AISI-1020 Low-Carbon Steel for UHV: Bare vs Magnetite

Water (Sips) + Hydrogen (Arrhenius) in twin chambers; implications for CE beamtubes

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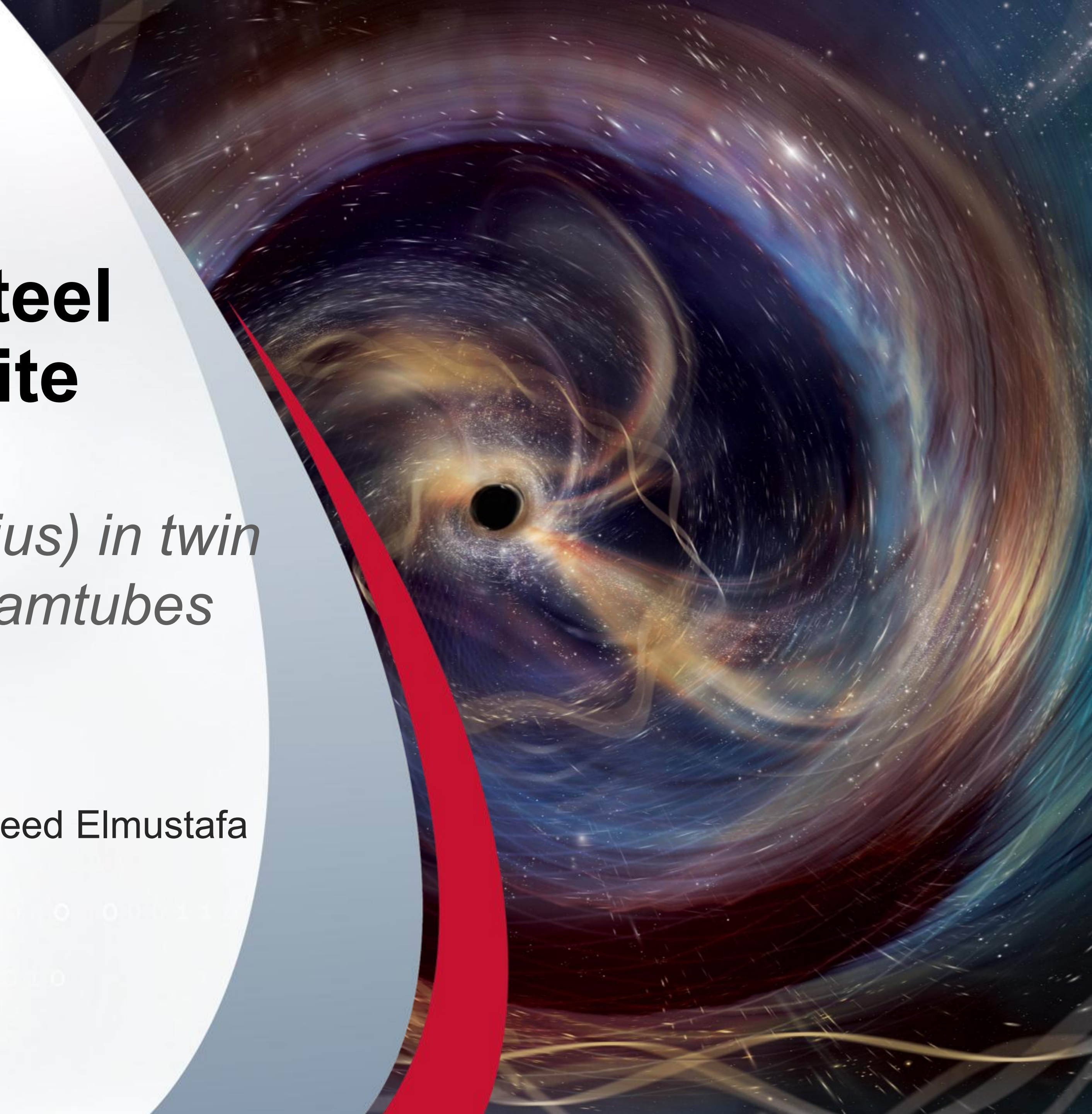

