needs any kind of refrigeration.
- **Maintenance-Free Lifecycle:** Engineered with no internal wear parts, the system eliminates the traditional maintenance burden, offering an unprecedented lifespan of up to 25 years without requiring heater-body interventions.
- **Profit-Generating Asset:** Unlike conventional resistance heaters—which act as ongoing cost centers due to frequent part replacements—our induction system is a profit-driven investment that maximizes plant uptime and ROI.
- **Superior Electrical Safety:** The system operates with **zero voltage** in the coiled process tubes, eliminating short-circuit risks and ensuring the highest level of operator and equipment safety.
- **Engineered for Hazardous Environments:** Specifically designed for the safe heating of flammable and explosive fluids, meeting the most stringent safety protocols for volatile industrial applications.

9.7 Concept Description

- The system utilizes advanced electromagnetic principles to deliver high-precision thermal energy. By applying voltage to the **primary winding**, a high-frequency magnetic field is generated. This field induces heat directly within the **tubular bundle (secondary coil)** via the **Joule effect**.

- Since the secondary coil terminals are short-circuited within the design, the electromagnetic energy is converted into thermal energy directly in the pipe walls. The process fluid circulates through these pipes, absorbing heat with **maximum Exergetic Efficiency**. This "direct-to-pipe" heating method eliminates the thermal lag and high-temperature "hot spots" common in traditional resistance-based shell and tube systems and providing near-instantaneous fluid heating, the thermal inertia is restricted to the coil's filling time.

Figure nº1 – Near-instantaneous heating performance: raising gas mixture temperatures from inlet (15°C NG / 125°C CO2) to a 600°C setpoint upon startup heating



9.8 Technical Highlight: Elimination of Hot Spots

- **Uniform Heat Distribution (No Hot Spots):** Unlike resistance heaters, where the element is always significantly hotter than the fluid, induction generates heat directly and uniformly within the tube wall. This eliminates the risk of **localized hot spots**, preventing fluid degradation and ensuring that surface temperatures never exceed the **T2 safety threshold**, even at high process temperatures.

9.9 Technical Comparison: The Physics of Heating

Feature	Magnetic Induction (Brascoelma)	Resistance Shell & Tube (Conventional)
Heat Generation	**Internal:** The Inconel 601 tube wall *becomes* the heater via magnetic field.	**External:** Heat must pass from a filament, through insulation/sheath, into the fluid.
Surface Temp (T-Class)	**Uniform:** No element is hotter than the tube itself. Easy T2 compliance.	**Hot Spots:** Elements must run at 800°C+ to output 600°C. High ATEX risk.
Mechanical Design	Continuous heavy-duty piping (ASME B31.3).	Hundreds of fragile resistance pins and seal points.
Thermal Inertia	**Near-Zero:** Immediate heat cessation upon power cut (Critical for SIL2).	**High:** Residual heat continues to dissipate after shutdown, risking fluid degradation.

9.10 Mechanical Integrity at 52 Bar

Traditional heaters utilize a large flange with hundreds of entry points for resistance elements. Under 52 Bar of pressure, each entry is a potential leak path. Induction heaters utilize **seamless, continuous welding**, offering the highest safety factor for hazardous gas containment. In a resistance system, the internal filament must exceed 800°C for the gas to exit at 600°C, which risks violating T2 safety limits if flow fluctuates. With induction, heat is distributed uniformly throughout the pipe mass. Combined with our SCR precision control, we ensure no surface ever exceeds safety parameters.

9.11 The "Hidden Tax" of Resistance Heating

Operating resistance heaters at 600/620 °C causes accelerated thermal fatigue. Over a 25-year period, a plant will spend more on bundle replacements and labour than the original cost of the heater—not to mention the costs associated with maintenance shutdowns over time. Brascoelma's induction heater eliminates this "maintenance cost" by operating without shutdowns, running continuously 24/24, 365 days a year.

9.12 Safety & Compliance (ATEX / SIL 2 / PED)

- **ATEX Compliance:** Induction avoids the "incandescence risk" inherent in resistance filaments. By heating the mass of the pipe, we ensure surface temperatures stay within safety envelope relative to the process conditions.

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- **SIL 2 Functional Safety:** In an Emergency Shutdown (ESD), the magnetic field collapses instantly. Unlike resistances, which stay dangerously hot for minutes, induction stops heating in milliseconds, preventing over-temperature accidents.
- **PED (Pressure Equipment Directive):** Our use of Inconel 601 and high-thickness piping ensures compliance with the most stringent European pressure standards for high-temperature service.

10. Preliminary CFD-Style Thermal Analysis

The figures below reproduce the preliminary reduced-order simulation results used in the original engineering review. They are intended to illustrate relative behaviour under the stated assumptions.

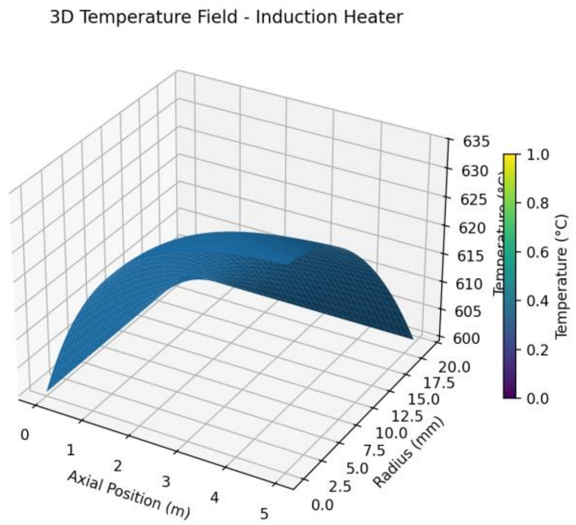

Figure 2 – 3D temperature field: DIFHEMI induction heater.

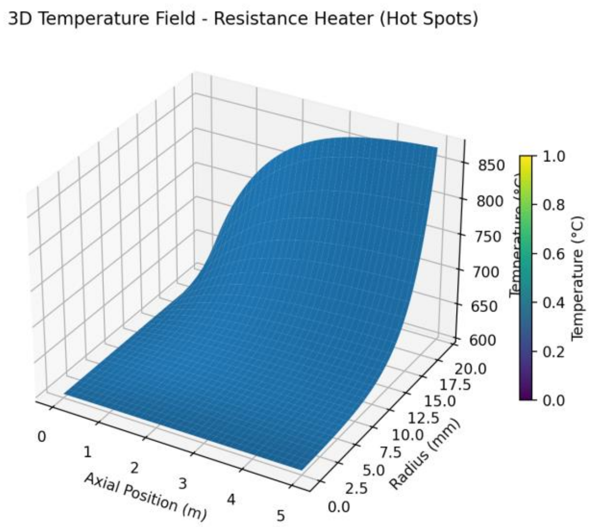

Figure 3 – 3D temperature field: conventional resistance heater, highlighting hot-spot behaviour.

