RAVEN

Raven SR: Hydrogen Production Methods

November 2025

Why Hydrogen Matters for Contra Costa

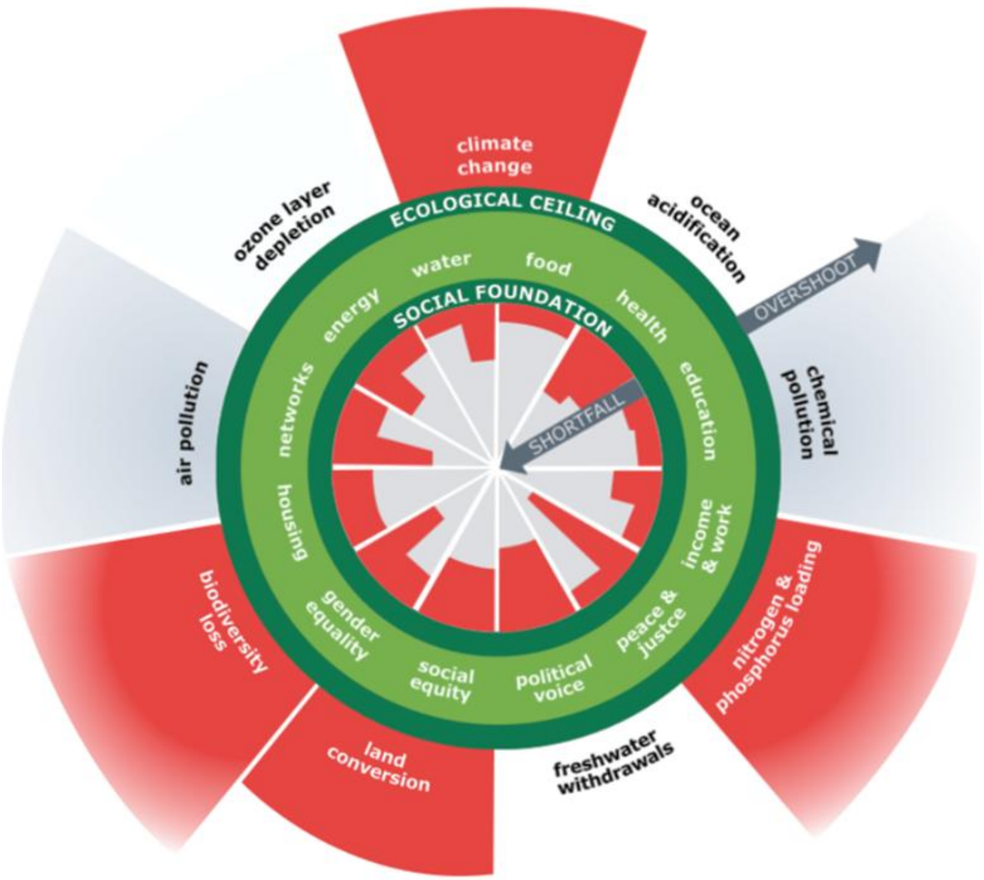
RAVEN

1. Delivers on Climate Action Plan goals by cutting transport, waste, and industrial emissions – key sectors driving the County's ~1 MMT CO_2e/yr on-road footprint (BAAQMD 2023).
2. Zero-emission freight is scaling now: the Bay Area's NorCal ZERO fleet (30 fuel-cell trucks) removes ~4,000 t CO_2e/yr, proving hydrogen works for regional logistics.
3. Improves local air quality: diesel exhaust causes ~70 % of air-toxic cancer risk in BAAQMD communities; fuel-cell trucks eliminate tailpipe PM & NO_x.
4. Turns waste into energy: diverting landfill organics or plastics to hydrogen avoids >2 t CO_2e per ton of waste – supporting the County's "Zero Waste by 2035" target.
5. Decarbonizes existing industry: Contra Costa refineries consume ~150 MM scf/day H_2; replacing it with low-CI hydrogen could cut ≈1 MM t CO_2e annually.
6. Advances BAAQMD Rule 11-18 goals by deploying systems with verified toxics controls and low-risk HRAs.
7. Creates local skilled jobs: a 6 t/day hydrogen plant supports roughly 40 direct & indirect positions across operations, maintenance, and supply.

