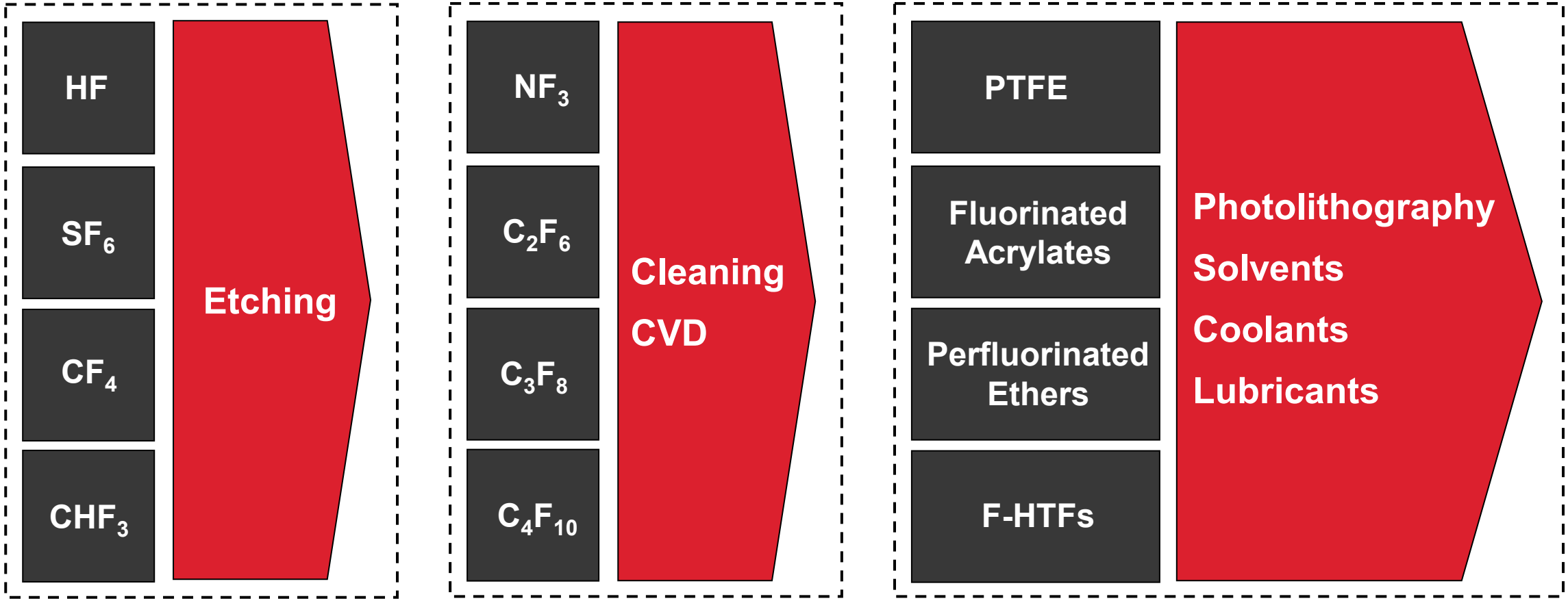
HONEYWELL CFX™
FOR PFAS WASTE DESTRUCTION

Honeywell
UOP

FLUORINATED WASTE / DISCHARGE PERSISTENT THROUGHOUT SEMICONDUCTOR PROCESSES



Key Semiconductor Processes

PFAS INVOLVEMENT IN SEMICONDUCTOR MFG

PFAS can be introduced and/or created at multiple stages of **semiconductor** manufacturing due to their exceptional **thermal**, **chemical**, & **surface** properties