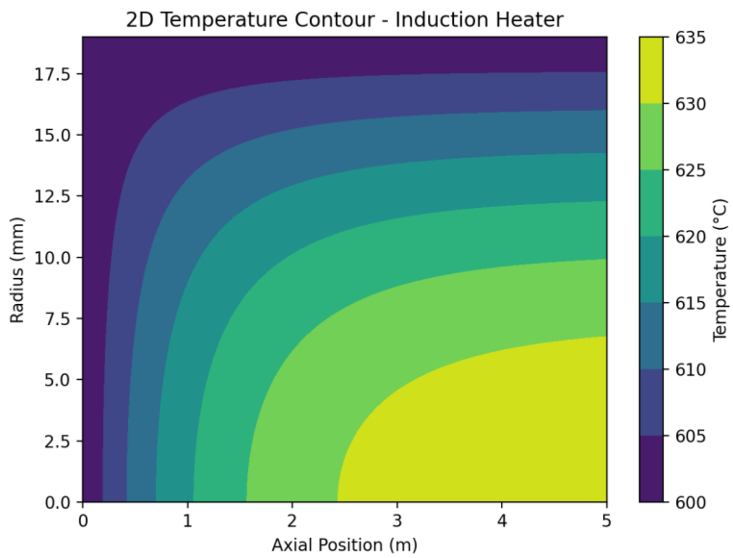

Figure 4 – 2D temperature contour: DIFHEMI induction heater.

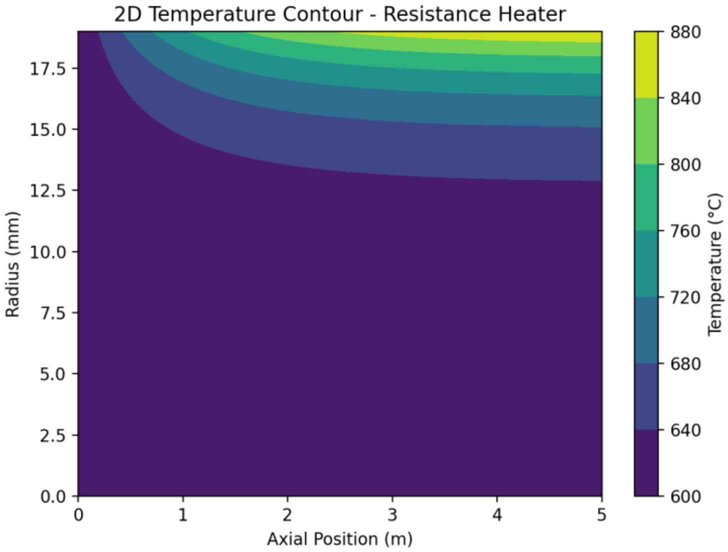

Figure 5 – 2D temperature contour: conventional resistance heater.

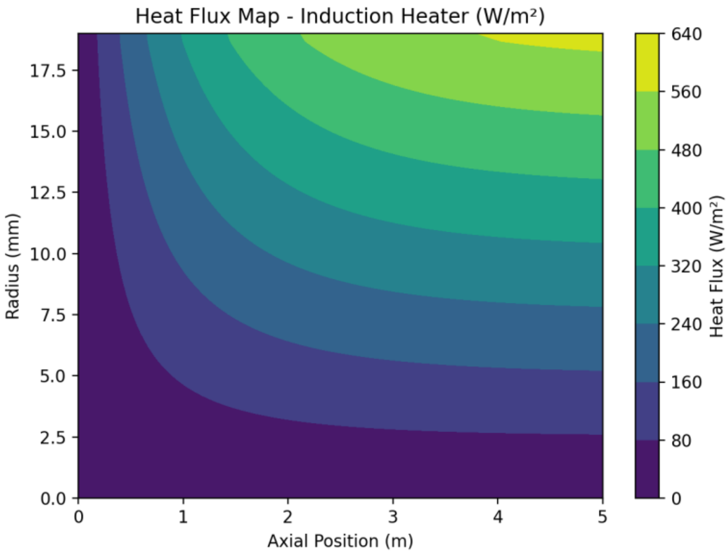

Figure 6 – Heat-flux map: DIFHEMI induction heater.

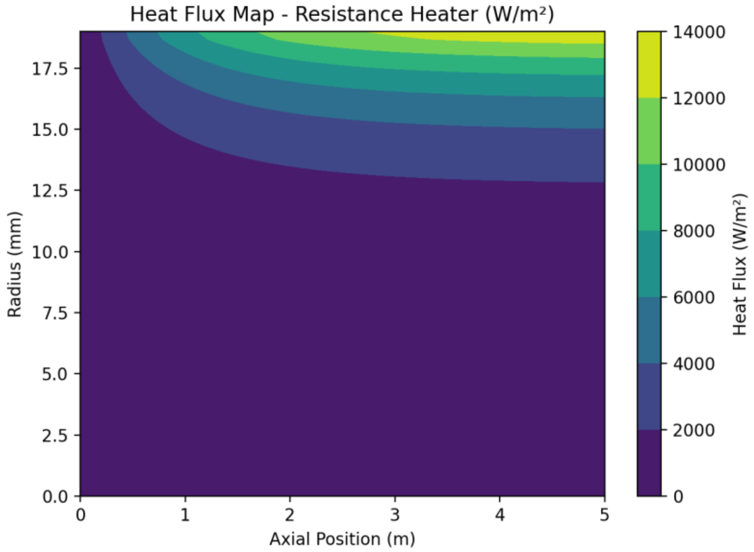

Figure 7 – Heat-flux map: conventional resistance heater.

