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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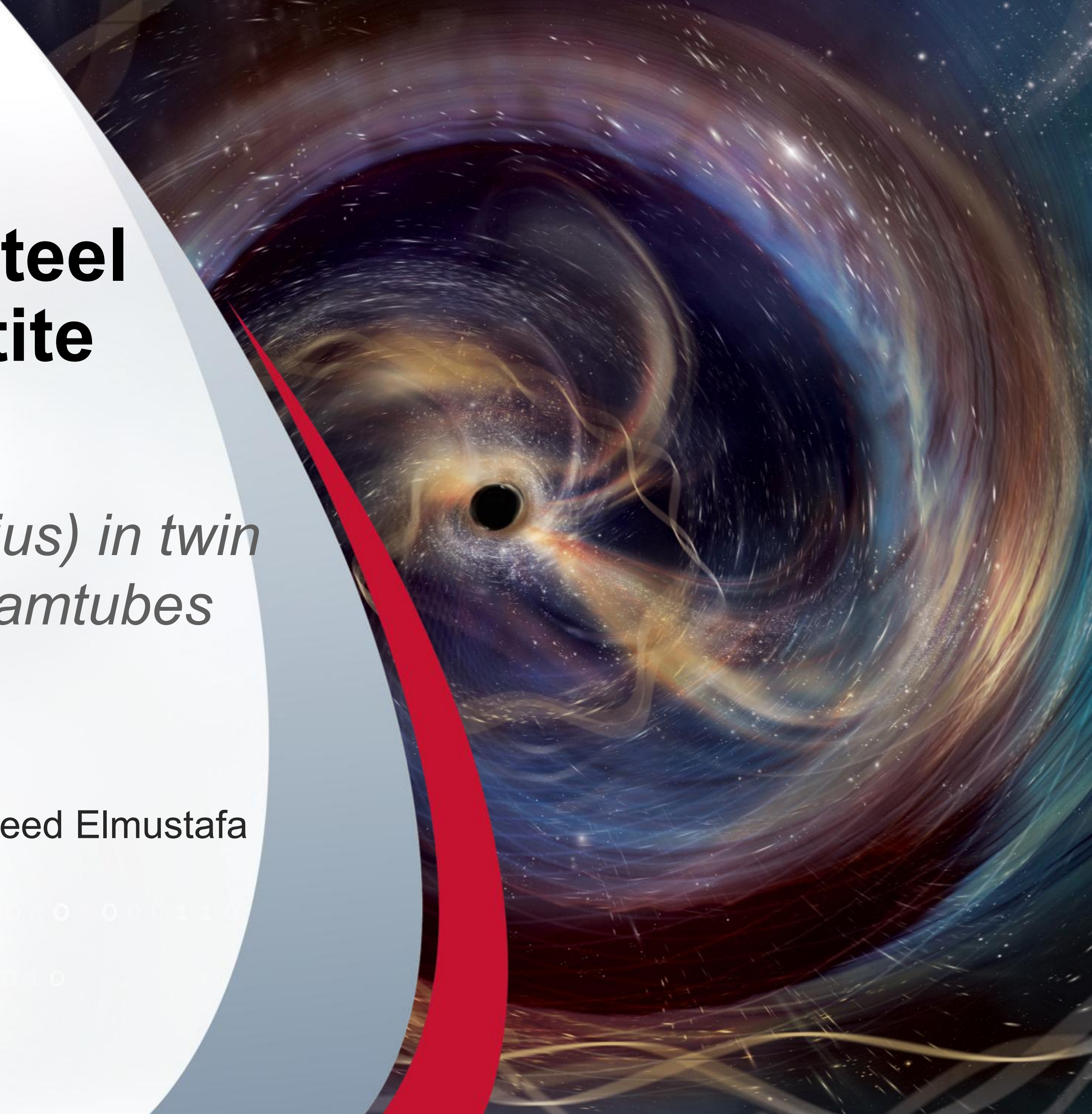
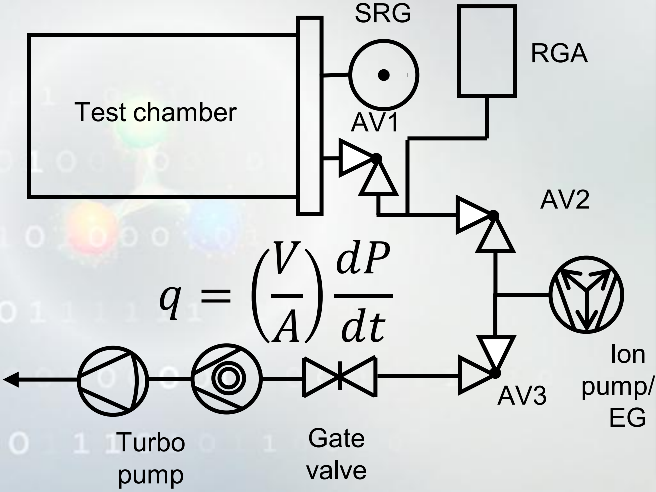
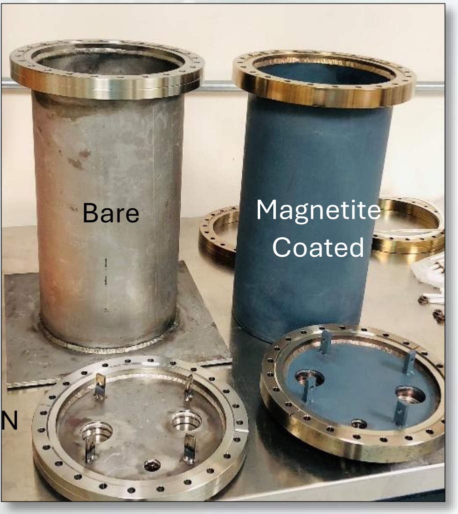