(Sources: BAAQMD GHG Inventory 2023; CARB ZEV Plan 2023; DOE Hydrogen Shot 2024; EPA GHG Equivalencies; Raven SR Richmond ATC data.)

What “Clean” Really Means

RAVEN



Planetary Boundary	Limit	Current
Freshwater Withdrawals (km^3/year)	4,000	~2,600–3,000
Climate Change (ppm CO_2)	350	~420
Land Conversion (% natural cover remaining)	≥ 75%	~62%
Biodiversity Loss (extinctions per million species per year)	< 10	> 100
Stratospheric Ozone (Dobson Units)	≥ 275	~283 *(recovering)*
Nitrogen Load (million tons N/yr)	≤ 62	~150
Phosphorus Load (million tons P/yr)	≤ 6.2	~14
Ocean Acidification (Ω Aragonite)	≥ 2.75	~2.9
Novel Entities (chemicals, plastics, etc.)	Near 0 increase	Exceeded

“Humanity’s 21st-century challenge is to meet the needs of all within the means of the planet—ensuring that no one falls short on life’s essentials, while not overshooting Earth’s life-supporting systems.” [Kate Raworth, Doughnut Economics]

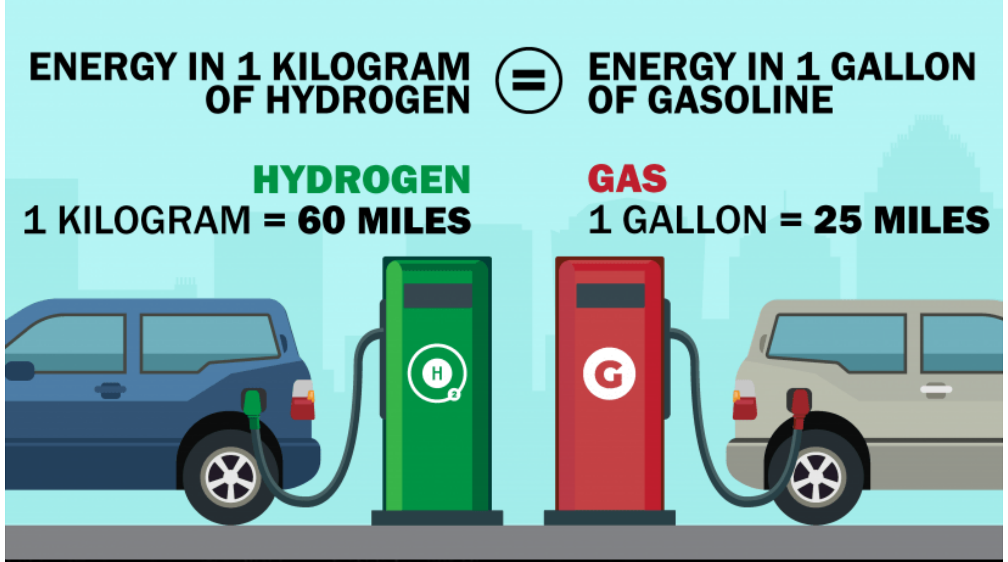
- Energy: The world uses over 160,000 TWh per year; hydrogen pathways should be efficient and scalable within that global energy budget.
- Water: Global freshwater withdrawals are ≈ 2,600 km^3 per year of a 4,000 km^3 limit; responsible hydrogen production must minimize freshwater demand.
- Local co-benefits: Cleaner air, reduced waste, and community resilience are equally vital measures of sustainability.

Bottom line: True sustainability balances energy, water, carbon, and community impact—green is measured by outcome, not label.

Hydrogen: Safe by Design

RAVEN

- Proven and familiar: Hydrogen has been used safely in industry for more than 50 years in refineries, fertilizers, and electronics.
- Safe when managed properly: Like gasoline or natural gas, hydrogen must be handled in closed systems—but its properties make incidents less likely and less harmful.
- Non-toxic and clean: It contains no carbon, produces only water when used, and is not carcinogenic, corrosive, or water-polluting.
- Light and dispersive: Being lighter than air, leaked hydrogen rises and disperses rapidly rather than pooling.
- Modern detection and storage: Sensors and sealed composite tanks provide multiple layers of protection during transport and fueling.



Sources: shell-h2-study-new.pdf, Hydrogen Compared with Other Fuels | Hydrogen Tools (h2tools.org), Hyundai, Toyota and Hyzon publications. Demonstration conducted under controlled conditions, U.S. Department of Energy Hydrogen Safety Program.