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Scope & Questions

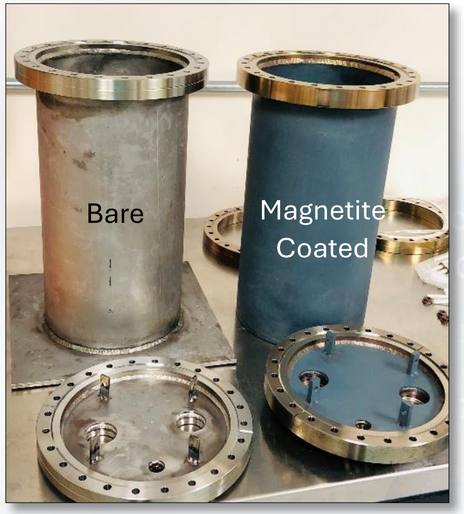
- Can **LCS** (AISI-1020) at **very low q(H_2)** help future **photoguns** and **long beamtubes**?
- Does a **magnetite surface** really help beyond RT pump-down for water?
- What are the **rate-limiting** processes for H_2 at RT?

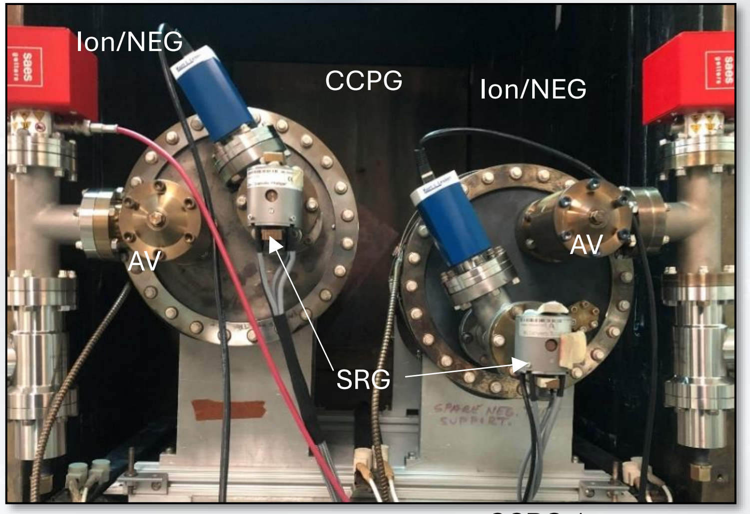
1 mbar = 0.750062 Torr

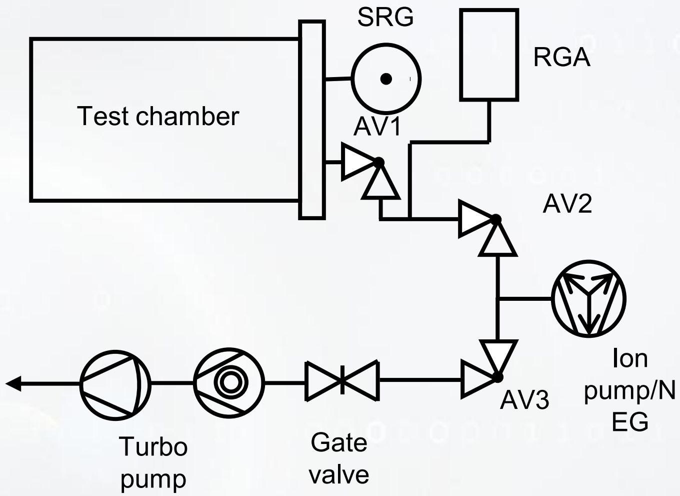
10^{-14} mbar·L·s^{-1}·cm^{-2} × 0.750062 = 7.5 × 10^{-15} Torr·L· s^{-1}·cm^{-2}

- Two identical **AISI-1020** chambers; one **bare**, one **Fe_3O_4-coated**; 11.0 L, 3165 cm².
- **H_2O (throughput/orifice)**; C≈0.36 L s^{-1} @ RT; uncertainties **±35 %**
- **H_2 (rate-of-rise/SRG)**; (SRG rate-of-rise, RT); uncertainties: **±15 %**

