MOERC (Metal Oxide Electrolysis Refinement Chamber)
Sand â Silicon (200âflg target) | 120âflV + Battery | <$10k v0.1

Earthâ first, ISRUâ ready benchtop line to convert ~1âflkg of oxide feed (beach sand, crushed rock, or simulant) into ~200âflg of refined silicon using molten oxide electrolysis (MOE) followed by vacuum refining and ingot casting. No external chemical reductants (no carbon, no chlorosilanes). Designed around offâ theâ shelf parts and minimal fabrication.

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0) Atâ aâ glance
Batch size: ~1âflkg dry feed (SiOâ â dominant) â ~200âflg Si (learning target; improved yields with practice)
Core process: MOE (Feâ Siâ Al staging) â vacuum refining (P removal) â directional solidification
Operating temps: 1600â 1700âfl´℃ MOE cell; 1600â 1900âfl´℃ vacuum refine; 1450â 1550âfl´℃ casting
Power: 120âflV AC, 15â 20âflA; battery/inverter (â¥1.8âflkW) inline for rideâ through; optional solar recharge
Atmosphere: lowâ leak sealed hotâ zone; argon backfill (closedâ loop reclaim); Oâ vent/capture
Footprint: bench stack, approx 0.8âflm ˆ 0.6âflm ˆ 1.2âflm total for all modules
Safety: highâ T, highâ brightness, Oâ evolution, offâ gas management; multiple interlocks & Eâ stop

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1) System Architecture (modules)
Feed Prep & Autofeed
Hopper + auger feeder (vacuumâ tolerant), inline dryer (150â 250âfl´℃), screen (â⁄250âfl´µm target), optional jawâ crusher for rocks.
MOE Cell (Melter + Electrolyzer)
Insulated hotâ zone, crucible/liner set, refractoryâ metal electrodes, 1600â 1700âfl´℃ setpoint, staged potential for Feâ Siâ Al.
Phase Separation
Weir/sump geometry to isolate Fe first, then collect molten Si away from slag/Fe (avoid Feâ Si alloying).
Vacuum Refining Pot
Dedicated vessel; 1600â 1900âfl´℃ at â⁄âfl10âflPa; coldâ traps on exhaust to capture SiO and Pâ species.
Ingot Casting
Directional solidification (Siâ Nâ â coated crucibles) for multicrystalline bricks; optional small floatâ zone head for rods.
Gas & Vacuum Skid
Argon loop (buffer tank, dryer, filter), Oâ vent/capture, vacuum pump (HFâ free process), baffles/coldâ traps.
Controls & Sensing
PID/PLC, twoâ color pyrometry, LIBS (preâ feed/melt fingerprint), OES (process), RGA (vac/offâ gas), interlocks.

Power & Energy
120âflV mains â inverter/UPS (â¥1.8âflkW continuous) â heater supplies; DC bus for controls; optional PV input.

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2) Bill of Materials (indicative, USD)
Prices are ballparks (new/COTS). Substitute equivalents as available.

2.1 Hotâ Zone & MOE Cell (~$3,150)
Highâ temp insulation kit (alumina fiber boards/blanket, 1700âfl´℃ class), panels + fasteners â $350
Modular steel frame (80/20 or welded), panels, hardware â $250
Crucibles/liners: primary ZrOâ liner (1.5â 2âflL), backup Alâ Oâ liners (x2) â $400
Refractoryâ metal electrodes: W cathode set + Mo spares; IrOâ â coated inert anode option (or consumable C anode minimized) â $900
Induction/element heater set: highâ temp MoSiâ elements (1700âfl´℃ rating) w/ holders OR compact induction coil + 3â 5âflkW driver (120âflV input PFC) â $950
Thermography: dual twoâ color pyrometers (melt & wall), 600â 2000âfl´℃ â $300
Fixtures: ceramic feedâ port, viewports (UVâ grade fused silica), fastâ shut baffles â $150

2.2 Vacuum Refining Vessel (~$1,750)
Small highâ vac furnace can (stainless shell, waterâ cooled feedthroughs) â $600
Heater: MoSiâ element set or induction coil insert â $450
Coldâ trap assembly (waterâ cooled finger + removable cryo cup) â $250
Vacuum hardware: KF25/KF40 set, valves, gauge (Pirani + capacitance manometer) â $300
Si crucible (graphite or highâ density SiC not in contact with silica stage) â $150