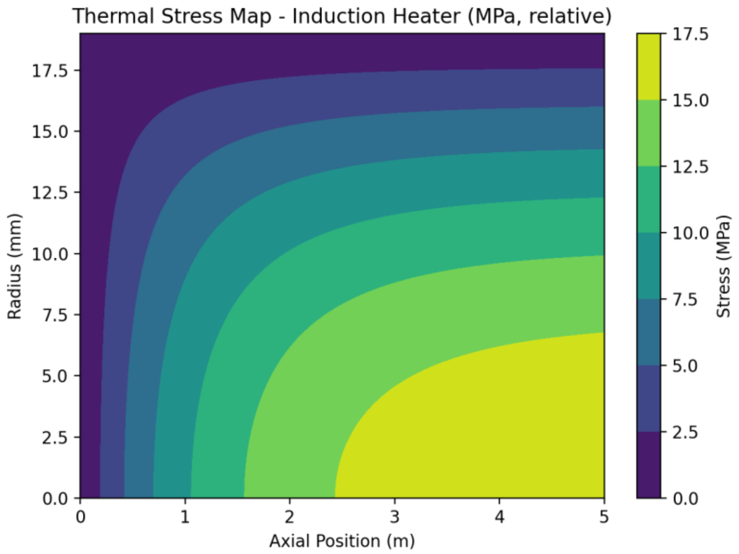

Figure 8 – Relative thermal-stress map: DIFHEMI induction heater.

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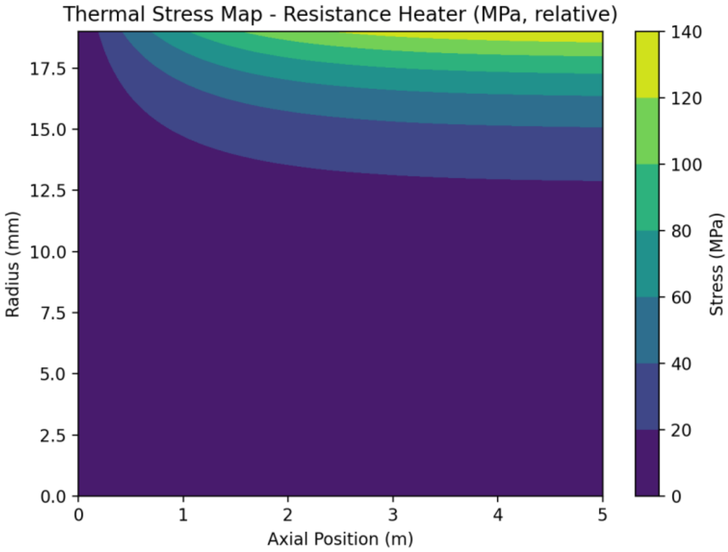

Figure 9 – Relative thermal-stress map: conventional resistance heater.

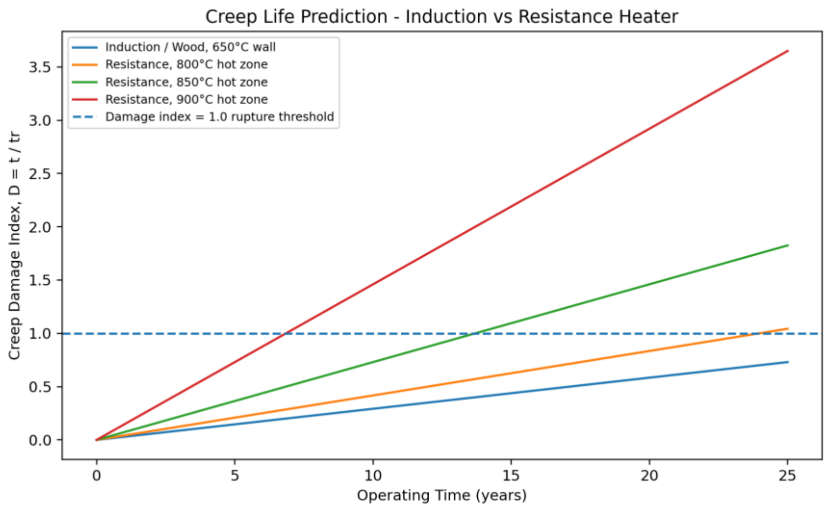

Figure 10 – Preliminary creep-life damage-index comparison.

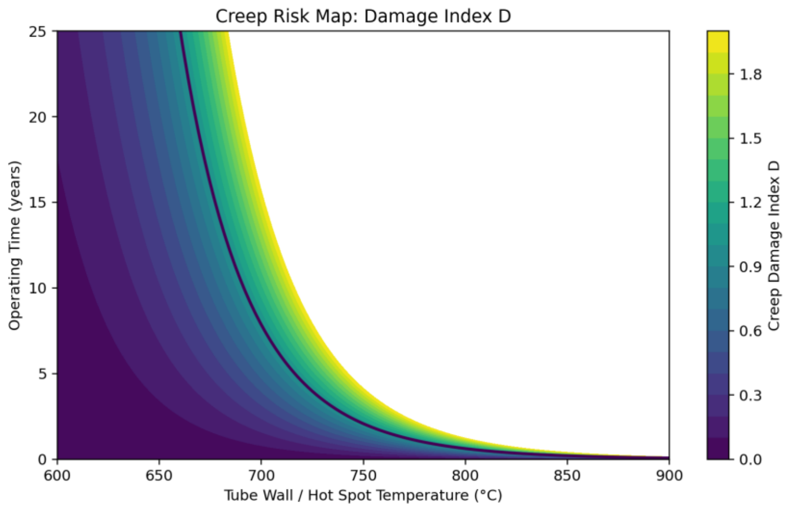

Figure 11 – Creep-risk map as a function of temperature and operating time.

11. Key Findings

Engineering Criterion	Preliminary DIFHEMI Perspective
Temperature uniformity	Preliminary induction gradients below ~30°C versus resistance gradients above ~200°C in the modeled hot-spot case.
Localized overheating	DIFHEMI avoids discrete immersed resistance elements and therefore reduces the mechanism responsible for concentrated hot surfaces.
carbon fouling tendency	Arrhenius screening indicates a materially Carbon formation-free potential for the induction Difhemi.
Thermal stress and creep	Lower temperature gradients correspond to lower modeled thermal-stress concentration and a more favourable creep-life perspective.
Shutdown behaviour	Rapid cessation of induction heating reduces residual heat and prolonged high-temperature exposure.
Maintenance and reliability	The preliminary comparison supports lower exposure to element replacement, carbon fouling-related cleaning and hot-spot-driven degradation.
Safety perspective	Lower local surface temperatures can't have thermal-degradation and temperature-class concerns; final ATEX compliance remains project-specific.