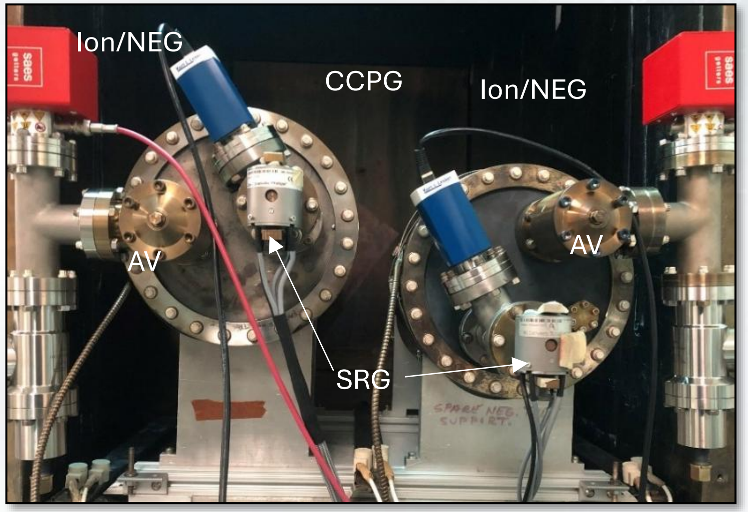
Scope & Questions

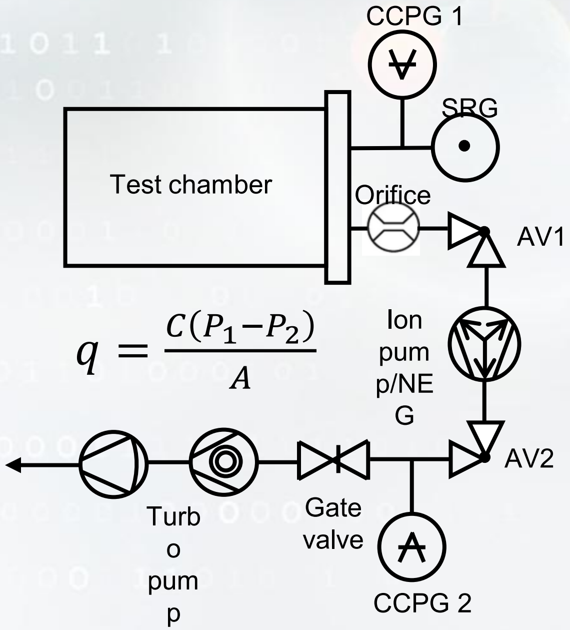
- Can **LCS** (AISI-1020) at **very low q(H_2)** help future **photoguns** and **long beamtubes**?
- Does a **magnetite surface** really help beyond RT pump-down for water?
- What are the **rate-limiting** processes for H_2 at RT?