1 Wafer Surface Prep	Fluorosurfactants | Rinse Aids	7 Deposition: PE/CVD, PE/ALD	Precursors and Chamber Cleaning Gases: WF_6, NH_3, CF_4, C_2F_6
2 Thermal Oxidation / Initial Deposition	Some Fluorinated Precursor Gases	8 Planarization: CMP	Fluorine-containing additives: HF, NH_4F, $NH_4F{\cdot}HF$, $[NR_4]^+F^-$
3 Photolithography	Resists | Anti-Reflective Coatings | Edge Bead Removers | Strippers	9 Wafer Final Cleaning & Drying	F_2, PF_3, ClF_3, AHF, HF | PFPEs | Fluorinated Solvents & Surfactants
4 Etching (dry / wet)	Fluorinated Plasma Gas: CF_4, C_3F_8, C_4F_6, C_4F_8, CHF_3, F_2, SF_6, NF_3, BF_3	10 Assembly, Test, & Package	Fluoro-Cleaners | Fluorinated Polymers | Adhesive Formulations
5 Photoresist Stripping / Ashing	Carbon-Fluorine-based Plasmas | Strippers (solvents)	11 Facility Operations and Waste Handling	Greenhouse Gases Emissions (≤ 80% unreacted) | PFAS in Air and Water Waste Streams | Incomplete Abatement with C-F-byproducts
6 Ion Implant / Diffusion	Lubricants: PFPE, PCTFE, PTFE | Facility Infrastructure		