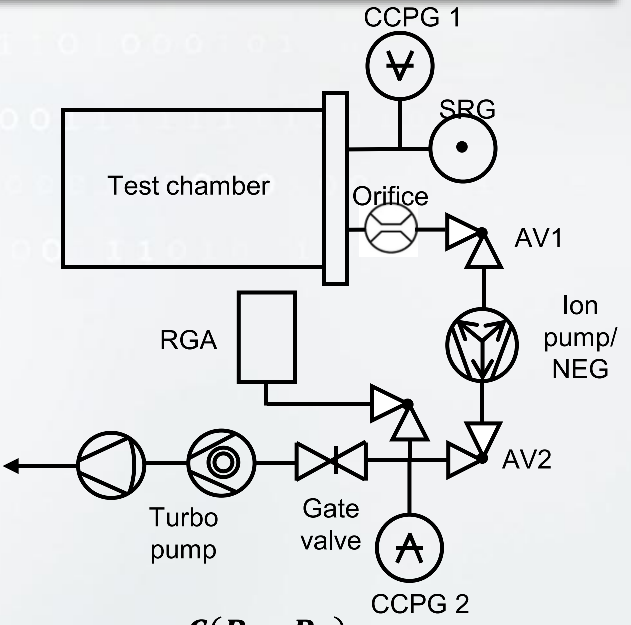
❖ Stainless steel flanges
❖ Sun Steel Steam Treatment





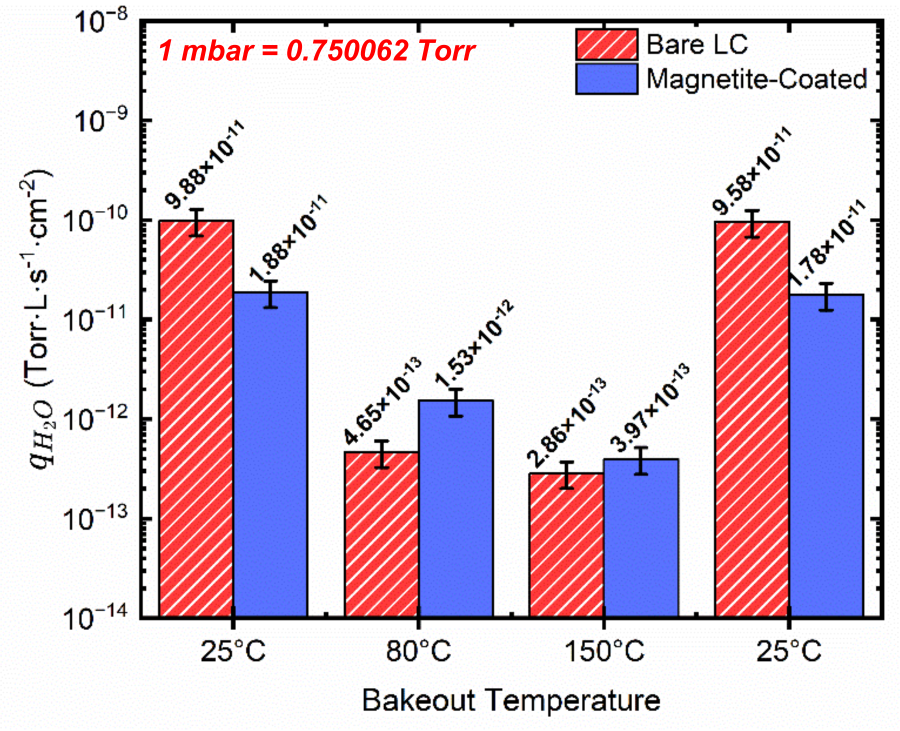


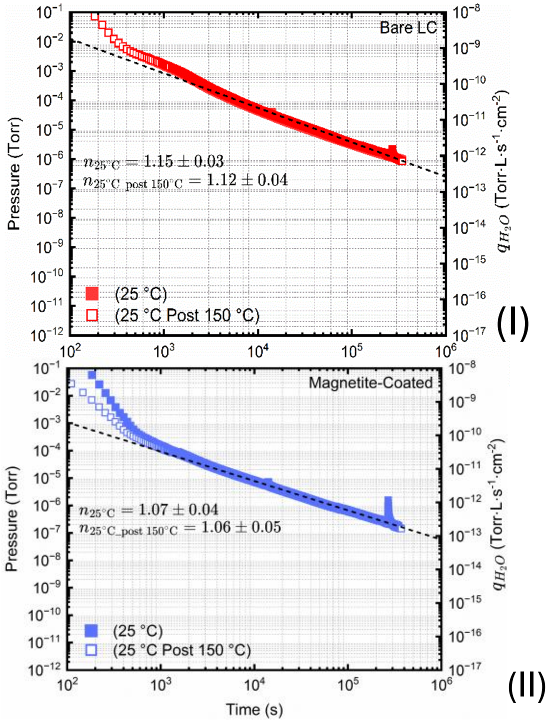
$$q = \left(\frac{V}{A}\right)\frac{dP}{dt}$$