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







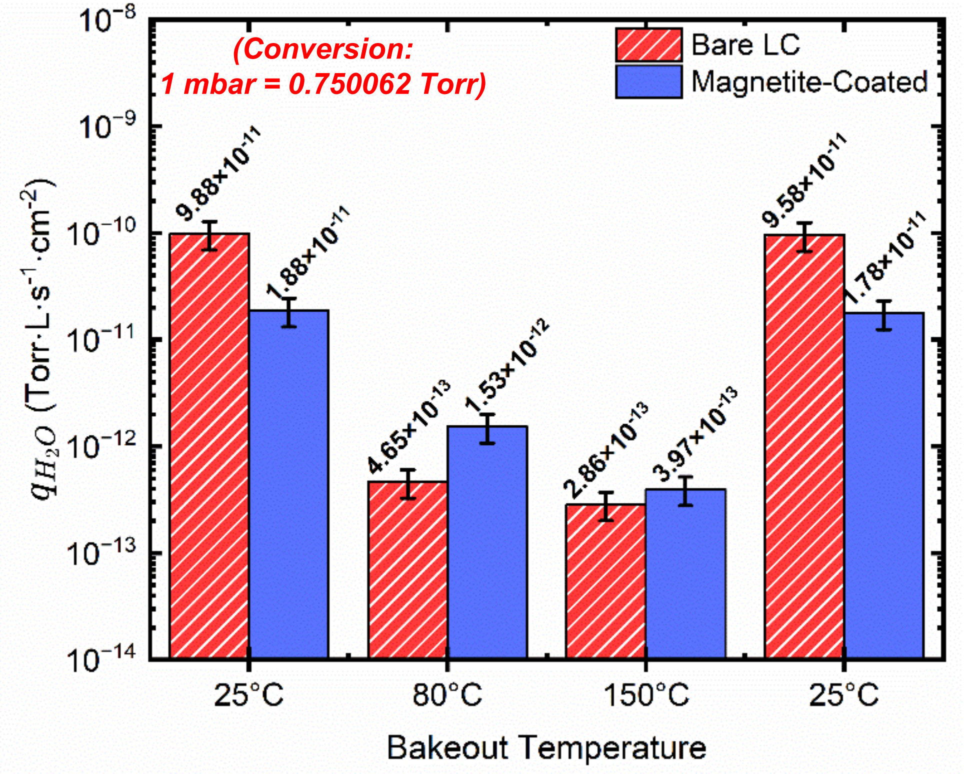
$$q = \frac{C(P_1 - P_2)}{A}$$

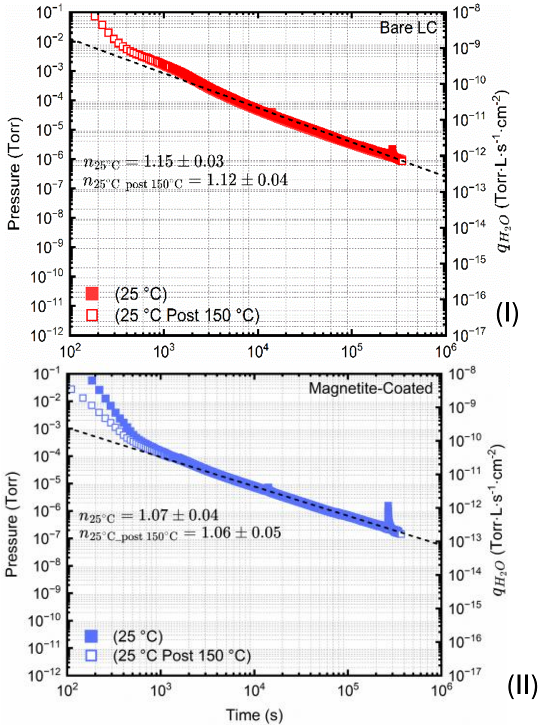
❖ Stainless steel flanges

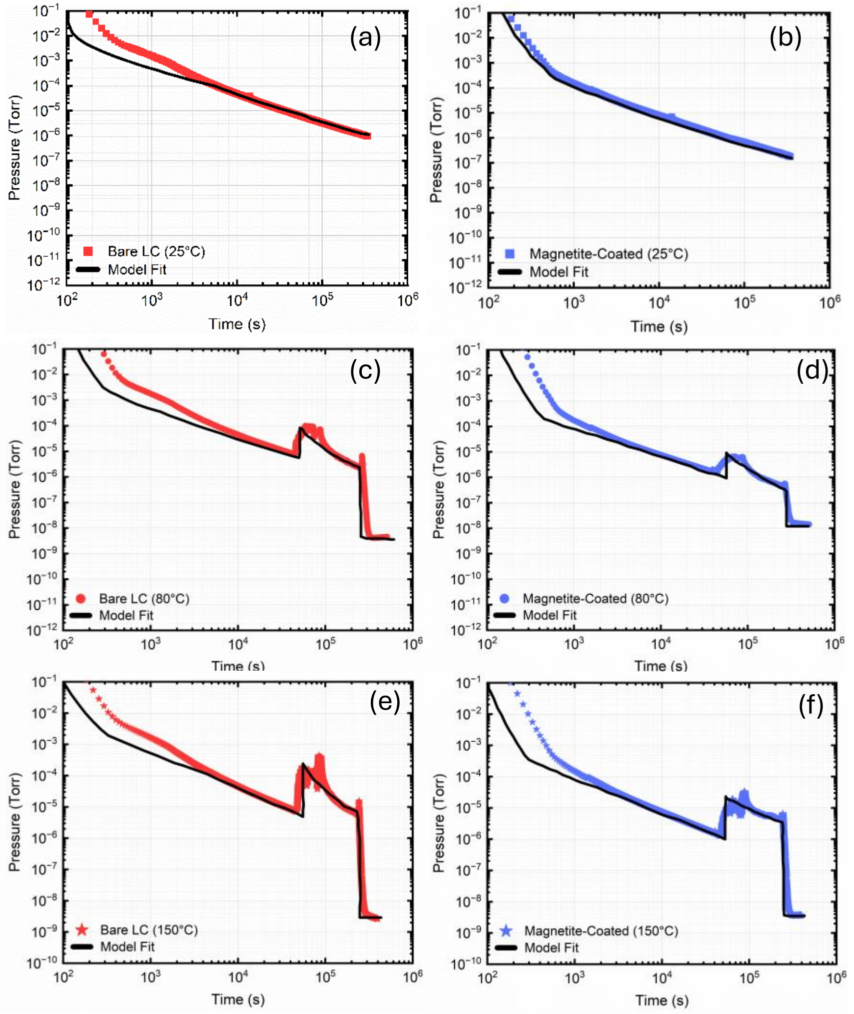
❖ Sun Steel Steam Treatment

- Two identical **AISI-1020** chambers; one **bare**, one **Fe_3O_4-coated**; 11.0 L, 3165 cm².
- **H_2O (throughput/orifice)**; **H_2 (rate-of-rise/SRG)**; uncertainties: **±35 %** (H_2O), **±15 %** (H_2).