HONEYWELL CFX™ — ADVANCED OXIDATION SYSTEM

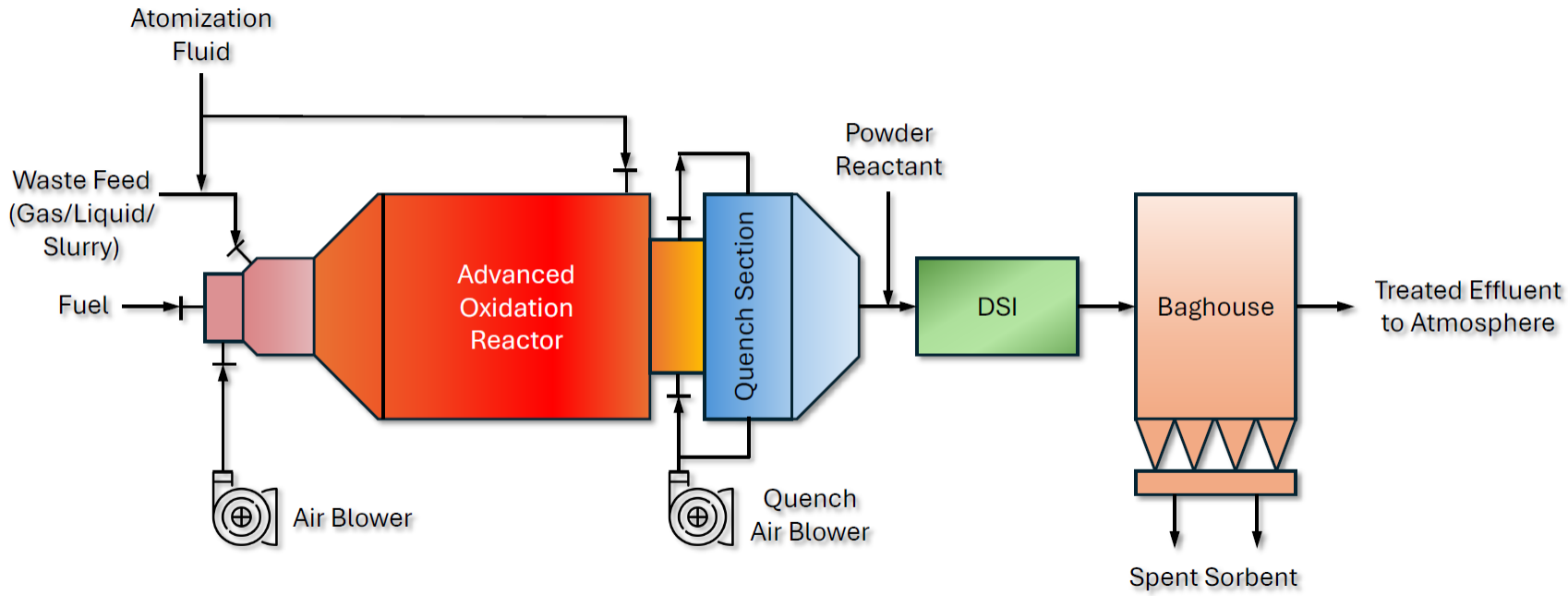
Up to **1400 °C** stable operation

1-1200 GPH capacity

Designed for **CF_4 destruction**

Zero liquid waste discharge

Automated with minimal maintenance



CF_4 DESTRUCTION SIGNIFICANCE

C—F BONDS

C–F is the **strongest** single **bond** in organic chemistry—dissociation energy of **485 kJ/mol**

- Short bond length of 1.35 Å—small atomic radii of C & F
- Large electronegativity difference between C & F makes for strong electrostatic attraction

CF_4 is comprised of **100% C-F bonds**

C–CHAIN LENGTH

Based on number of carbons—the shorter the molecule, the stronger it is

CF_4 has **no C–C** bonds nor functional end groups—no weak sites to initiate attack

MOLECULAR SYMMETRY

Perfectly symmetrical—tetrahedral geometry, minimizing electron-electron repulsion

109.5° bond angles—most stable for 4 electron pairs around central C atom

STABILITY

1,200°C+ uniform temp for decomposition—inert to many reagents, acids, & hydroxides

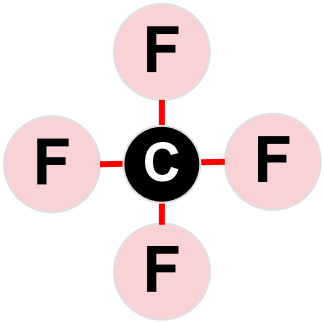
50,000-year atmospheric lifetime—potent GHG—**7,390 times** the **GWP** of CO_2

INCOMPLETE DESTRUCTION BYPRODUCT

Occurrence of fragmentation, generating fluorinated radicals: CF_3•, CF_2•, CF•, F•, with most stable endpoint being CF_4

- Molecular strength of **CF_4** makes it an effective chemical dead-end (with other destruction techs)

CF_4 **destruction** is **benchmark**



for **measuring** fluorocarbon **destruction** efficiency

HONEYWELL CFX™ — FOR PFAS WASTE DESTRUCTION

TECHNOLOGY

- Optimized by **30+ years** of experience **destroying PFAS** waste
- Leverages **Honeywell Automation** for consistency of operation, safety, and **personnel avoidance**
- **Sustains 1,400°C** throughout reactor for **complete destruction**

APPLICABILITY

- CFX already **destroys** the **same** fluorinated and chlorinated **compounds** found in **semiconductor** manufacturing **discharge**
- Proven **>99.998% DRE** for **ultra-short chain** C-F gas **at scale**
- **15 systems** worldwide **continuously** destroying waste streams **identical** and comparable **to semiconductor waste** streams

VALUE

- Unique **consolidated** PFAS destruction technology that efficiently handles **all phases** and a **variety** of **media** at **commercial scale**
- Leverages caloric value of waste, like spent solvents, for **energy savings** while **avoiding disposal** fees **and logistics** costs
- Seamless **integration** with a broad **range** of pretreatment capture and **concentration** technologies for **maximum water reuse**

BENEFIT

- Optimized reaction kinetics enable short residence times, **boosting throughput** and supporting **maximum wspm**
- Reliable, **continuous** operation ensure negligible downtime, **maximizing throughput** and supporting **highest wspm**
- **Recycled CaF_2** byproduct helps address global supply shortage and reduces reliance on imports, primarily from China

HONEYWELL CFX™ — HOW IT WORKS

SYSTEM DESIGN

- Targeted **placement** of varied **injection ports** specific to **waste** feeds' **phases** and chemistries
- Built on **proprietary metallurgical** architecture and **special refractory** for **corrosion-resistant** halogenated waste destruction
- **Low** system **pressure** drop **eliminates** the need for upstream **compressor**