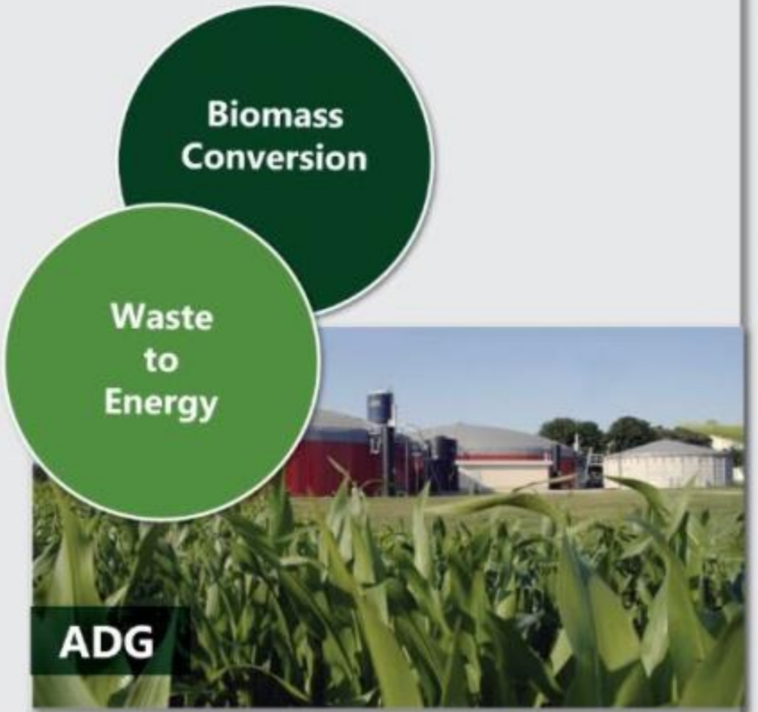
Hydrogen Production Methodologies

FOSSIL RESOURCES

- Low-cost, large-scale hydrogen production with CCUS
- New options include byproduct production, such as solid carbon

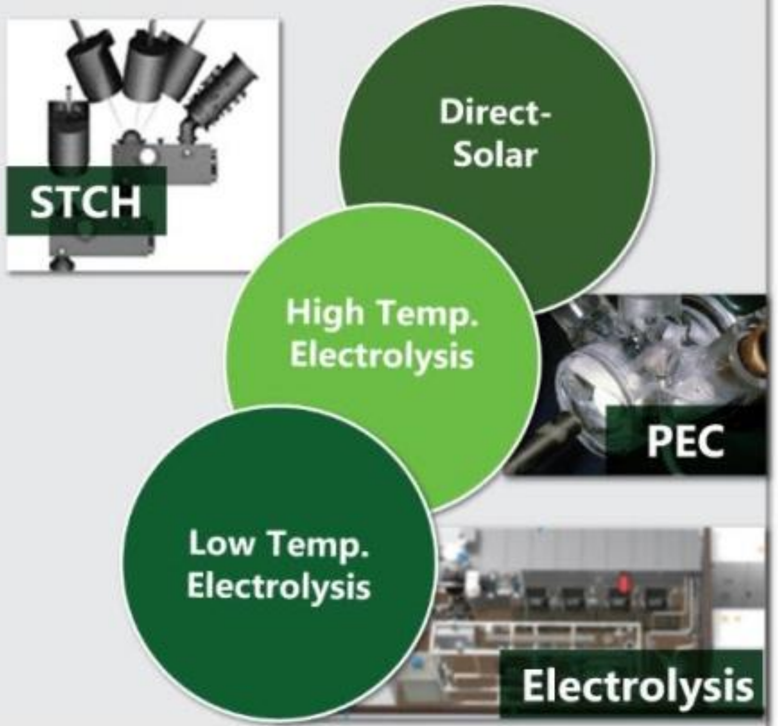
BIOMASS/WASTE

- Options include biogas reforming and fermentation of waste streams
- Byproduct benefits include clean water, electricity, and chemicals



H_2O SPLITTING

- Electrolyzers can be grid-tied, or directly coupled with renewables
- New direct water-splitting technologies offer longer-term options