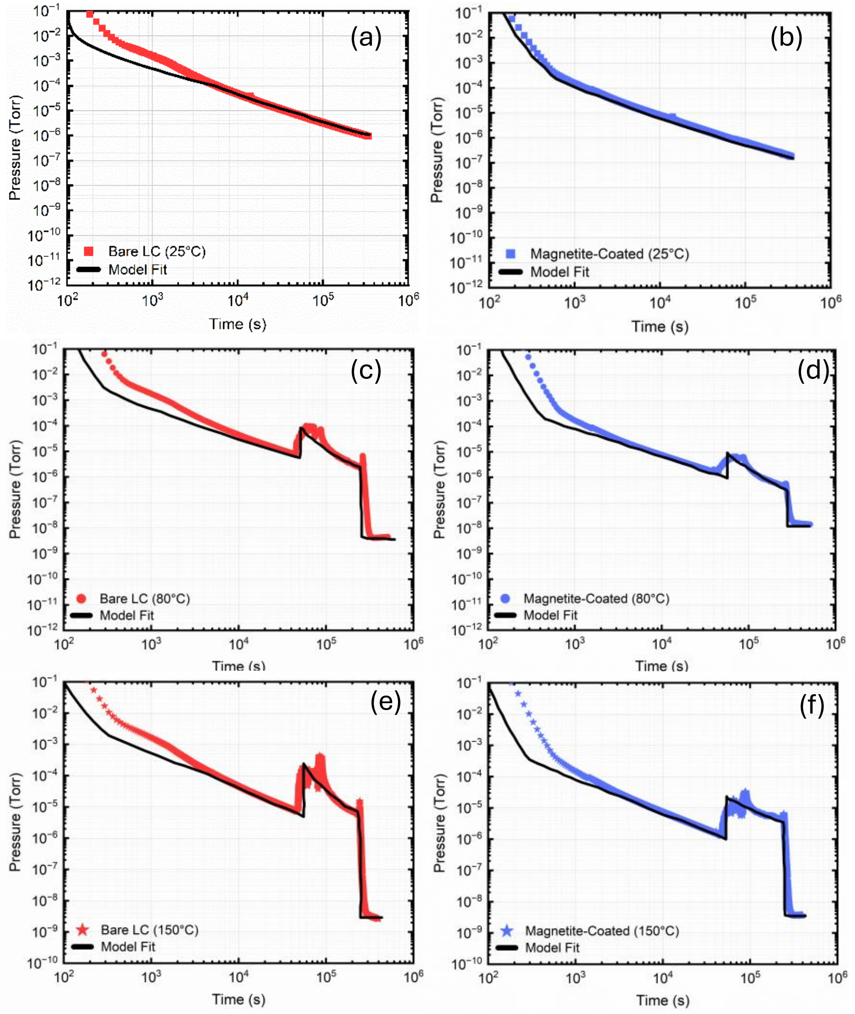


$$q = \frac{C(P_1 - P_2)}{A}$$

Water Outgassing Results



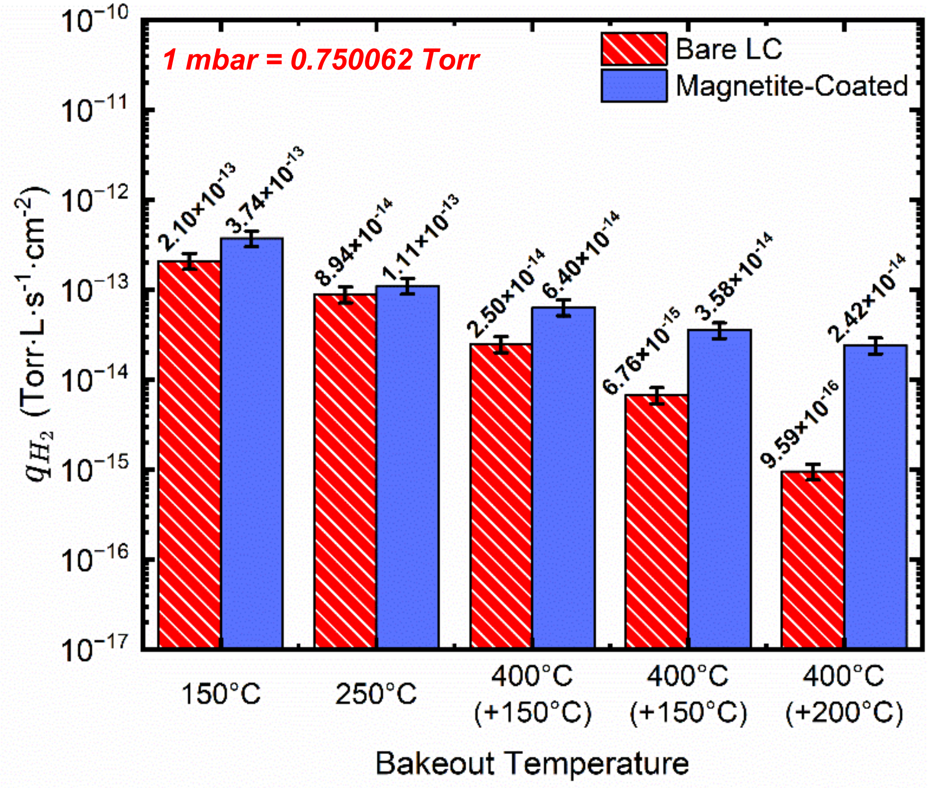


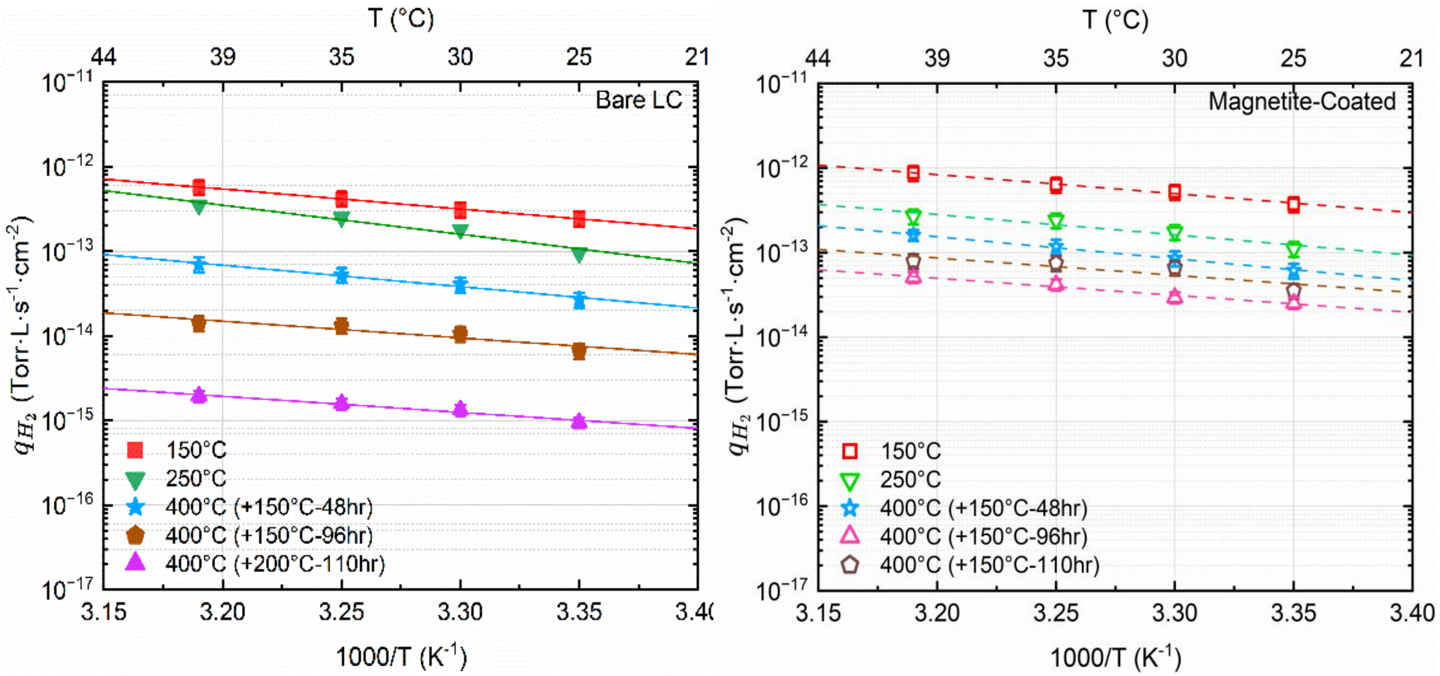


- **25 °C (100 h):** magnetite-coated **1.88×10⁻¹¹** vs bare **9.88×10⁻¹¹ Torr·L·s⁻¹·cm⁻² → ~5× lower RT H_2O** (throughput; **±35 %**; NIST-style method)
- **80–150 °C: bare < magnetite** for H_2O; Sips fits show $\boldsymbol{\alpha_s}$ ↑ and **apparent $\boldsymbol{E_{LF}}$** (van't-Hoff of $K(T)$) ↓ on bare → explains the **mild-heat crossover**
- **RT tail (molecular flow):** $P = At^{-n}$ with $n \approx 1.1$ (water-limited range); **fits limited to $t \leq 10^5$** → use for **RT planning**, not long extrapolation.

$$\theta = \frac{(K_{LF}(T)\,p)^{\alpha_s}}{1 + (K_{LF}(T)\,p)^{\alpha_s}} \qquad K_{LF}(T) = K_{LF\,T_0} \exp\left[\frac{E_{LF}}{R}\left(\frac{1}{T} - \frac{1}{T_0}\right)\right]$$