EXTREME HEAT — 1,400°C

- Needed for near-**complete destruction** of very **strong carbon-fluorine** bonds (with dissociation energies up to **485 kJ/mol**)
- Used to **destroy ultra-short** chain gaseous **C-F** species
- For increased reaction kinetics, enabling **shorter residence times** for **greater** overall **throughput**
- Quickly creating carbon radicals and **fluorine radicals**

EXCESS OF HYDROGEN RADICALS

- **•H** is sourced from fuel (usually natural gas), spent solvents (like isopropanol, which also lowers energy costs), and **water** / **steam**
- **•H** radicals are **highly reactive** to **form HF** as an **intermediate**
- Thus **avoiding** (reversible) **carbon-fluorine recombination** reactions and **stoichiometrically** ensuring destruction of ultra-short chain C-F-gases for **optimal d**estruction **r**emoval **e**fficiency

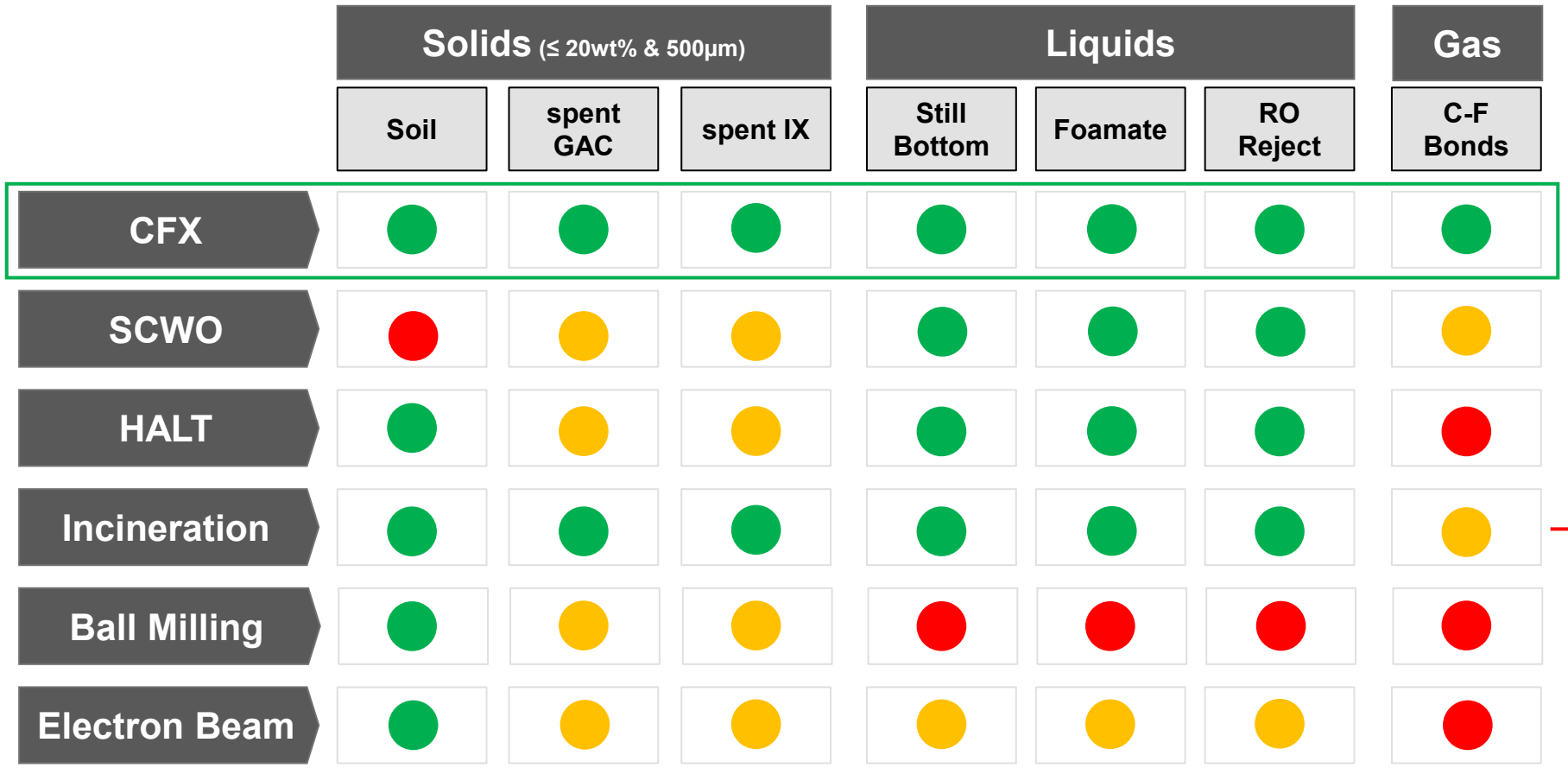
MINERALIZATION OF FLUORINE

- **D**ry **s**orbent **i**njection, using lime, allows calcium to react with the HF intermediate to **produce** a **recycled CaF_2**
- By 2035, CaF_2 **demand** is projected **to surpass supply by 40-70%** – highlighting the need for **circularity**
- United States & Europe rely heavily on CaF_2 **imports** from China, Mexico, Vietnam, Mongolia, Pakistan, and Afghanistan

HONEYWELL CFX™ — DIFFERENTIATED OFFERING

	Honeywell CFX™	Plasma	Catalytic Reduction	Incineration	SCWO	HALT	ECO
Scalability	15 Systems at Industrial Scale	Point-of-Use	Small Scale / Lab Systems	Commercial	Commercial / Pilot	Pilot	Bench and Pilot