Hydrogen Production Methodologies

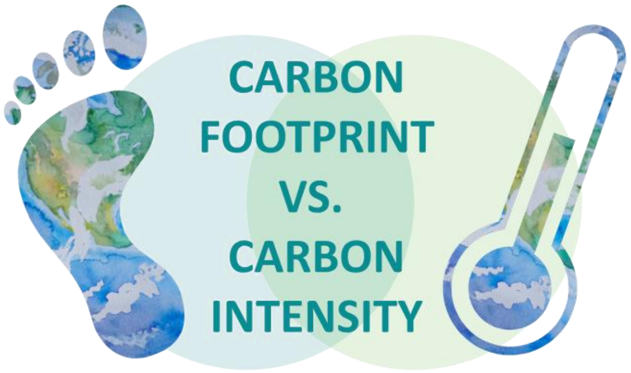
RAVEN

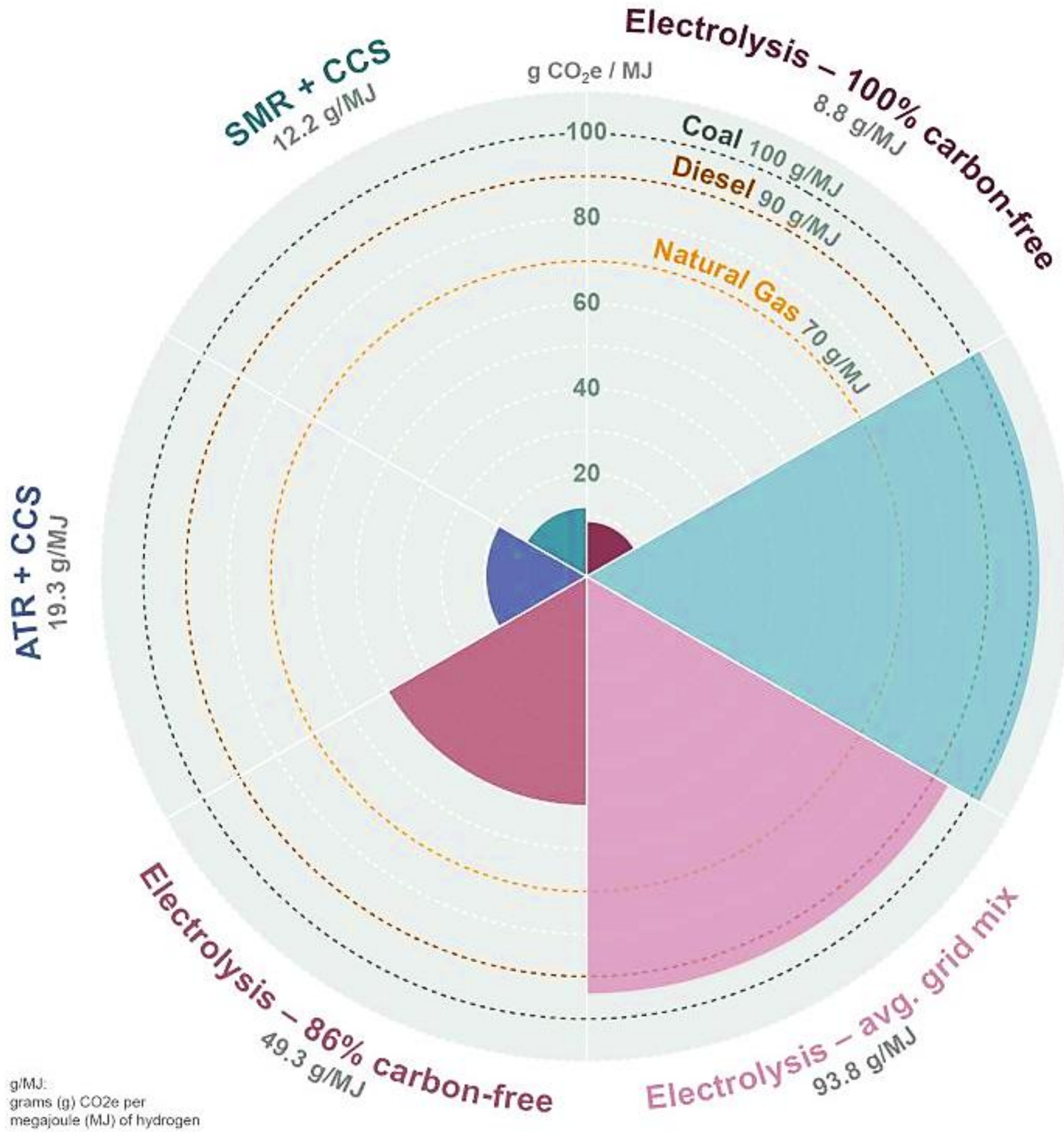
Method	Feedstock / Source	Typical Carbon Intensity (kg CO_2e / kg H_2)	Air Quality & Pollutants	Energy Source	Waste / By-products	Regional Suitability (Contra Costa)	Key Co-Benefits	Main Challenges
Autothermal Reforming (ATR)	Natural gas / LPG	8 – 10 (2–3 with CCS)	Moderate CO_2, NO_x from O_2 combustion	Steam + O_2	CO_2	Possible retrofit at refinery or industrial hub	Easier CCS integration than SMR	Still fossil based; needs carbon storage infrastructure
Biological / Fermentative H_2	Organic wastewater, algae	≈ 0 (biogenic)	Very low air impact	Biological	CO_2 (biogenic)	Good fit with wastewater plants	Co-treats organic waste streams	Low yield; R&D stage
Biomass Gasification	Wood waste, crop residue	0 to –5 (biogenic credit)	Very low; minimal NO_x	Steam heat (renewable)	Biochar, ash	Strong fit with urban forestry & organics diversion	Converts ag/urban waste to fuel + carbon sink	Feedstock collection logistics; tar management
Coal Gasification	Coal / Pet-coke	18 – 20 (7–10 with CCS)	SO_x, NO_x, PM	Combustion + steam	Slag, CO_2	Not regionally relevant	Base-load power co-generation	Not aligned with CA climate targets
Electrolysis (PEM or Alkaline)	Water	0 – 2 (renewable electricity)	None (only O_2 release)	Renewable electricity	O_2 by-product	Excellent fit for Contra Costa microgrids and renewable PPAs	Grid balancing, energy storage	High power cost / capacity factor dependence
High-T Electrolysis (SOEC)	Water + steam	0 – 2	None	Heat + renewable power	O_2	Industrial co-location (e.g. refineries, cement)	Highest efficiency (> 80%)	Early commercialization