2.3 Gas & Vacuum (~$1,600)
Rotary vane pump (5â 8âflm´‡/h) + backing filter â $700
Dry scroll (used or small new) optional upgrade â $700
Argon loop: 20â 40âflL buffer tank, 0.1âfl´µm filter, desiccant dryer â $200

2.4 Feed & Casting (~$900)
Hopper + auger (stainless screw, NEMA 17/23 stepper, driver) â $300
Inline dryer (500âflW cartridge + PID, 150â 250âfl´℃) â $150
Screens (250âfl´µm, 100âfl´µm), small jawâ crusher (benchtop) â $250
DS casting station: Siâ Nâ â coated quartz crucibles (2â 3), mold base & slowâ cool plate â $200

2.5 Controls & Sensing (~$1,900)
PLC or industrial micro (e.g., Codesys/Compact PLC), IO modules, SSRs/contactors, Eâ stop â $600
LIBS mini head (OEM pulsed laser + gated spectrometer, 200â 900âflnm) â $800 (entryâ level; upgrade later)
OES spectrometer (300â 900âflnm, fiber, lens) â $250
RGA (bench quadrupole, 1â 100âflamu, used/reconditioned) â $250

2.6 Power & Energy (~$1,500)
120âflV line conditioner/UPS or portable power station (â¥1.8âflkW cont., ~1.5âflkWh) â $1,000
PDU, breakers, cabling, GFCI, ground kit â $300
Optional 400â 600âflW PV input cabling for recharge â $200

Subtotal (new parts): ~\$10,800
Targeted v0.1 underâ \$10k strategies: source used/auction items for RGA/pump/UPS (â \$800 to â \$1,500); choose resistance elements over induction (â \$300); use a single pyrometer (â \$150); DIY frame (â \$200). Practical v0.1 BOM â \$8.8â 9.8k.

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3) Stepâ byâ Step Build

3.1 Frame & Insulation
Build a rigid frame (80/20 extrusion or angle steel). Interior clear volume for hotâ zone: ~200âflmm ˆ ˆ 250âflmm H.
Line with 1700âfl´℃ fiber boards; add blanket layers; install reflective shields (Mo or W foil) with standoffs.
Add service ports: feeder entry, viewport, pyrometer peeks, electrode feedthroughs, gas ports. Keep leak paths short; use ceramic bushings.

3.2 Heater & Hotâ Zone
Option A â MoSiâ elements: Install 3â 4 elements around the liner; wire to SSRs/transformer per vendor specs; keep sightlines to melt.
Option B â Induction: Wind waterâ cooled copper coil around liner zone; mount driver; ensure RF shielding/grounding.
Install primary ZrOâ liner (melter) nested in a structural setter. Place W cathode tip ~10â 20âflmm above floor sump; mount anode opposite wall (prefer inert anode or protected graphite with minimal exposure).

3.3 Phase Separation Geometry
Machine/fit a weir that lets light slag overflow to a slag pocket while dense Fe collects in a deep sump under cathode.
Add a Si collection pocket isolated from Fe sump by a sill. Later, a tilting ladle or tap hole can draw Si to a transfer ladle.

3.4 Vacuum Refining Pot
Assemble small vacuum can with internal crucible support and heater.
Fit coldâ trap on exhaust path; add baffles cooled by water loop. Route to pump via isolation valve; include pressure gauges at can & foreline.

3.5 Gas/Vacuum Skid
Mount rotary vane pump on vibration pads; plumb KF manifold to MOE cell and refining pot with isolations and check valves.
Build Argon loop: buffer tank â dryer â filter â massâ flow controller â process. Return through filter to buffer.
Oâ vent line from MOE headspace to an exterior safe vent (or Oâ bottle if you choose to

capture).

3.6 Controls & Sensing
Install PLC, IO, SSRs/contactors; wire interlocks (door, overâ temp, vacuum OK).
Mount pyrometers (twoâ color) with purged sight tubes toward melt and refining pot.
Mount LIBS windowed port over feeder/melt; align fiber to gated spectrometer.
Mount OES fiber to watch electrode/plasma zone.
Plumb RGA to refining pot foreline (through throttled tee after coldâ trap).

3.7 Power
Route mains (120âflV) â portable power station/UPS â PDU â heaters/controls.
Separate clean supplies for controls; bond grounds; GFCI where appropriate.
Verify breaker sizing (20âflA recommended), wire gauge, and earth bonding.