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12. HISTORY OF DIFHEMI

The origins of DIFHEMI date back to 1983, when Dr. Ing. MSc. Mario Di Giulio pioneered the development of an advanced system for the direct heating of fluids by electromagnetic induction.

At a time when conventional electrical resistance heaters, steam systems and combustion-based technologies dominated industrial process heating, this concept introduced a fundamentally different approach: generating heat by electromagnetic induction directly in the metallic heating assembly through which the process fluid circulates.

The development was based on extensive engineering calculations, thermal analysis and practical experimentation. Working within the field of thermal engineering, the pioneers of technology developed specific calculation methods for the design and sizing of electromagnetic-induction fluid heaters for different operating conditions, fluids, temperatures, pressures and thermal duties.

Experimental prototypes were subsequently developed and validated, establishing the foundation of what became known as DIFHEMI — Direct Fluid Heating by Electromagnetic Induction.

One of the distinguishing characteristics of DIFHEMI is its ability to heat a wide range of industrial fluids, in either liquid or gaseous phase.

Over the subsequent decades, technology has been applied to demanding process-heating duties involving thermal oils, petroleum-derived products, aviation fuels such as Jet A-1, natural gas (NG), nitrogen, process gases and other industrial fluids.

This versatility is particularly important when dealing with temperature-sensitive or carbonaceous fluids.

Unlike conventional resistance heating, where an electrical element may operate at a temperature considerably higher than the bulk-fluid temperature, DIFHEMI generates heat in the metallic heating assembly itself.

Combined with continuous fluid circulation and appropriate thermal design, this allows the wall-to-fluid temperature difference to be closely controlled and reduces the conditions that can promote localized overheating, thermal degradation, fouling and carbon fouling.

Technology is also particularly suitable for demanding industrial environments where safety, reliability and process integrity are essential. DIFHEMI systems can be engineered according to the applicable requirements for hazardous areas, pressure equipment and functional safety, including ATEX, PED and SIL 2, as required by the specific project.

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Applicable pressure-vessel and piping codes are selected according to the equipment configuration and project requirements.

From Energy Efficiency to Decarbonization although the development of DIFHEMI began well before the international climate initiatives of the 1990s, its original emphasis on efficient electrical process heating anticipated many of the challenges that industry would subsequently face.

The adoption of the Kyoto Protocol in 1997 marked an important stage in international efforts to reduce greenhouse-gas emissions. In the following decades, industrial companies faced two increasingly important and simultaneous requirements: improving energy efficiency and competitiveness while reducing dependence on fossil-fuel combustion and lowering the carbon intensity of industrial processes.

In this context, direct electromagnetic-induction fluid heating became increasingly relevant.

Where technically and economically appropriate, an electrically powered DIFHEMI system can replace or complement heating systems based on fossil-fuel combustion, steam generation or conventional electrical resistance heating.

The environmental benefit must nevertheless be evaluated according to the electricity source and the complete process-energy balance.

DIFHEMI eliminates combustion at the heater itself, while the overall carbon footprint depends principally on the electricity-generation mix and the efficiency of the complete installation.

Energy, Exergy and the DIFHEMI Concept The thermodynamic significance of DIFHEMI can also be considered from the standpoint of exergy.

According to the classical thermodynamic concept developed by Rant and subsequently treated extensively by Kotas, energy is conserved according to the First Law of Thermodynamics; however, not all energy possesses the same capacity to perform useful work.

The total energy of a system can conceptually be separated into: Energy = Exergy + Anergy where exergy represents the maximum useful work that can theoretically be obtained as a system comes into equilibrium with its reference environment, while anergy represents the portion of energy that cannot be converted into useful work under those conditions. This distinction is particularly relevant to industrial heating.

The objective should not simply be to supply a given quantity of energy, but to deliver that energy to the process with the minimum practicable losses and at the temperature and location where it is actually required.

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DIFHEMI addresses this objective by converting electrical energy into heat through electromagnetic induction in the heating assembly and transferring this heat directly to the circulating process fluid. By avoiding a conventional combustion stage and, in suitable applications, intermediate heat transfer stages, the system can reduce unnecessary energy transformations and associated losses.

Properly designed DIFHEMI installations have demonstrated electrical-to-thermal efficiencies approaching approximately 98% under defined operating conditions.

The exact efficiency, however, must always be established for the particular equipment and operating point, taking into account electrical losses, heat losses to the environment, auxiliaries and the complete system boundary.

DIFHEMI — Direct Fluid Heating by Electromagnetic Induction: more than four decades of development in the direct, controlled and efficient heating of industrial fluids. Its fundamental principle remains unchanged:

Electrical Energy → Electromagnetic Induction → Heated Metallic Surface → Process Fluid

Rather than relying on an excessively hot resistance element, flame or an intermediate heating medium, DIFHEMI is designed to deliver controlled heat directly to the fluid flowing through the heater. This combination of high energy efficiency, controlled wall temperature, rapid thermal response, reduced localized overheating, absence of combustion at the heater and applicability to both liquids and gases makes DIFHEMI particularly relevant to modern industrial requirements for process efficiency, electrification, reliability and decarbonization.

13. HOW IT WORKS:

8.1 The Operating Principle of DIFHEMI Electromagnetic Induction Heating

The DIFHEMI Electromagnetic Induction Heater (GEI) is a static electrical heating system designed to transfer electrical energy directly into thermal energy for heating liquids and gases. Unlike conventional systems that first generate heat in a separate source and then transfer and transport that heat to the process, DIFHEMI generates heat directly in the metallic tubular heating assembly through which the process fluid flows.

This direct-heating concept allows the equipment to be installed close to the point of consumption. Its compact footprint can reduce the need for long thermal-fluid circuits, remote heat exchangers and the associated distribution losses found in many conventional indirect-heating installations.

13.1 Transformer-Based Electromagnetic Principle

The operating principle of DIFHEMI originates from the same fundamental electromagnetic principles used in a transformer. An alternating voltage is applied to the primary winding, creating an alternating magnetic field in the magnetic circuit. This field induces a high electrical current in the secondary heating circuit.

In the DIFHEMI configuration, the metallic tubular assembly acts as the electrically coupled secondary circuit. Because this secondary circuit is effectively closed, the induced current circulates through the metallic tubes. The electrical resistance of the metal converts the induced electrical energy into heat by the Joule effect (I^2R). Consequently, the heat is generated directly in the tube wall rather than being transferred from a separate resistance element, flame or external heating surface.