Methane Pyrolysis (Turquoise H_2)	Natural gas → solid carbon + H_2	0 – 2 (renewable power)	Low – no CO_2; some PM if uncontrolled	Electric heat	Solid carbon product	Possible industrial co-location	Carbon solid as saleable material	Technology still pilot-scale
Plasma Gasification	MSW, medical waste	4 – 8	Some NO_x from plasma arc	Electric arc	Inert slag + CO_2	Niche industrial uses	High destruction efficiency for hazardous waste	High power demand
Pyrolysis (Waste/Biomass)	MSW, plastics	2 – 6 (depends on electric source)	Moderate organics and tars	Electric heat	Bio-oil, biochar	Viable for local waste diversion	Reduces landfill volumes	Tar handling and permitting ambiguity
Steam / CO_2 Reforming (Raven SR)	Mixed biomass & organic waste	–5-15 (LCA 2024)	No combustion: virtually zero NO_x / SO_x / PM / dioxins	Electric + steam (renewable option)	Stable biochar + CO_2 for reuse	Uses landfill gas + organic waste at Richmond site	Cuts methane emissions; creates local jobs; aligns with Rule 11-18	Grid interconnection and utility tariff complexity
Steam Methane Reforming (SMR)	Fossil natural gas	9 – 12 (2–4 with CCS)	High CO_2, NO_x unless CCS used	Combustion of CH_4	Large CO_2 stream	Already used in Martinez refineries – retrofit potential	Quick scaling from existing plants	High carbon footprint without CCS; limited local air benefit

Average Carbon Intensity of Typical Production Methods

RAVEN

Lifecycle carbon intensity of hydrogen varies more than tenfold depending on how it's made. Hydrogen's climate benefit depends on its origin, locally sourced renewable or waste-to-hydrogen offers the steepest emissions reduction and the greatest regional co-benefits for air quality.





g/MJ:
grams (g) CO2e per
megajoule (MJ) of hydrogen

Elizabeth Abramson & Dane McFarlane,
Carbon Solutions LLC, 2022.