Ultra-Short Chain DRE	99.998%	90 – 99.9%	60 – 95%	60 – 99.99%	TFA's shortest C-F with 99%	>90% for TFA	Unknown
Feed Compatibility	Gas, Liquid / Solvent, & Solid	Primarily Gas	Primarily Gas	Gas, Liquid, & Solid	Primarily Liquid	Primarily Liquid	Primarily Design Liquid
Residence Time	~1.5–2 seconds	<1 second	0.5–2 seconds	2–7 seconds	10–90 seconds	10–60 minutes	1–24 hours
Operational Simplicity	Runs Continuously via HON Automation	Power & Gas Flow Tuning	Reducing Gas Control	Feed Swings Impact Temps	Sensitive to Feed Changes	Batch / Semi-Batch	Limited by Electrode
Energy Efficiency	Steady-State, Heat Recovery	High Electrical Input	Lower Input, Less Effective	High Energy Demand	High Pressure	Chemically Assisted	Low Net Energy
Maintenance Needs	Minimal	Electrode Wear; Fouling	Catalyst Poisoning	Corrosion Checks	High Pressure	Chemical Control	Fouling Cleaning
Reliability / Life	>90% Uptime; >15 Year Life	Frequent Part Replacement	<1 year Catalyst Life	Refractory Lasts 1+ yrs	3–10 yrs, Liner	2–5 yrs, Batch Vessels	1–3 yrs, Electrodes

HONEYWELL CFX™ — ENCOMPASSING SOLUTION



Developing Technologies

Limited applicability & **expensive**

Technically **challenging** & **slow**

Shortcomings of Others

Landfilling is future **liability**

→ **Incineration** can have **incomplete** destruction that releases to atmosphere

GAC reactivation has **limited** applicability

Solving the **problem** of **diverse waste** with a **one-stop** shop for **total destruction**

HONEYWELL CFX™ — READY-NOW AT INDUSTRIAL-SCALE

SUPERIOR — **destroys** strongest waste and highly persistent pollutants like PFOA, PFOS, GenX, biosolids, & industrial byproducts