Water Outgassing Results



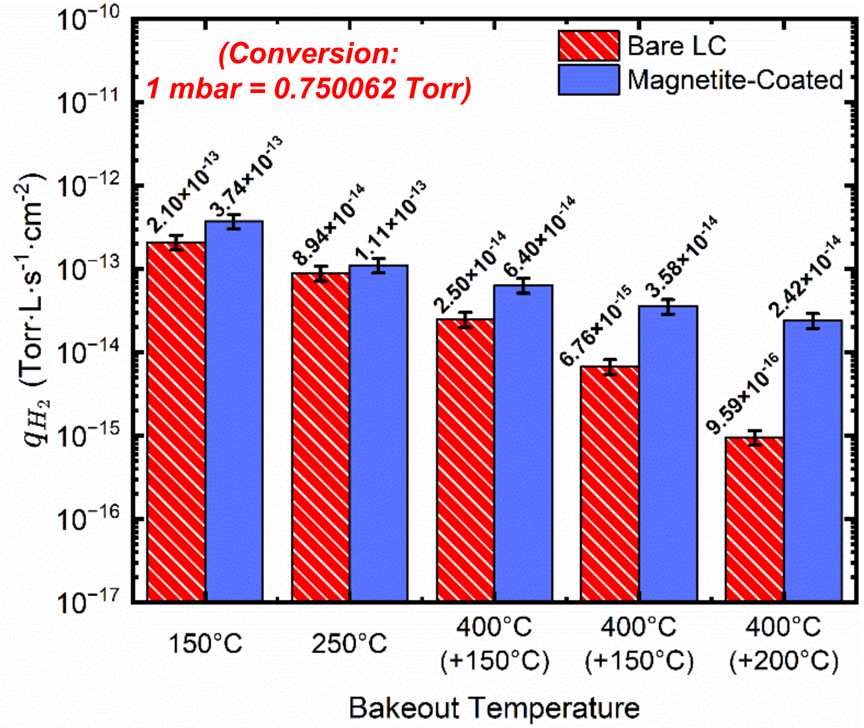


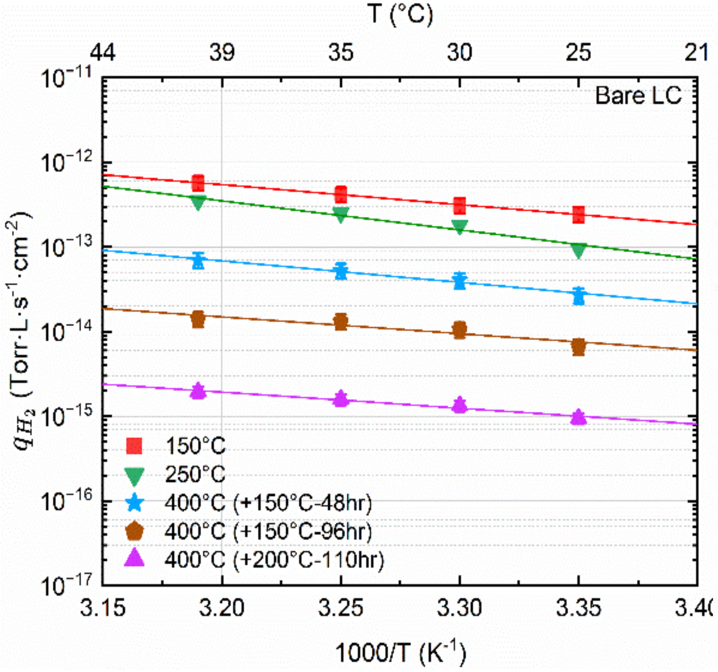


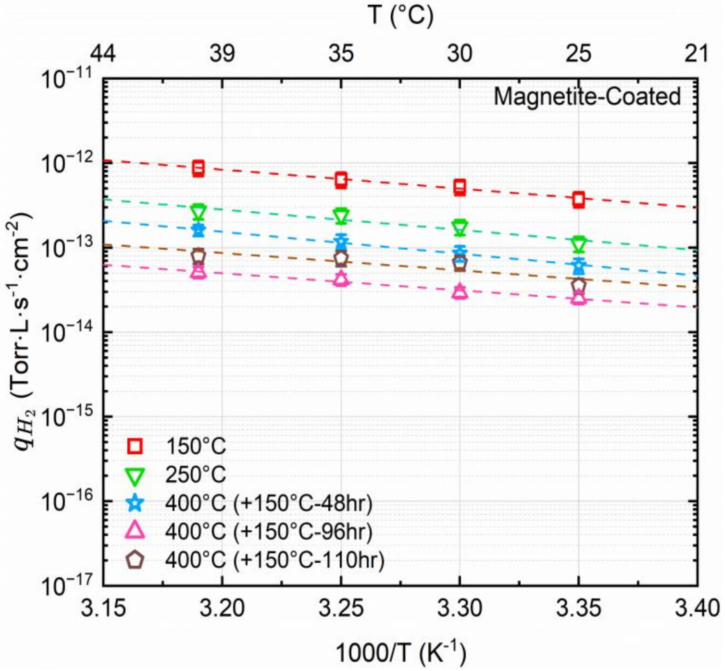
- **25 °C:** magnetite ≈ **5**× lower H_2O than bare (throughput; ±35%).
- **After 80–150 °C: bare < magnetite** for H_2O (crossover captured by Sips fits: $\boldsymbol{\alpha_s}$, $\boldsymbol{E_{LF}}$ on bare).
- Model reproduces pump-down over ~**9 decades**; CIs by **residual bootstrap**.
  - Method: throughput with calibrated orifice; uncertainties: ±**35%.**
  - Fits: robust time-weighted log-P; **Sips parameters with CIs**.

