Plasma Torches

- Energy vector: Electricity (all-electric heating).
- Investment risk: Medium–High.
- Technology maturity: 6-8 depending on the sector.
- Decarbonation potential: Up to ~100% of fuel-combustion (scope 1) emissions for the replaced burner heat when powered by low-carbon electricity; process/chemistry emissions remain (e.g., calcination in cement).

Process description

Working principle (thermal plasma): An electric power supply ionises a working gas to create a high-temperature plasma jet (≈5,000–20,000 °C at the jet). The jet transfers heat by convection/radiation into the process [1][2].

Depending on design:

- DC arc torch: an electric arc forms between a cathode and anode nozzle, heating and ionising the gas as it flows through.
- Radio Frequency / ICP torch: uses an induction coil (no electrodes in contact with plasma) to energise the gas electromagnetically.

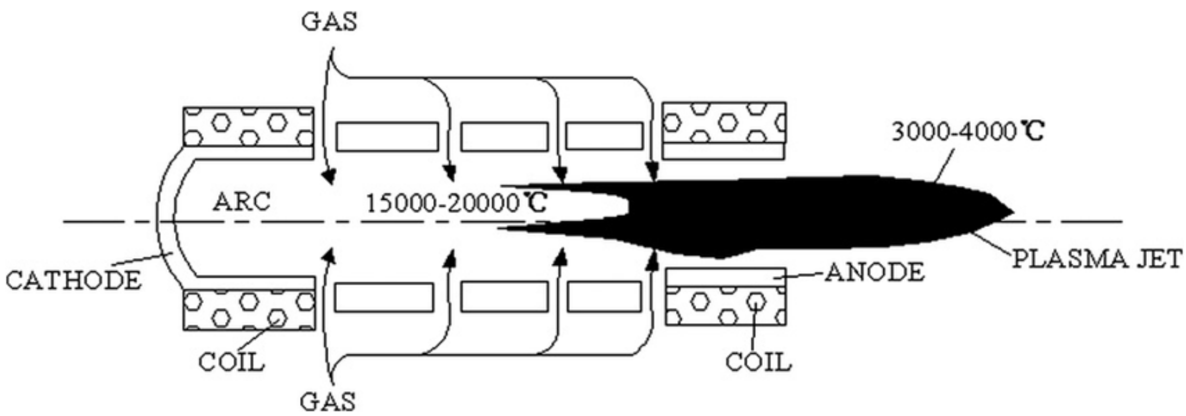

Figure 1: Plasma Torch with DC arc torch design schematic [3].

Performance:

- **Heat Generation Capacity (per torch):** Commercial designs have a capacity going up to 5 MW_{th} ; larger designs up to ~1–10 MW [4].
- **Typical Load Range:** ~20–100% of nominal (power turndown depends on torch/power supply [2]).
- **Efficiency / COP:** Electrical to thermal efficiency typically 85–95% at torch nozzle, with up to 70% system efficiency depending on integration and flue losses [2].
- **Technical lifetime:** Torch body & power supply designed for multi-year service; electrodes/consumables: hundreds to >1,000 hours per set (DC arc [4]); ICP/RF torches can achieve >10,000 h between major overhauls [5]. Preventive maintenance critical [6,7].
- **Process conditions** : Plasma jet 5,000–20,000 °C [21]. Gases: N_2/air/Ar with optional H_2 or O_2. Pressure ≈ ambient.
- **Water use:** Closed-loop cooling with high-pressure deionised water [7]).
- **Safety issues:** Arc/UV radiation, hot surfaces/jet, electrical hazards, noise, NO_x formation with air plasmas, metal fumes if interacting with metals [8, 9].

Main applications: Burner replacement in kilns/calciner/riser ducts, iron-ore induration, steel reheating & tundish superheating, non-ferrous and glass furnaces, high-temp reactors, waste vitrification & gasification [10-15].

TRL (by use case, 2025):

- Burner replacement in iron-ore induration / steel reheating: TRL 7–8 (pilot → early commercial) [10, 15, 16].
- Cement direct electrified clinkering (plasma-assisted): TRL 5–7 (pilot/demonstration) [11, 17].
- Waste gasification / melting: TRL 8–9 [9, 19].