13.2 Energy Conversion Sequence

1. Electrical Input - Alternating electrical power is supplied to the primary induction winding.

2. Magnetic Field Generation - The primary winding creates an alternating electromagnetic field in the magnetic circuit.

3. Induced Secondary Current - The electromagnetic field induces a high current in the closed metallic tubular secondary circuit.

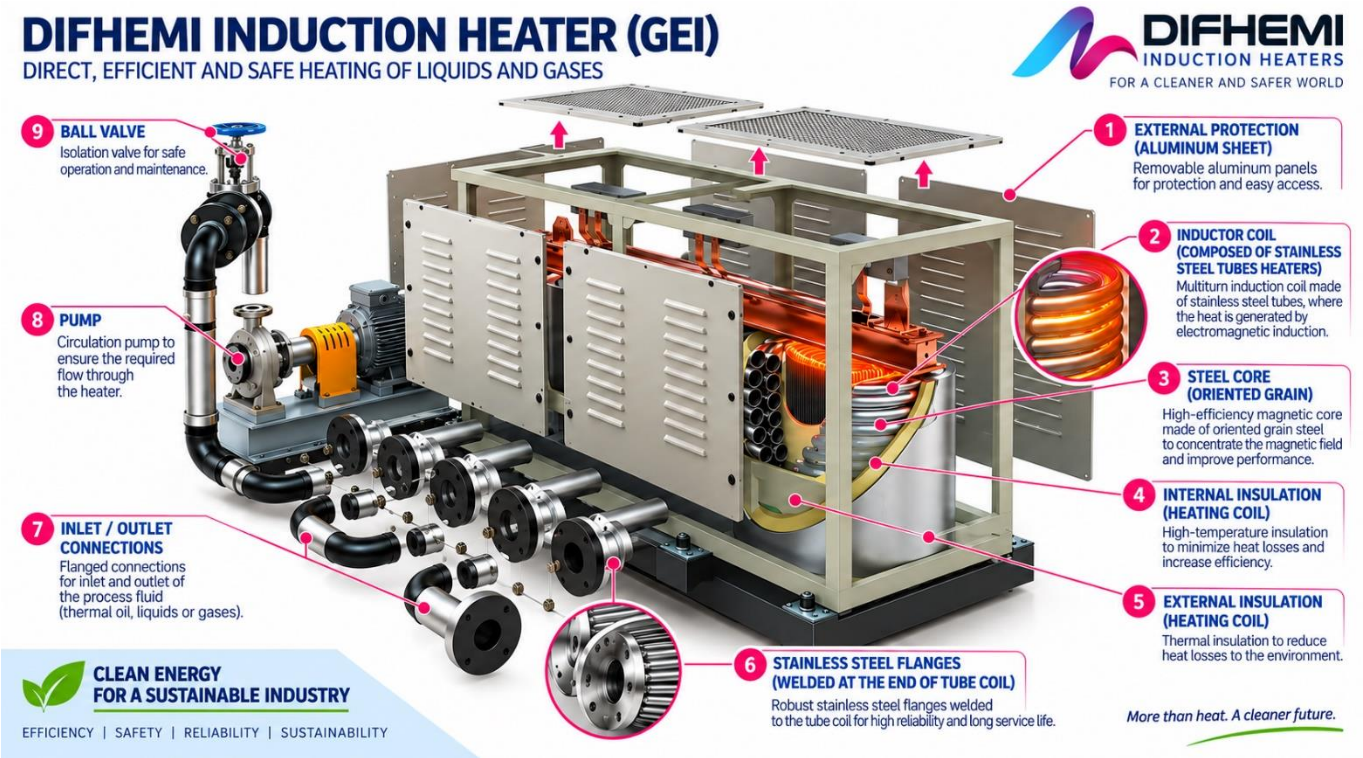
4. Direct Joule Heating - The induced current produces heat directly within the tube wall through the I^2R Joule effect.

5. Heat Transfer to the Process Fluid - The liquid or gas flowing inside the tubes receives heat directly from the heated tube wall.

6. Precise Power Control - Electrical power can be modulated rapidly to match the required process temperature and thermal duty.

13.3 High Thermoelectric Efficiency

Because the energy conversion takes place directly in the metallic heating circuit surrounding the process flow, intermediate heat-transfer stages are minimized. In DIFHEMI applications designed for this purpose, the electrical-to-thermal conversion efficiency can reach approximately 98%, subject to the specific equipment design, operating conditions, insulation and system boundaries used for the efficiency calculation.



THE KEY DIFHEMI DIFFERENCE
Electrical energy is converted into heat directly in the metallic tubular secondary circuit, placing the heat source immediately adjacent to the process fluid and avoiding a separate high-temperature heating element.

13.4 Engineering Advantages of the Direct Induction Concept

Direct generation of heat in the metallic tube wall.

Compact installation close to the point of process consumption.

Reduced thermal-distribution losses compared with remote indirect-heating systems.

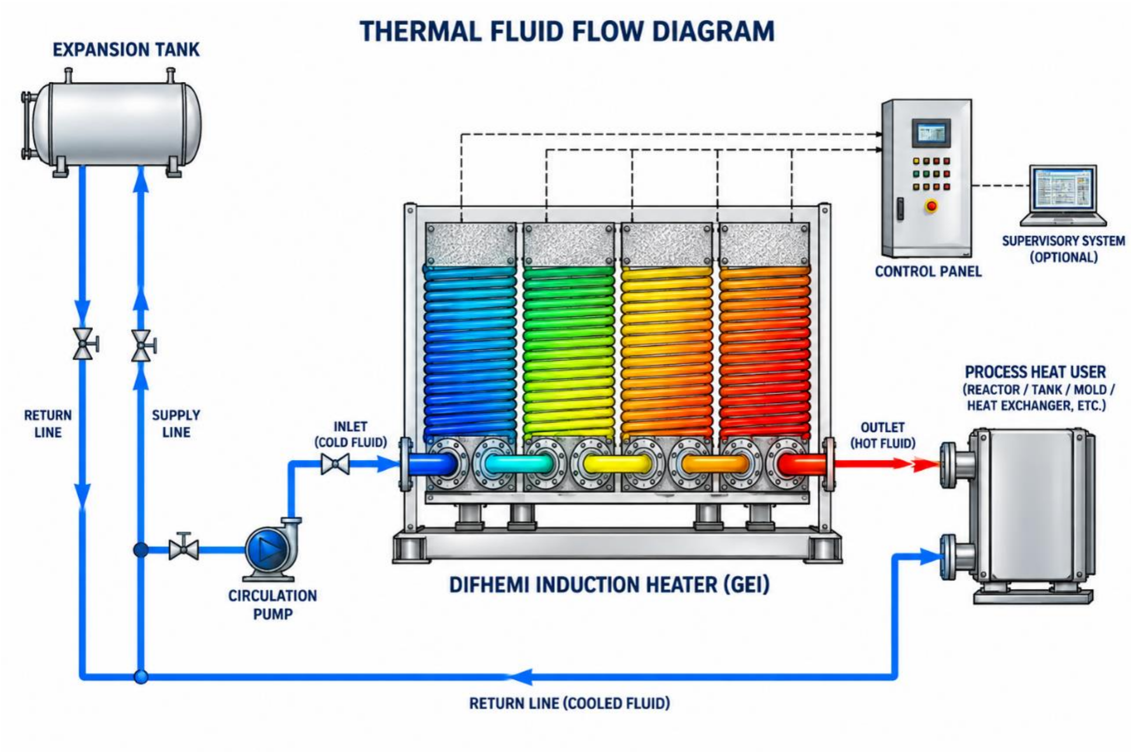
Rapid electrical power modulation and fast response to process demand.