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

Hydrogen Outgassing Evolution

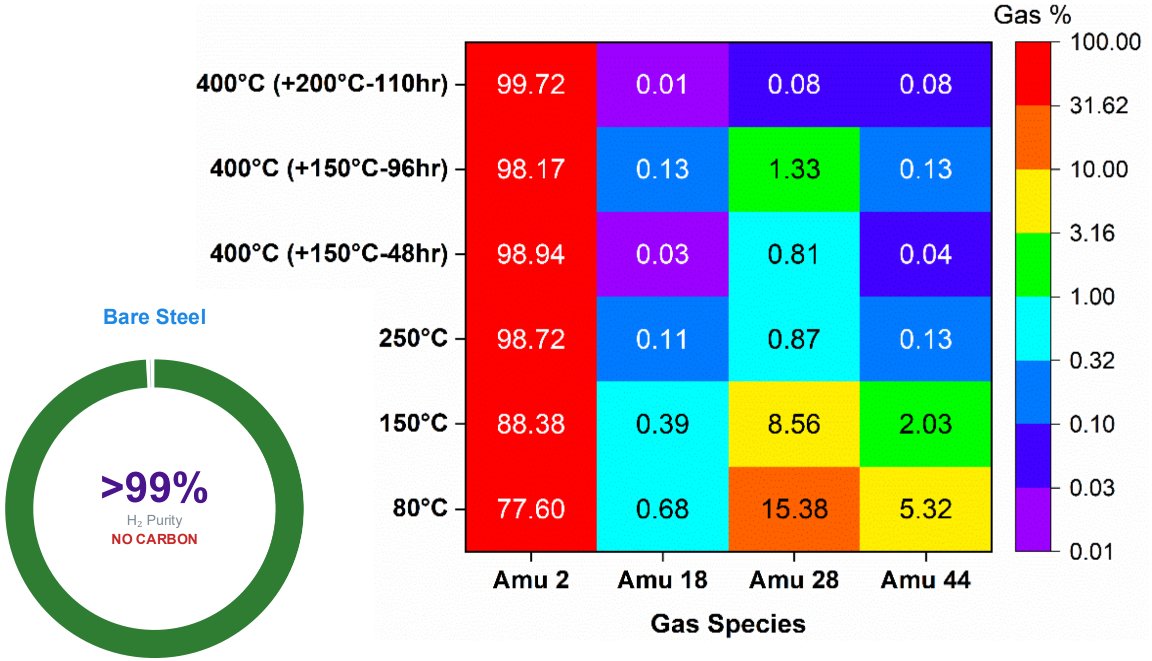




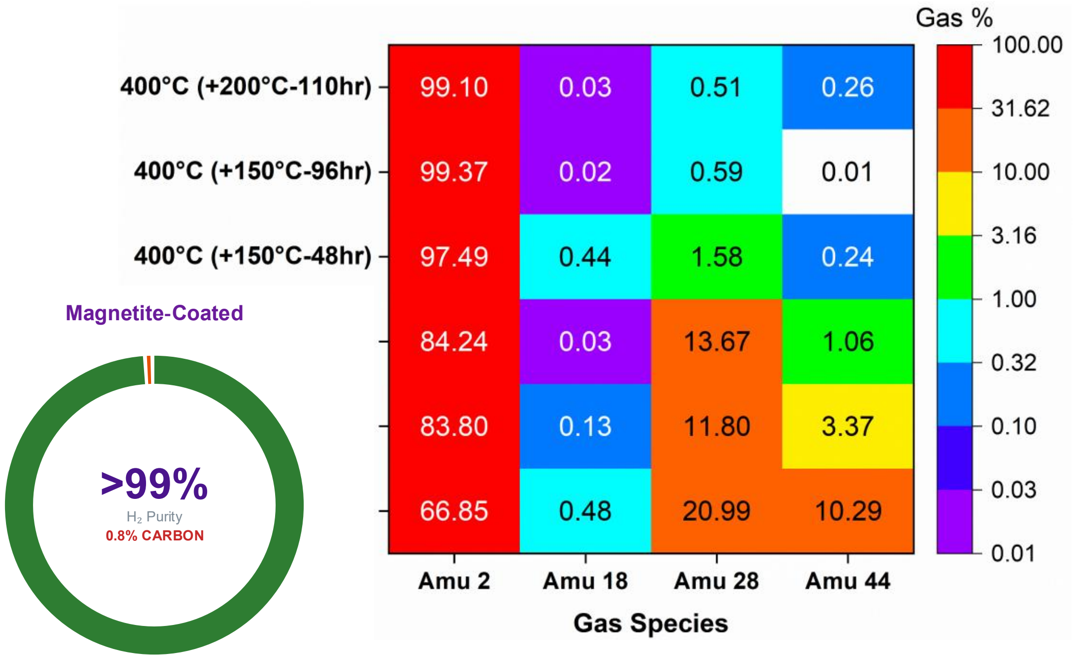


- **Final (400 °C + 200 °C/110 h, RT): bare** $q_{H_2} = 9.6 \times 10^{-16}$ vs **magnetite** 2.4×10^{-14} Torr·L·s^{-1}·cm^{-2} (**≈25**× gap; ±**15 %**).
- **Apparent E_a (25–55 °C):** post-150 °C: **0.46** ± **0.05** eV (bare), **0.44** ± **0.04** eV (mag); **final: 0.33** ± **0.03** eV (bare), **0.39** ± **0.04** eV (mag).
- **Interpretation:** small apparent E_a shifts; the rate gap is driven by **pre-exponential/site availability**

Gas Composition After Conditioning: >99% H_2