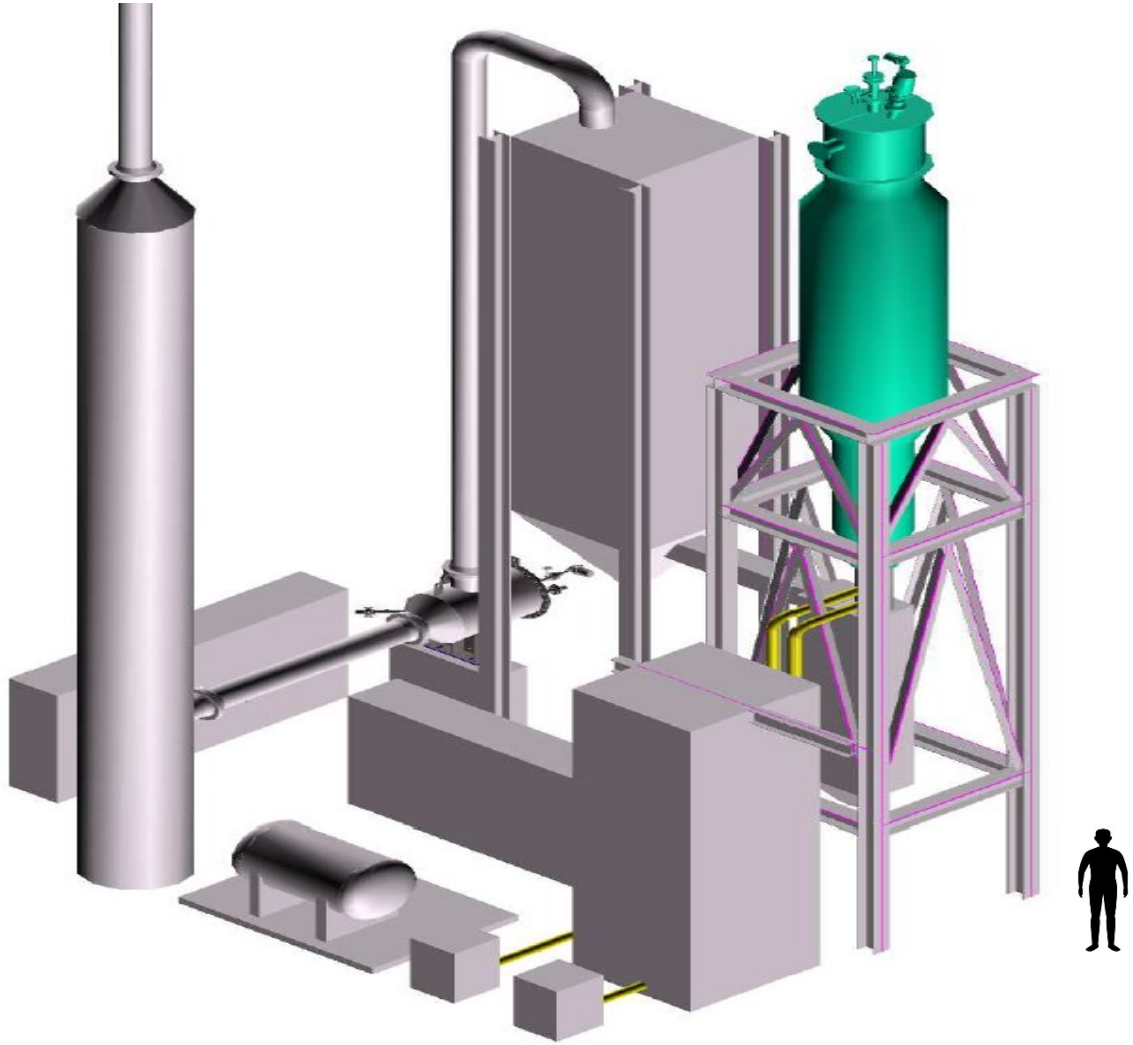
SUSTAINABLE — **avoids** gaseous release of CF_4, C_2F_6, & C_3F_8, which are 7,390 – 12,200 times the GWP of CO_2