No conventional electrical resistance element in direct contact with the process fluid.

Uniform and controllable heat generation when the induction circuit is properly engineered.

High electrical-to-thermal conversion efficiency, reaching approximately 98% in suitable DIFHEMI designs.

Applicable to both liquids and gases across a wide range of industrial process-heating duties.



14. Electromagnetic Heating Principle and Direct-to-Pipe Energy Transfer

The DIFHEMI / Brascoelma architecture uses the process-tube assembly as the electrically induced heating body. The primary winding generates an alternating magnetic field; induced currents in the metallic secondary circuit produce Joule heating directly in the pressure-containing tube wall. The process gas therefore receives heat from the same metallic boundary that contains it, rather than from a separate high-temperature resistance element located inside a pressure vessel.

This direct-to-pipe mechanism is the central engineering distinction. It shortens the thermal path, distributes heat over the available tube surface, reduces dependence on discrete high-temperature elements and allows power to be modulated electronically. In the source technical material, the induction-generator electrical conversion efficiency is stated at approximately 98%; the project-level thermal performance remains dependent on insulation, geometry and process losses.

The secondary process-tube circuit is not energized as a conventional resistive element. Heating is induced electromagnetically in the metal, while the power electronics and primary electromagnetic circuit remain functionally separated from the process fluid. This architecture is particularly attractive where containment, electrical isolation and predictable thermal response are critical design objectives.

15. High-Pressure Mechanical Integrity and Containment Philosophy

At a design pressure up to 52 bar and process temperatures approaching 600–620°C, pressure-boundary integrity becomes as important as heat-transfer performance. The project basis uses Inconel 601 process tubing in a continuous multi-tube serpentine arrangement. The induction concept avoids placing a large bundle of individually penetrated resistance elements through the process pressure boundary.

Conventional circulation heaters typically require multiple element penetrations, sheaths, seals and termination interfaces. Each additional penetration is a component that must be engineered, inspected and maintained under combined pressure and temperature cycling. By contrast, the DIFHEMI concept concentrates the pressure boundary in robust process piping and welded connections, reducing the number of heater-element interfaces exposed to the pressurized gas.

The engineering basis references ASME B31.3 piping practice and PED requirements for pressure equipment. Final compliance, material thickness, weld procedures, NDE, allowable stresses and pressure testing remain project-specific and are established during detailed mechanical design.

16. Control, Shutdown Response and Functional-Safety Architecture

Power modulation is performed electronically through SCR-based control, enabling continuous adjustment of heater output to process demand. This is important for a gas stream with large temperature lift because outlet-temperature control can respond without mechanical switching of heater stages. The thermal inertia is dominated by the heated tube mass and contained process inventory rather than by a separate bank of very hot resistance elements.

On an emergency power command, electromagnetic heat generation collapses essentially with removal of excitation. The metallic tube and process fluid still retain sensible heat, but there is no separately energized resistance element continuing to supply heat. This characteristic is valuable when designing high-high temperature trips, low-flow interlocks and Emergency Shutdown (ESD) functions.

For a SIL 2 safety function, the complete Safety Instrumented Function must be engineered and verified as a system. A practical architecture may include independent temperature and flow measurement, redundant or appropriately voted sensors where required, a safety PLC or certified logic solver, independent trip paths, and positive removal of heater power. DIFHEMI's rapid electrical de-energization is a favourable actuator characteristic; SIL capability is confirmed only through the project-specific SIF/SIL verification.

17. Hazardous-Area, ATEX and Surface-Temperature Considerations

For hazardous petrochemical service, the relevant safety question is not simply the 600°C process temperature; it is the temperature of exposed equipment surfaces, electrical equipment protection concept, gas group, zone classification and the defined ignition hazards. The induction concept removes open flame and eliminates conventional incandescent resistance elements from the process stream, simplifying several ignition-source considerations.

Where an ATEX classification such as Zone 2 / gas group IIB is applicable, external enclosure temperatures, terminals, instrumentation and electrical assemblies must be engineered for the specified equipment protection and temperature requirements. Thermal insulation and enclosure design can decouple the hot internal process boundary from accessible external surfaces. Final ATEX marking must therefore follow the certified equipment design rather than being inferred from process temperature alone.

18. Three Technology Perspective: Induction, Electrical Resistance and Fired Heating

Engineering criterion	DIFHEMI / Brascoelma induction	Electrical resistance circulation heater	Fired heater
Heat generation	Induced directly in metallic process tube wall	Discrete resistive elements transfer heat through sheath	Combustion flame and hot flue gas
Local hot-surface tendency	Distributed wall heating; lower local peak potential	Element surface must be hotter than process fluid; local peaks possible	Very high flame-zone temperatures; tube skin managed by furnace design
Pressure boundary	Continuous process tubing / welded piping philosophy	Multiple element penetrations and seals may be required	Pressurized process coils inside fired enclosure
Power response	Fast electronic modulation; heat generation stops with excitation	Electrical modulation possible, but element residual heat remains	Burner turndown and combustion-control dynamics
Combustion products	None at heater	None at heater	Flue gas, requiring stack / combustion management
Maintenance focus	Power electronics, coils, instrumentation, insulation, process piping	Elements, seals, flanges, terminations, controls	Burners, refractory, flame scanners, fuel train, stack, coils

Hazardous-service advantage	No open flame; no conventional hot resistance element in process stream	No flame, but very hot element surfaces require careful design	Open combustion requires dedicated safeguards and fuel-system protection

This comparison is qualitative and intended to explain the physical architecture of the three technologies. Final selection depends on duty, plant utilities, site standards, emissions strategy, plot space, maintainability and project-specific safety studies.