	Amu 2	Amu 18	Amu 28	Amu 44
400°C (+200°C-110hr)	99.72	0.01	0.08	0.08
400°C (+150°C-96hr)	98.17	0.13	1.33	0.13
400°C (+150°C-48hr)	98.94	0.03	0.81	0.04
250°C	98.72	0.11	0.87	0.13
150°C	88.38	0.39	8.56	2.03
80°C	77.60	0.68	15.38	5.32



	Amu 2	Amu 18	Amu 28	Amu 44
400°C (+200°C-110hr)	99.10	0.03	0.51	0.26
400°C (+150°C-96hr)	99.37	0.02	0.59	0.01
400°C (+150°C-48hr)	97.49	0.44	1.58	0.24
	84.24	0.03	13.67	1.06
	83.80	0.13	11.80	3.37
	66.85	0.48	20.99	10.29

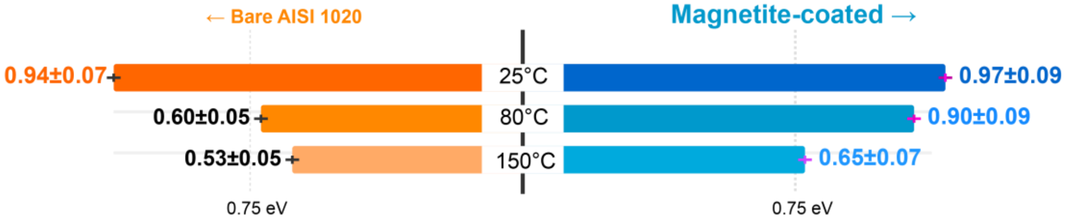
Post-conditioning spectrum is H_2-dominated; only the magnetite chamber retains a small carbon tail.

- 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 H_2 q).