Hydrogen Outgassing Evolution

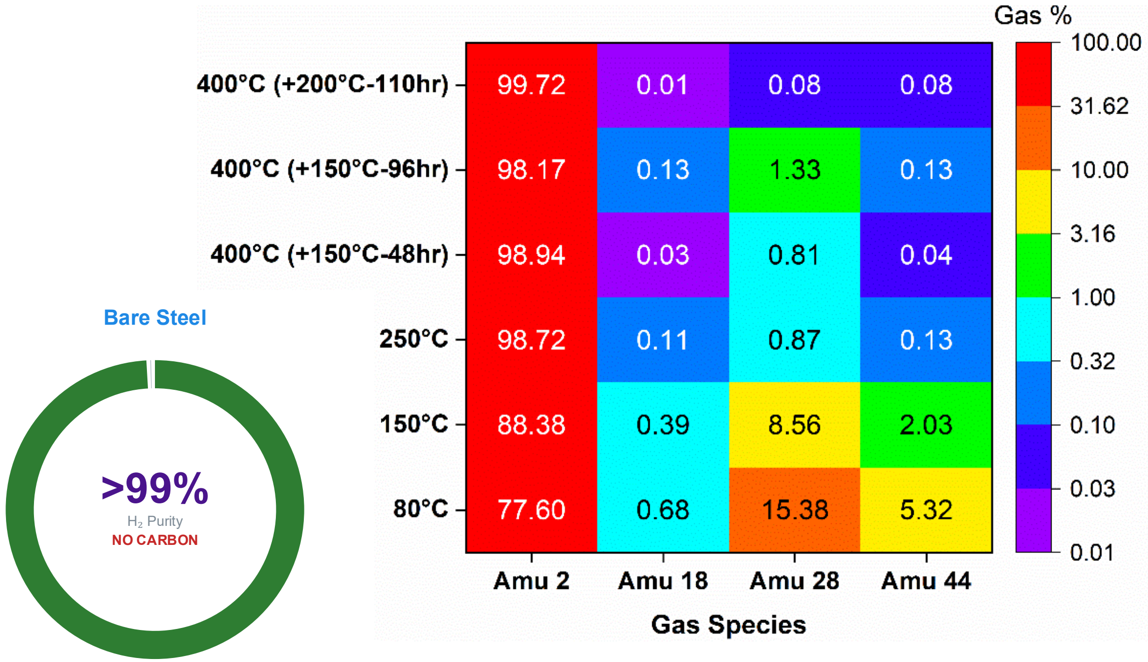


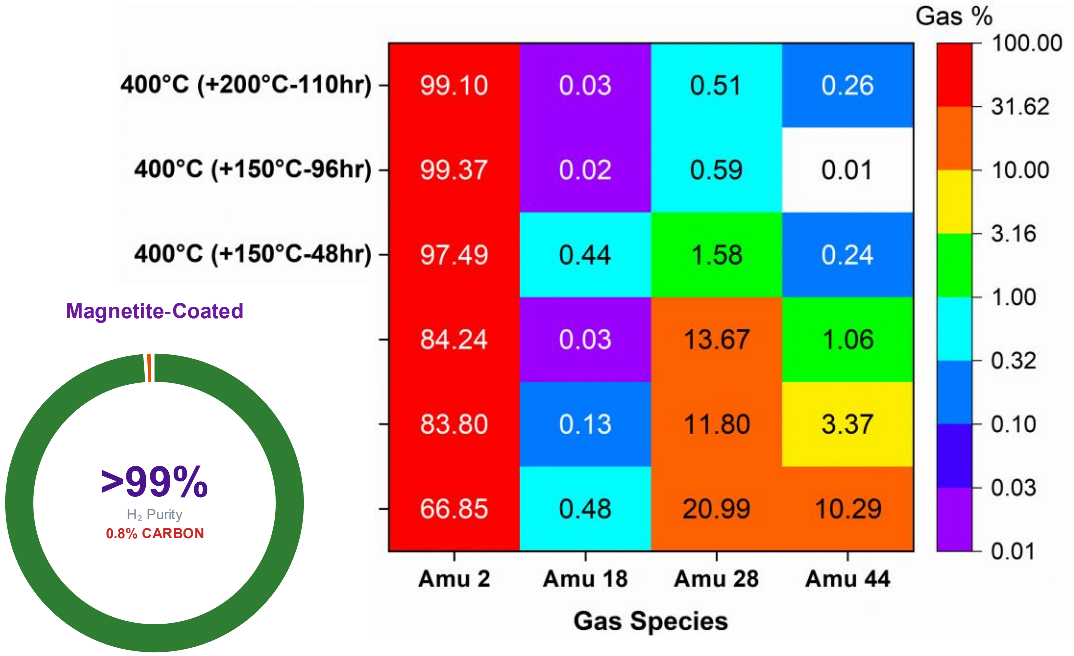


apparent E_a of net rate (25–55 °C); fixed state per treatment.

- **Final (400 °C + 200 °C/110 h, RT): bare** $q_{H_2} = 9.6 \times 10^{-16}$ vs **magnetite** 2.4×10^{-14} Torr·L·s^{-1}·cm^{-2} → **~25×** gap (**RoR/SRG; ±15 %**).