Barriers	Enablers
High capital intensity / long asset lifetimes: Existing kilns/furnaces are long-lived; retrofits must minimise downtime and interface risk. **Lack of regulatory incentives:** Economics hinge on electricity versus fuel prices; value of CO_2 avoided (ETS) may be uncertain. **Technological immaturity/uncertainty**: Sector-specific integration (e.g., cement clinkering) still pilot-scale; electrode life/NO_x control design-dependent. **Limited infrastructure:** Sufficient clean electrical capacity (and PPAs), robust MV connections, cooling and gas supply. **Skills gap:** High-voltage plasma, power electronics, and advanced process control skills required. **Market structure / competitiveness:** Exposure to international competition with lower energy prices and/or looser carbon constraints. **Supply chain bottlenecks:** Lead times for power electronics, specialty electrodes, and integration contractors.	**Policy support:** EU ETS & CBAM; free allocation eligibility for electrified heat under heat/fuel benchmarks; Innovation Fund grants; state-aid frameworks; Electricity **Market Design (PPAs, CfDs);** national/regional aid (EU innovation fund, CEEAG, CISAF), Energy Efficiency Directive 2023/1791. **Mature low-carbon tech availability:** Modular electrification; demand-side management; hybridisation with other electric heaters. **Green finance & incentives:** Grants, contracts for difference, power price support; taxonomy alignment. **Public acceptance / demand:** Low local air pollutants; potential for "green" products.
Applicable sectors	**Economic Aspects and investment risks**
Cement & lime Calciner/kiln burner replacement [25]; pilots for all-electric clinkering [11, 17]. **Iron & steel** Plasma-assisted CO/CO_2 conversion reactors [20]). **Waste treatment & gasification / vitrification** [22]. **Why/when applicable:** Highest value where very high-temperature, clean, controllable heat is needed; where fuel emissions are material and electricity can be procured at competitive/green prices; and where retrofits can be achieved with limited civil works.	**Cost drivers:** Electricity price and procurement strategy (PPA), torch/power supply sizing, electrode consumption, integration works, downtime risk. **Sensitivity:** Economics highly sensitive to €/MWh_e and EU ETS price (value of avoided CO_2). **Sensitivity:** Economics highly sensitive to €/$MWh_{electricity}$ and EU ETS price (value of avoided CO_2). Hybrid operating strategies (e.g., partial electrification, load-shifting) can improve LCOH. **Bankability:** Improves with standardized modular systems, proven project references, long-term power price hedges, and supportive policies such as grants, free allocations, and price guarantees.

Regulation maturity and fit	Reference projects
EU ETS & CBAM: Electrified heat is eligible under heat/fuel benchmarks (supports early electrification) [15]. CBAM reduces carbon leakage risk in traded goods. **Innovation Fund / state aid:** Grants/CFDs for industrial electrification & demos [16]; looser state-aid rules for green projects until 2030 [17]. **Electricity Market Design (PPAs/CfDs):** Facilitates long-term hedging of clean power for industry. **Belgium/Flanders:** Moonshot (industry innovation towards 2050) [14], regional energy-intensive industry supports (plasma technology is mentioned, although it focuses on non-thermal).	ArcelorMittal is advancing plasma technology for steel decarbonization through two flagship initiatives. The IGAR project in Dunkirk, France uses a plasma torch to reform captured CO_2 and natural gas into syngas ($CO + H_2$), which is then reused in the blast furnace to reduce fossil fuel demand and lower emissions. Meanwhile, at ArcelorMittal Gent in Belgium, a plasma conversion unit developed by D-CRBN—supplied with CO_2 from a Mitsubishi Heavy Industries capture system—converts CO_2 directly into CO using renewable electricity, marking the world's first industrial trial of this kind. Together, these projects demonstrate how plasma technologies can recycle or reform CO_2 into useful reducing gases, supporting circular and low-carbon steelmaking.; not a direct torch retrofit but evidences plasma integration in steel [20, 21].Together, these projects demonstrate how plasma technologies can recycle or reform CO_2 into useful reducing gases, supporting circular and low-carbon steelmaking.; it is not a direct torch retrofit but it evidences plasma integration in steel [20, 21]. SaltX + Holcim electric plasma clinkering concept, EU, 2025, Investment/scale-up towards all-electric clinker with concentrated process CO_2 (demo/commercialisation path announced) [12]. The SUSPLASM project (2025-2029) [14] is developing a sustainable, low-carbon thermal plasma processing platform in Flanders for valorising problematic waste streams (such as sewage sludge, PFAS-contaminated sediments, etc.) by using plasma torches to convert mixed organic-synthetic waste into tar-free syngas and solid, non-leachable slag with potential applications in hydrogen production and phosphorus recovery. The technology is electrically powered (potentially via renewables) and thus enables a near-zero or even carbon-negative footprint, while also enabling "power-to-X" flexibility in the grid.

Key conclusion of the scenarios
This will be completed during year 3 of the project

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