Energy Analysis Summary: What the Numbers Tell Us

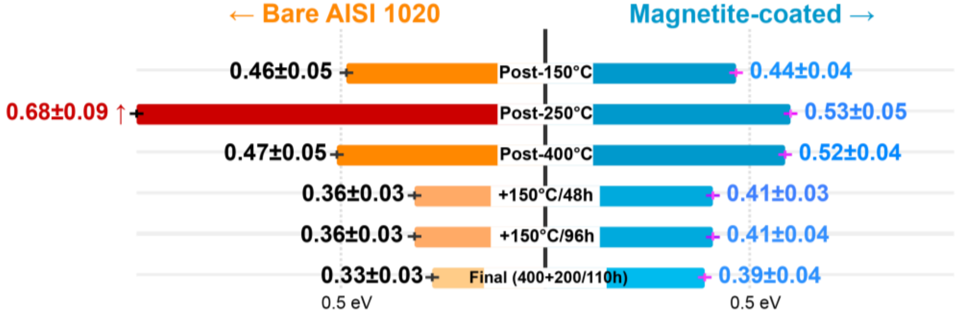
- **Sips (H_2O, pump-down):** We fit a temperature-dependent Sips isotherm. The $\boldsymbol{K(T)}$ term uses a van't Hoff form; the reported $\boldsymbol{E_{LF}}$ is an **apparent adsorption enthalpy** inferred from the temperature dependence of K, not a binding energy. **Values** for 25/80/150 °C show **bare** decreases strongly with modest heat, while **magnetite** remains higher until 150 °C.
- **Arrhenius (H_2, RT 25–55 °C):** We determine an **apparent activation energy of the net outgassing rate** (denoted E_a) from $\ln q$ vs $1/T$.
  - ☐ **Post-150 °C** 0.46 ± 0.05 eV (bare) vs 0.44 ± 0.04 eV (mag);
  - ☐ **final (400 °C + 200 °C/110 h)** 0.33 ± 0.03 eV (bare) vs 0.39 ± 0.04 eV (mag).
- The similar E_a values **cannot alone explain** the 25× rate gap; **factors beyond activation energy** (e.g., the pre-exponential q_0 , number of available sites) contribute to the observed difference.

E_{LF} (apparent; van't-Hoff from K(T))



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

Apparent E_a of the net H_2 outgassing rate (25-55°C)



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

Observations

- **Low-carbon steel (AISI 1020) can reach very low H_2 outgassing.**
  - In our side-by-side tube tests, q_{H_2}**≈ 2.4×10^{-16} Torr·L·s^{-1}·cm^{-2}** after a 400 °C bake for **AISI 1020**, versus **5.6×10^{-13}** for **316L** (**≈2.3×10^{3}× lower**, same method).
  - **Independent groups report similarly low H_2 from mild steels.** Recent JVST B work for next-gen GWDs finds mild steels **< 7.5 × 10^{-15} Torr·L·s^{-1}·cm^{-2}** after low-temperature bakes (e.g., 80 °C/48 h), supporting the trend that mild steels outgas H_2 far less than austenitic stainless under comparable conditioning.
    (Conversion: 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})

- **Ultimate pressure is a *system* outcome (conductance + stainless fraction).**
  - Material wins on q_{H_2} do **not** translate 1:1 to P_{ult}; minimizing exposed stainless and maximizing conductance near the chamber are required to realize lower *P*.

- **Water behavior: RT vs mild heat.**
  - Our chamber data show that **magnetite surfaces help RT H_2O pump-down**, while after **80–150 °C** conditioning **bare steel performs better** (modeled with Sips; E_{LF}reported as an *apparent* van't-Hoff parameter).
  - Surface science on Fe-oxides (Fe_3O_4/Fe_2O_3) is consistent with facile hydroxylation and strong initial H_2O interactions at RT.

- **Photocathode programs care about composition.**
  - For lifetime, **H_2-dominant** residuals are preferred; the GWD and accelerator literature emphasize reducing reactive species (H_2O/CO/CO_2). Our RGA result (>99% H_2 after conditioning) is squarely in that direction.

QUESTIONS?

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

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