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IVYS Energy Solutions

PDC MACHINES.COM

Hydrogen Fueling for Home and Fleet Applications

Ivys Energy Solutions • enabling clean mobility™


New Class of Turnkey
Hydrogen Refueling Appliance
Enables Cost-Effective Commercial & Industrial Fleets
Produces Hydrogen On-Site & On-Demand: Water & Electricity
Modular, Drop-In Installation, Supports 10-20 FCEVs
Solution for Smart Distributed Networks and Urban Environments
H2refuel
U.S. Department of Energy
$1MM H-Prize Winner
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Why Develop Small-Scale Refuelers?

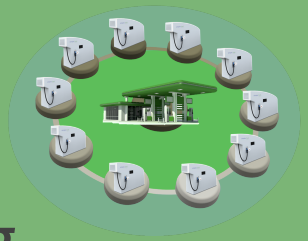
Range of Market Applications

Residential

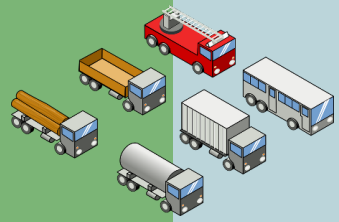
Condo, Office Parks

Roadside Emergency Refueling

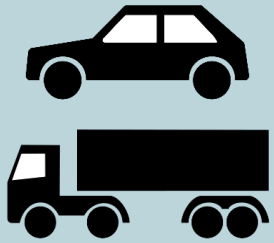
Extended Light Duty Networks



Fleet & Municipalities



Light Duty Public
Medium and Heavy Duty



Distributed Small-Scale Fueling

Low Cost

Simplified Installation

Onsite H2 Generation

Slower Fill Rates (5 – 30 min/kg)

Comparable to BEV charging

Centralized Fueling

Higher Capacity

Increased Cost

Delivered H2

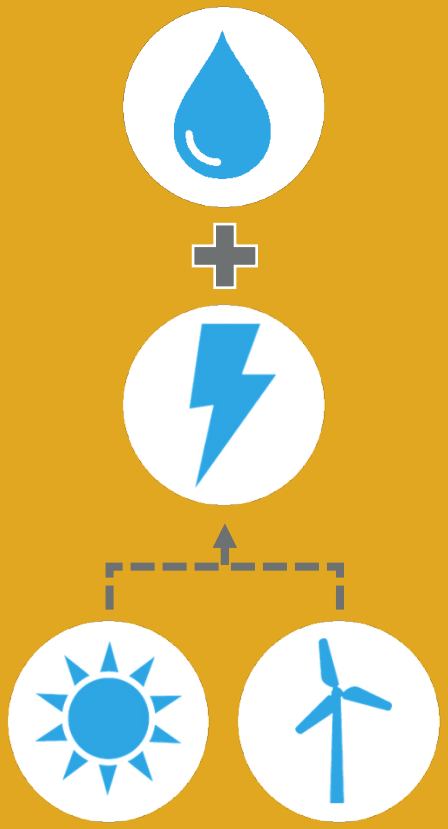
Fast Fill (≥1 kg/min)

Compare to Liquid Fuels

Increase Fueling Technology Options – Accelerate Market Adoption

Fleet Model: Incremental, managed conversion to FCEV for Federal, State/Municipal, Government, Workplace, Ride Share & University Programs