- **Arrhenius (25–55 °C, apparent):** post-150 °C **0.46/0.44 eV** (bare/mag); final **0.33/0.39 eV** → **small slope shifts**.
- **Interpretation: pre-exponential/site availability** drives the rate gap (recombination-limited surface).

Gas Composition After Conditioning: >99% H_2



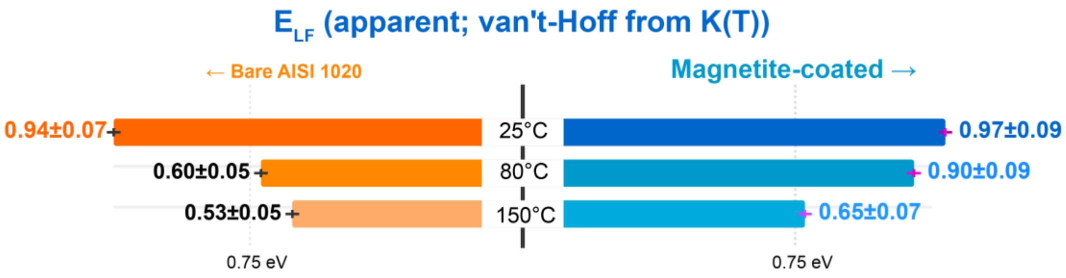


Post-conditioning spectrum is H_2-dominated; only the magnetite chamber retains a small carbon tail.