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4) Commissioning & First Run

4.1 Dry Runs
Leakâ check with argon; verify <âfl50âflsccm leak at 50âflmbar over ambient.
Heatâ soak hotâ zone to 1000âfl´℃; check element balance, pyrometers, thermal uniformity.
Pump down refining pot; test coldâ trap condensation with water/ice first.

4.2 Feed Characterization
Sieve feed â⁄250âfl´µm; bake at 150â 200âfl´℃ to dry salts/moisture.
LIBS scan (190â 900âflnm) over a representative sample to estimate oxide fractions
(Feâ oxides, SiOâ , Alâ Oâ , CaO, TiOâ , alkalis). Save the spectrum for the run file.

4.3 MOE Operation (Feâ Siâ Al)
Melt/hold: Bring hotâ zone to 1600â 1650âfl´℃ under light argon (50â 150âflmbar over ambient).
Fe stage: Apply low cathodic overpotential/current density; monitor OES for Fe lines. Once
Fe pool accumulates in sump, tap/skim Fe or park it (mechanically isolated).
Si stage: Step potential upward; watch Si emission grow, and OES oxygen lines. Maintain
controlled headspace; ensure Fe sump temperature slightly lower to limit mixing.
Manage bubbles; avoid vigorous stirring. If LIBS/OES signals coâ reduction (alloying), step
back, let Fe settle, then proceed.

4.4 Transfer to Refining Pot
Ladle/tap molten Si into covered transfer crucible; minimize air exposure.
Move to refining pot; close, evacuate to â⁄10âflPa; heat to 1600â 1850âfl´℃ for 30â 90âflmin.
RGA watch: Pâ species decay; SiO (m/z ~44) rise indicates overâ evaporation â increase
trapping/cool baffles or adjust temperature.

4.5 Casting
Pour into Siâ Nâ â coated quartz mold; directional cool (1â 5âflK/min) from bottom to top to
segregate residual impurities to the hot end; crop tail.
Optional: mini floatâ zone pass on a small rod for semiconductor experiments.

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5) Control Logic (simplified)
Preheat to 1600âfl´℃ â stable for 20âflmin.
LIBS feed OK? If not, abort.
MOE: set Fe window â Fe sump mass threshold â tap or isolate.
MOE: set Si window â Si rate threshold met â end Si stage.
Transfer â vacuum refine â RGA P below setpoint â cool.
Cast â cool â log batch & spectra.

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6) Safety
Thermal: >1700âfl´℃ potential. Use shields, IR PPE, lockouts. No combustible clutter.
Gas: Oâ evolution; ensure venting away from personnel. No HF used; offâ gas is primarily Oâ /Ar/SiO; coldâ trap captures condensables.
Electrical: 120âflV at high current; bonded grounds; GFCI; Eâ stop. UPS/inverter must be rated for continuous draw.
Optical: Bright hot surfaces; avoid direct viewing; use proper IR/UV eye protection when inspecting.
Mechanical: Interlocks on doors/panels; guarded auger; hotâ work signage.

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7) Maintenance
Inspect liners & electrodes every ~10 hours at temp; replace worn anodes.
Bake argon dryer, change filters quarterly.
Clean coldâ traps each run; reclaim condensed SiO where feasible.
Calibrate pyrometers quarterly; verify LIBS/OES wavelength daily warmâ up.

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8) Upgrade Path
Inert anode (ceramicâ metal) to fully eliminate carbon contact.
Larger MOE pot w/ dualâ zone heaters for higher throughput.
Better spectrometers for trace B/P detection (deepâ UV arms).
Automated tapping, robotic ladle, and closedâ loop recipe tuning from spectra.

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9) Appendices

A) Target Setpoints (starting)
MOE hotâ zone: 1625âfl´℃
Fe stage: low overpotential; current density ~0.2â 0.4âflAâflcmâ»´† (tune by OES)
Si stage: step +10â 20% vs Fe stage; watch OES (Si) & headspace
Vacuum refine: 1700â 1800âfl´℃, â¼10âflPa, 30â 90âflmin

B) Minimal Tools
IR thermometer, torque drivers, crimp kit, TIGâ level gloves, face shield, tongs, scale, sieve set.

C) Expected Consumables (per 10 runs)
Argon: â⁄1âflm´‡ (with reclaim)
Liners: 1 ZrOâ primary + 1 Alâ Oâ backup
Anode face: 1 (if consumable)

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v0.1 total (with used/auction gear): \$8.8â 9.8k
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