19. Process Relevance: NG + CO_2 Heating for Syngas-Oriented Service

The NG + CO_2 duty is technically consistent with feed preheating for syngas-oriented petrochemical processes, including CO_2 reforming (dry reforming) service. In dry reforming, methane and carbon dioxide are converted principally to carbon monoxide and hydrogen according to the overall reaction $CH_4 + CO_2 \rightleftharpoons 2CO + 2H_2$. Because the reforming chemistry is strongly endothermic, high feed temperature is an important part of the process thermal balance.

For public communication, this article intentionally describes the application at this process-family level and does not identify the end user, EPC contractor, proprietary reactor scheme or confidential process configuration. The engineering significance is the heater duty itself: controlled delivery of high thermal power to a pressurized NG + CO_2 stream at very high temperature, while maintaining containment, thermal uniformity and rapid controllability.

20. Industrial Platform and Scale-Up Perspective

The Brascoelma induction-heater platform has been engineered in industrial power classes ranging from hundreds of kilowatts into multi-megawatt installations. The supporting technical material includes 200 kW classified-area equipment, 600 kW and 760 kW multi-unit installations, and a 1,800-kW heater platform. These references demonstrate that the electromagnetic heating principle is not limited to laboratory scale; it is an industrial architecture that can be configured for demanding continuous-duty service.

For the present NG + CO_2 concept, the design basis uses modular power sections and a multi-tube Inconel 601 flow path. Modularity supports thermal distribution, maintainability and staged electrical architecture while preserving the direct-to-pipe heating principle.

21. Consolidated Engineering Advantages

- Direct heat generation in the process-tube wall, minimizing the thermal path between electrical energy conversion and the process fluid.

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- Distributed heat input with reduced susceptibility to discrete extreme-temperature hot spots compared with conventional resistance elements.
- High-pressure containment based on continuous process tubing rather than a pressure vessel populated by numerous heater-element penetrations.
- Fast SCR-based power modulation and rapid cessation of electromagnetic heat generation on trip or shutdown.
- No open flame, no local combustion products and no stack at the heater, providing a fully electric heating architecture.
- Compatibility with high-temperature nickel-alloy tubing such as Inconel 601 and project-specific PED / ASME B31.3 engineering.
- Favourable architecture for hazardous area integration and SIL-oriented shutdown design, subject to complete project certification and SIF verification.
- Industrial scalability from hundreds of kilowatts to multi-megawatt heater systems.

22. Final Engineering Assessment

On the engineering basis reviewed, DIFHEMI / Brascoelma induction heating presents a compelling architecture for high-temperature, high-pressure petrochemical gas service. Its principal strength is not a single efficiency figure but the combination of direct wall heating, distributed thermal input, robust pressure containment, fast electronic control, low residual heat generation after trip, and elimination of open flame and conventional immersed resistance elements.

The most important engineering differentiator is the heating mechanism itself: DIFHEMI generates heat directly in the metallic tube wall by electromagnetic induction, avoiding the very high local surface temperatures associated with discrete resistance elements.

ENGINEERING POSITION: For demanding NG + CO_2 service approaching 600–620°C and pressures up to 52 bar, DIFHEMI / Brascoelma offers a technically differentiated all-electric heating platform designed around process integrity, controllability, thermal uniformity and industrial reliability.

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Annex 1 – Comparative Selection Table commented by an expert:

Selection Criteria	DIFHEMI Induction Heater (GEI)	Conventional Resistance-Based Heater (Shell & Rod)
Heater Geometry	Tube-side flow: Process gas flows through the heated tubular circuit. Electromagnetic induction generates distributed heat directly in the metallic tube wall.	Shell-side flow: Process gas passes around high-temperature resistance elements installed inside the heater shell.
Thermal Efficiency	High: Direct electrical-to-thermal conversion in the process-tube wall minimizes intermediate heat-transfer stages and thermal lag.	Potentially high, but heat must pass from the resistance element through its sheath/interfaces and then to the gas; overall performance depends strongly on insulation, element temperature and flow distribution.
Thermal Inertia / Response	Low: Heat is generated directly in the metallic process circuit, and solid-state power control enables rapid modulation and shutdown.	Higher: The resistance elements, sheaths and surrounding internal mass must heat and cool, increasing stored thermal energy and response time.
Heating-Element / Tube Temperature	Controlled tube-wall temperature: The process tube itself is the electrically induced heating circuit. Wall temperature is engineered above the gas temperature only by the margin required for heat transfer.	Higher element temperature: Resistance-element and sheath temperatures must exceed the gas temperature to drive heat transfer; the required margin can become substantial at high duty or reduced flow.
Risk of Fouling / carbon fouling	Reduced hot-spot potential: Distributed heat input and controlled tube-wall temperature can reduce localized overheating that promotes thermal degradation or carbon fouling.	Higher localized-temperature potential: Concentrated surface heat flux on resistance elements can increase hot-spot severity if flow distribution deteriorates or deposits form.
ATEX / Hazardous-Area Integration	Favorable architecture: No flame or fuel train at the heater. Primary electromagnetic components can be thermally separated from the hot process boundary; final ATEX compliance remains a property of the complete certified assembly.	Feasible but design-intensive: High-temperature elements, terminals and penetrations require careful surface-temperature control, insulation and hazardous-area certification.
Equipment Lifetime	Long-life potential more than 25 years: The heating principle has no conventional immersed resistance element. Service life is governed mainly by pressure-boundary integrity, insulation, power electronics, instrumentation and operating conditions.	Element life is duty-dependent: Repeated high-temperature cycling, oxidation, dielectric degradation and local overheating can require element inspection or replacement over time, in aprox. 4-5 years.