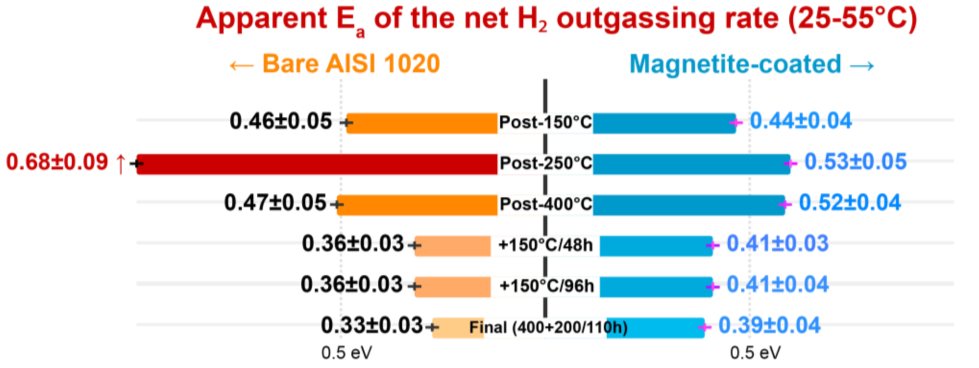
- After the full protocol (**400 °C + 200 °C/110 h, RT**): **>99% H_2** in both chambers.
- **Bare: CO/CO_2 undetected** (below instrument threshold).
- **Magnetite: ~0.8% CO+CO_2** persists → fewer clean H-recombination sites (consistent with higher q_{H_2}).

Energy Analysis Summary: What the Numbers Tell Us

- **Sips (H_2O):**
  - **bare: $\boldsymbol{E_{LF}}$** ↓ (0.94→0.53 eV), $\boldsymbol{\alpha_s}$↑ (0.16→0.99) → **lower RT occupancy**
  - **magnetite** remains higher $\boldsymbol{E_{LF}}$, $\boldsymbol{\alpha_s}$~0.5 → explains **mild-heat crossover**
- **Arrhenius (H_2, 25–55 °C):**
  - **apparent** E_a of **net** rate: post-150 °C **0.46/0.44 eV**; final **0.33/0.39 eV** (bare/mag)
  - **small** slope shifts; **25× gap** comes from **pre-exponential/ site availability** (RT H_2 often recombination-limited).
- **Context:** RT water tails **~1/t** on metals/oxides; Sips is an appropriate heterogeneous isotherm; SRG RoR for H_2 matches NIST practice.



Schematic; not PES. E_{LF} is apparent from van't-Hoff of K(T) in Sips.



Apparent E_a of net H_2 rate; RT outgassing of degassed steels is often recombination-limited.

Observations

- **LCS can reach very low H_2:** AISI 1020 ≈ **2.4×10^{-16}** vs 316L **5.6×10^{-13}** **Torr·L·s^{-1}·cm^{-2}** (400 °C bake) → **~$2.3\times10^{3}\times$** gap (same method). (**Our 2025 pipes paper, *J. Vac. Sci. Technol. B* 43, 034203 (2025), https://doi.org/10.1116/6.0004446**)

- **Mild-steel trend (independent): ≤ 10^{-14} mbar·L·s^{-1}·cm^{-2}** after **80 °C/48 h → ≤ 7.5×10^{-15} Torr·L·s^{-1}·cm^{-2}** (mbar→Torr × 0.750062). (**Scarcia et al, *J. Vac. Sci. Technol. B* 42, 054202 (2024) https://doi.org/10.1116/6.0003820)**

- **Ultimate P is system-level:** $P = \frac{Q}{S_{eff}}$ → **high S_{eff} , stainless < 1–2 %** in the flow path.

- **Water behavior: RT magnetite faster**; **80–150 °C: bare < magnetite** (Sips: α_s ↑, E_{LF}↓ on bare; Fe_3O_4 literature: hydroxylation/dissociation at RT).

- **Composition matters:** post-conditioning **> 99 % H_2** is preferred (reactives minimized) for photoguns & long tubes. *(Design target context.)*

QUESTIONS?

(details related to these slides can be found in a preprint I can share with you)

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