Carbon footprint: the total amount of greenhouse gases released by an activity or product, usually measured in tons of CO_2e.

Carbon intensity (CI): the amount of emissions per unit of useful output or energy – it shows how clean or efficient the process is.

Raven S-Series Plant 70 wtpd in Richmond, CA

RAVEN

Milestones

- ✓ Feedstock agreement
- ✓ Offtake agreement
- ✓ FID
- ✓ Tier 1 Registration
- ✓ Land Easements
- ✓ Grid Connection
- ✓ CEQA IS/MND
- ✓ Community support
- ✓ Labor Endorsement
- ✓ EJ/NGO Endorsement
- ✓ Richmond CUP
- ✓ SWFP → BCF
- ✓ Article II Compliance
- ✓ HRA Approval
- ✓ ATC Issued

Feedstock	Input Capacity	Output Capacity	Partners + Offtake
Green & Wood Waste	70 wtpd	~ 7,000 kg/day H_2 (SAE J2719 grade)	Chevron, REPUBLIC SERVICES

Raven's Reforming System – Proven, Efficient, Scalable

RAVEN

SR-1 Electric Rotary Reformer

Converts solid waste into syngas and bio-carbon. Core Advantages:

- Electric heating for precise heat control
- Non-catalytic
- 95% cold-gas efficiency
- Lower temps + steam = no tars or slag
- Robust, modular design

SR-2 Electric Steam Reformer

Converts methane-rich syngas to high-purity H_2. Core Advantages:

- Electric heating for precise heat control
- Non-catalytic
- >97% CH_4 conversion
- Destroys sulfur & nitrogen impurities
- Lower pressure than traditional SMR