ADVANCED — **runs** on **Honeywell automation** – avoids dedicated personnel

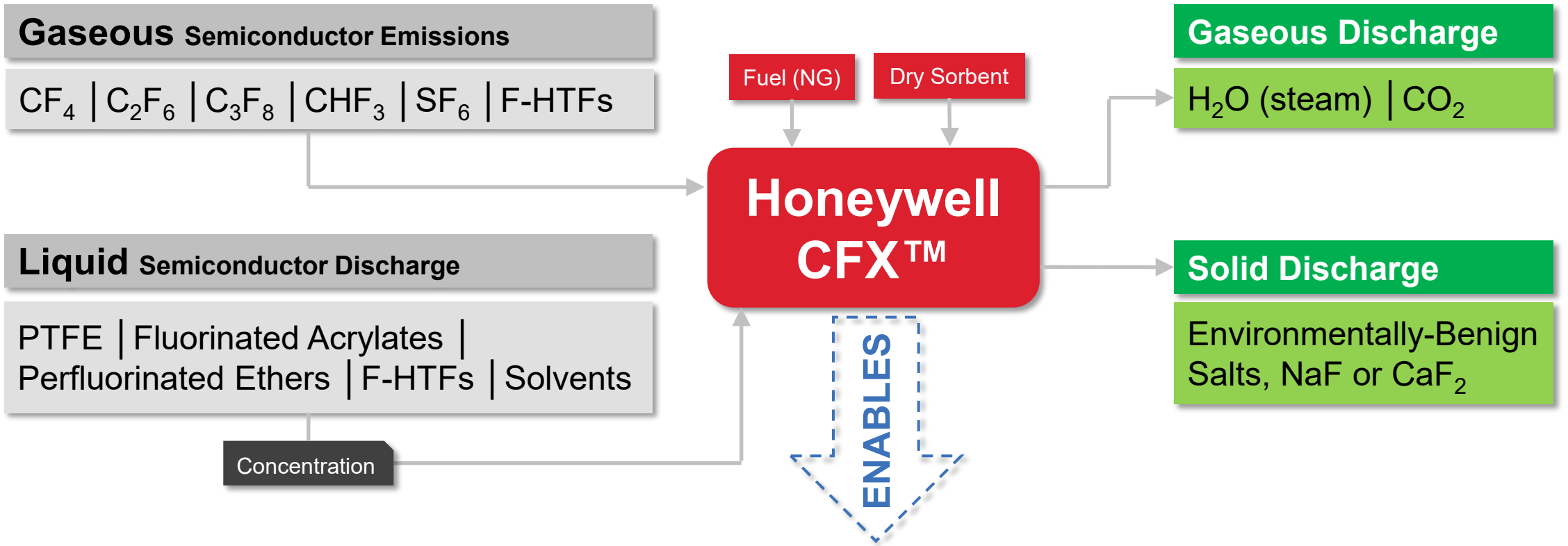
PRACTICAL — mature & ready-now with 30 years proven performance

RISK AVERSE — **>99.99% destruction** of all waste (ex-nuclear), **eliminating** landfilling & long-term **contamination** & **liability** risks

ECONOMICAL — **high** throughput and corrosion resistant for **MAX** system **life**



SEMICONDUCTOR PFAS WASTE DESTRUCTION VIA CFX



COMPLIANCE
with current & future environmental regulations by minimizing releases

AVOIDANCE
of LIABILITY common with disposals to landfills / wastewater

SUSTAINABILITY
that is technologically advancing the semiconductor industry to achieve corporate values & low GWP

SAVINGS
using high-caloric waste (solvent) to save energy & avoiding disposal logistics, insurance, & external charges

SUSTAINABILITY SOLUTION

The **Honeywell CFX™** technology is a **proven** solution for managing challenging and diverse wastes effectively to avoid environmental threats & associated liabilities.

KEY FEATURES of Honeywell CFX™

High Success Rate

Eradicates over 99.99% of hazardous/toxic wastes.

Landfill Avoidance

No risk of landfill contamination to groundwater and soil.

Cost-Effectiveness

Eliminates disposal, logistics, insurance costs and liabilities with onsite solution.

Environmental Safety

No toxic emissions/byproducts – cleaner water and air for safer communities.