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Maintenance / Cleaning Profile	Predominantly non-intrusive electrical maintenance: Induction components are external to the process flow path. The process tube can be designed for appropriate decoking or cleaning methods if required.	More intrusive when elements require service: Depending on design, element bundles, seals and penetrations may require access, removal and replacement.
Inherent Process-Safety Features	No combustion at the heater; fast electrical de-energization; distributed heat generation; compatible with independent ESD and SIL-rated safety functions when properly engineered.	No combustion, but high-temperature electrical elements remain stored-heat sources after trip; safe design depends on element temperature, flow protection, controls and certified enclosure architecture.
Initial CAPEX	Project-dependent: May require dedicated transformer, magnetic circuit, SCR power electronics and specialized fabrication.	Project-dependent: Conventional equipment may be simpler in some duties, although high-temperature materials, element design and hazardous-area requirements can materially affect installed cost.
Total Cost of Ownership (TCO)	Potentially favorable in severe high-temperature service where long element life, reduced intrusive maintenance, rapid control and high availability are valuable.	Highly application-dependent; periodic element replacement, access requirements and downtime can increase lifecycle cost in severe high-temperature duty.

Annex 2 – Notes Supporting the Comparison

1. In a conventional shell-and-rod electric heater, electricity flows through high-resistance rods (elements), which get very hot and transfer heat to the gas via radiation and convection.

a. The heat must travel from the center of the rod, through the ceramic insulation/cladding, across a gas gap, and finally into the process gas. This creates a significant temperature gradient.

b. Because the rods must be much hotter than the target gas, the shell absorbs a massive amount of radiant energy. Even with enough insulation, heat leakage to ambient can be significant.

c. Process gases like CO_2 are relatively poor conductors of heat. In a shell-and-rod design, the gas channels through the shell, meaning that the velocity is low (lower heat transfer coefficients) and some gas molecules never come in contact with the hot rods, leading to lower overall thermal efficiency.

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2. Many induction heaters supplied have been in operation for over 25 years, without requiring maintenance. The most common failure mode is related to control electronics (mainly thyristor short-circuit or firing control board burnout). When needed, these problems can be addressed very quickly on the control panel itself, allowing the unit to come back up to full capacity operation very quickly.

3. At 600°C process outlet temperature (and correspondingly higher electric rod temperatures) conventional resistance heaters operate near their metallurgical limits. The insulation inside the rods tends to degrade, leading to dielectric breakdown. The induction heater eliminates this failure mode entirely, because the "heating element" is the steel (in this case Inconel 601) of the tube itself.

4. The induction heater proposed by Brascoelma can be cleaned by steam-air decoking, online spalling (thermal shocking) and/or chemical cleaning, provided proper adjunct facilities/connections are in place. If customer requires the heater to be mechanically cleaned by pigging, Petrochemical can incorporate that requirement into the design as well.

Figure 12 -Typical assembled Difhemi of 900 kw each one

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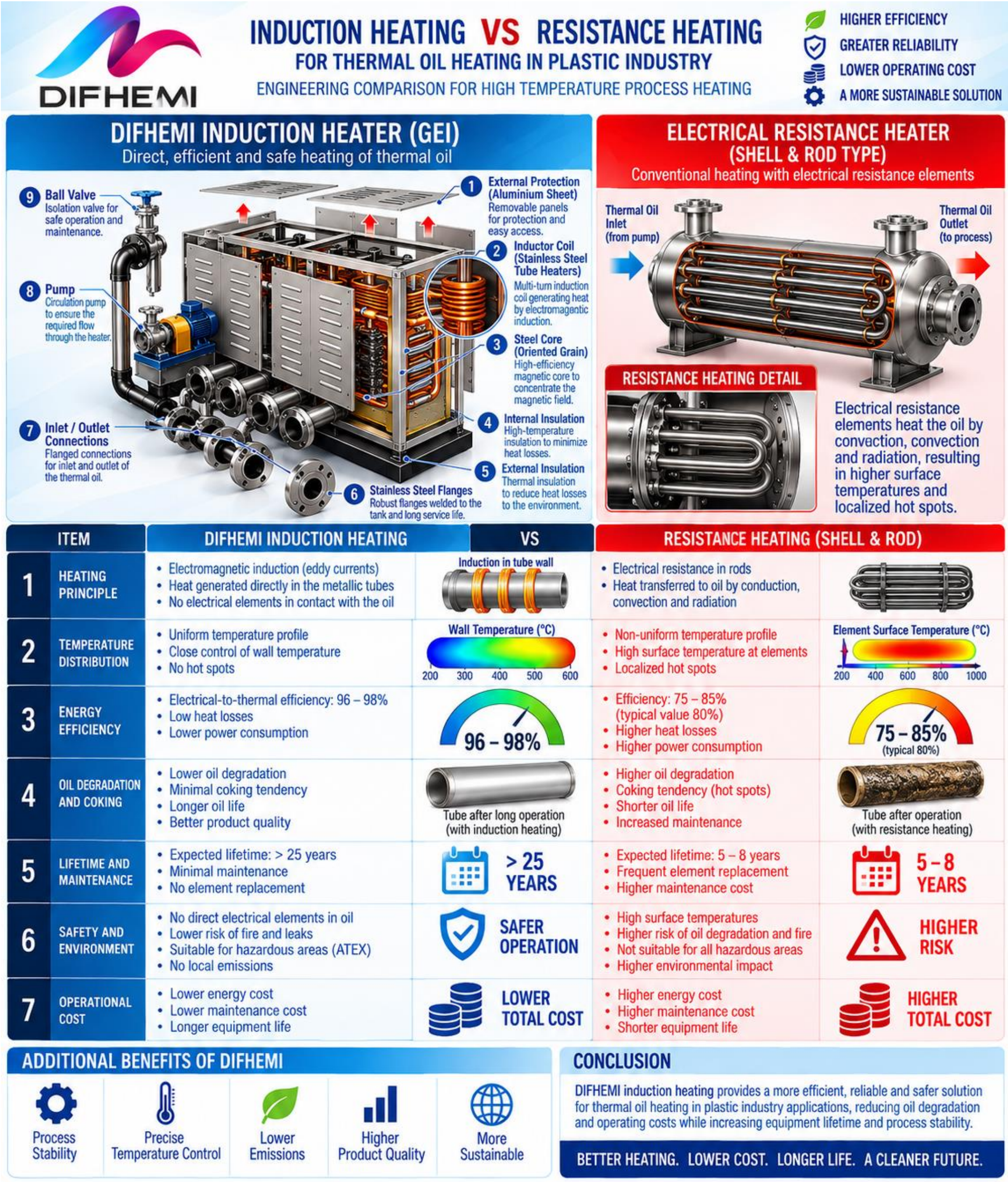
Annex 3 – DIFHEMI Technical Infographic



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