SR1

Decades of proof
Large-scale kilns have been built and run around the world

Strong Technology and IP
22 patents issued and 12 patents pending

Commercially Built to Scale
SR2 reactor already fabricated and shop-tested

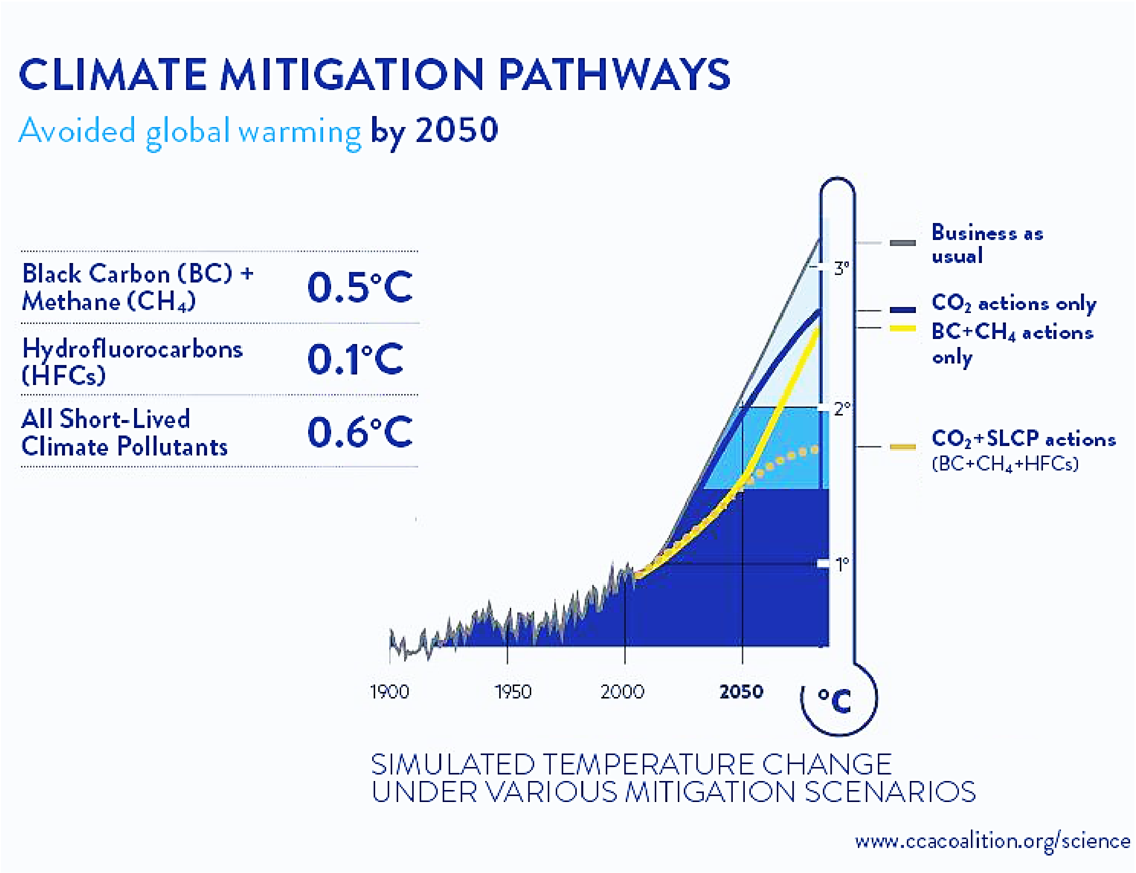
SR2

Together, SR1 and SR2 enable non-combustion hydrogen production from solid waste – cleanly, efficiently, and at commercial scale.

The Other Half of the Climate Equation

RAVEN

Short-Lived Climate Pollutants and Near-Term Warming. Pair long-term CO_2 cuts with biomass-focused SLCP reductions to deliver near-term cooling and local air-quality gains



"It is not too late to avoid disastrous climate changes. If we stabilize CO2 concentrations and simultaneously reduce Short Lived Climate Pollutants (SLCP), we can limit the end-of-century warming by 50 percent and reduce the cumulative sea-level rise by about 30 percent.... SLCP reductions are the last lever we have left to avoid catastrophic climate change..." [Dr. V. Ramanathan, UCSD Scripps Institute]

- Methane (CH_4) and black carbon (BC) account for nearly half of observed warming.
- Reducing SLCPs complements CO_2 mitigation — fast benefits within 10–20 years.
- Waste-to-hydrogen projects that destroy methane and eliminate combustion directly address this category.

Data: Climate & Clean Air Coalition; UNEP; UCSD Scripps Institute; 2023 IPCC AR6 Summary.

Local Co-Benefits

- 🏭 Cleaner air – Replacing diesel with hydrogen eliminates tailpipe PM & NO_x. Diesel exhaust causes ≈ 70 % of BAAQMD's air-toxic cancer risk; 100 fuel-cell trucks remove > 400 t CO_2e and ~2 t PM per year.
- 💼 Local jobs – A 6 t/day plant sustains ~40 skilled positions in operations, maintenance & construction—matching Contra Costa's industrial workforce.
- ♻️ Circular reuse – Converting 75 TPD of organics & plastics avoids ≈ 150 t CO_2e daily and supports the County's Zero Waste by 2035 goal.
- 💧 Water efficiency – Closed-loop reforming recovers > 80 % of process water and uses no potable supply.
- 📈 Energy resilience – Distributed hydrogen production adds local backup power and grid stability for emergency response.

(Sources: BAAQMD 2023; CARB ZEV Plan 2023; DOE Hydrogen Shot 2024; EPA GHG Calculator; Raven SR Richmond ATC Data.)

Disclaimer

This presentation is provided by Raven SR, Inc. solely for informational and educational purposes in connection with regional sustainability and clean-energy planning efforts. It is intended to share technical, environmental, and policy information about hydrogen production pathways and related technologies relevant to Contra Costa County's Climate Action Plan goals.

This material does not constitute an offer, solicitation, or recommendation for any commercial transaction, investment, or partnership. It should not be interpreted as marketing, financial advice, or endorsement of any specific project or technology.

All data, projections, and examples are presented for discussion and planning purposes only. While care has been taken to ensure accuracy, Raven SR makes no representation or warranty, express or implied, as to the completeness or reliability of the information contained herein. Figures, emissions data, and lifecycle values are subject to change as regulatory guidance, models, and scientific understanding evolve.

This presentation may include statements about potential environmental or community benefits of various hydrogen technologies. Such statements are illustrative only and are not intended to compare, rank, or disparage other companies, technologies, or stakeholders operating in the region.

Any forward-looking statements are based on current assumptions and should not be interpreted as guarantees of future performance or outcomes. Raven SR assumes no obligation to update or revise this material.

By reviewing this presentation, attendees acknowledge that its contents are non-confidential and informational, and that Raven SR is not offering or promoting any financial product or service.