Automotive Fleets



100 tons GHG/year savings possible with renewable grid-tie options

One Refueler supports up to 650 fleet miles driven per day

Up to 10-20 FCEVs per Refueler

Zero Emissions

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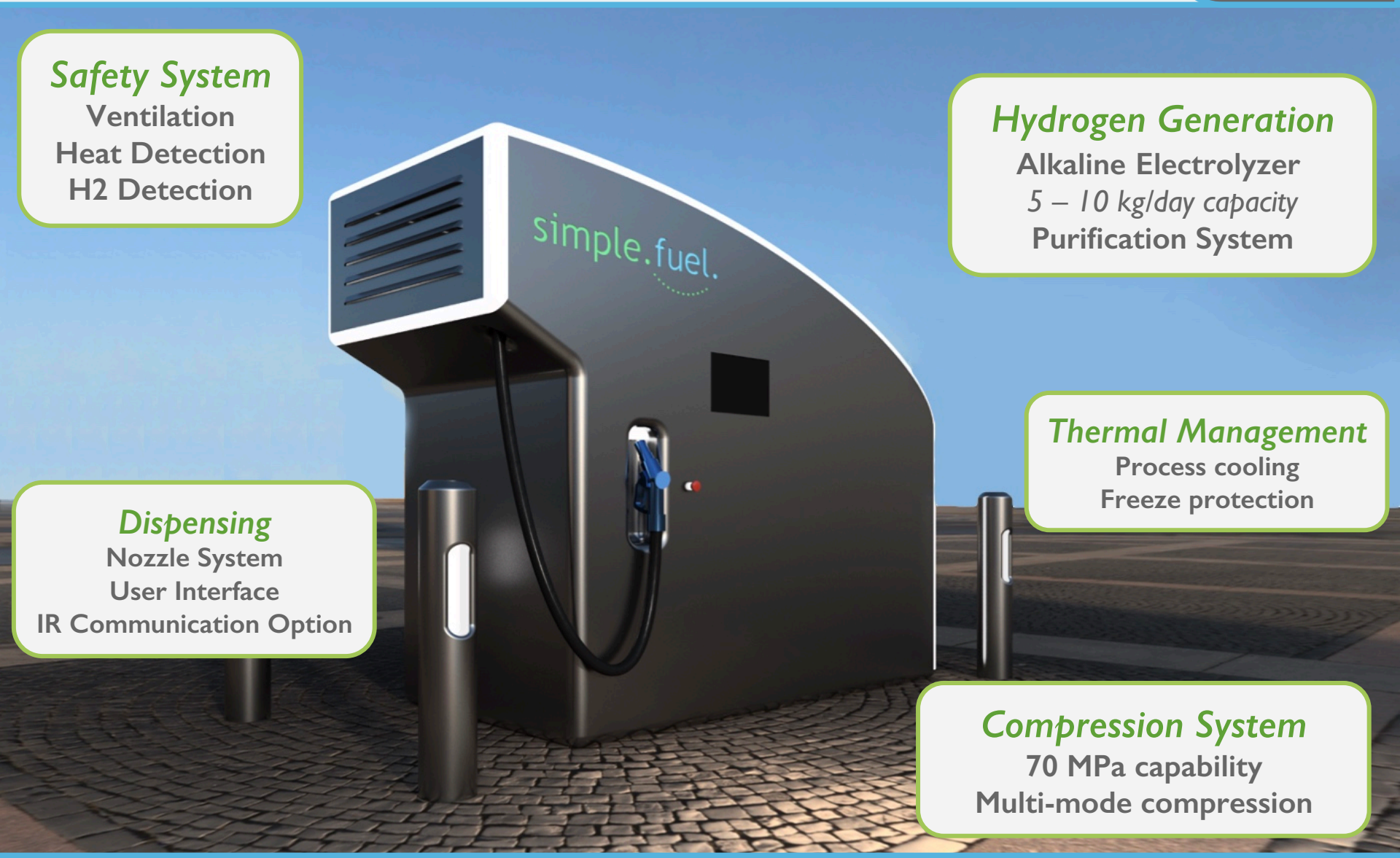
Core Technology

H_2 Fueling Appliance



Safety System
Ventilation
Heat Detection
H2 Detection

Hydrogen Generation
Alkaline Electrolyzer
5 – 10 kg/day capacity
Purification System

Thermal Management
Process cooling
Freeze protection

Dispensing
Nozzle System
User Interface
IR Communication Option

Compression System
70 MPa capability
Multi-mode compression

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Target Entry Markets

H_2 Fueling Appliance

Captive Fleets – Industrial Trucks

- >20,000 H2-powered forklifts in US today!
- ~60% market is less than 50kg/day H2
- Saves valuable real estate, enables incremental DC expansion & retail stores

Tethered Fleets – Commercial Vehicles

- Up to 10-20 FCEVs per Refueler
- Affords incremental, managed conversion
- State/Municipal, Workplace, Ride Share & University Programs
- ~1.9M Fleet cars in US commercial and government use

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PDC Machines, PA

Automotive H_2 Fleets

H2 Refuel H-Prize Winner

2 years operation to date

> 340 fill events, > 380 kg dispensed

Average fill rate 10 – 30 min/kg

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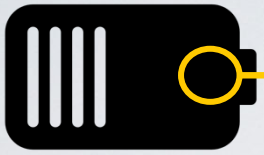
Iwate Prefecture, Japan

Industrial H_2 Fleets

- On-site fueling in FC forklift application
- Kesen Precut: sustainable wood and woodchip production
- Remote site – local water and solar power
- Listed and labeled product – ETL mark
- In daily use since March 2018 – over 94% availability
- Average vehicle fill time 5-10 minutes

simple.fuel.® *Next:* Greentown Labs, MA

Mixed ZEV Automotive



Sparkplug Power 280 kW / 510 kWh
Energy Storage Solution

Greentown Labs Global Center for Cleantech Innovation & 120 kW_e Solar Array

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Ivys SimpleFuel e+
Hydrogen & Battery Electric Vehicle
Charging Appliance with Integral ~150 kWh
Energy Buffer & Charge Assist

Hyundai Ioniq BEV & Tucson FCEV

MASSACHUSETTS CLEAN ENERGY CENTER

- **Landmark Demonstration of Commonwealth Leadership in *ZEVs*, *Renewables*, *Energy Storage* & *Power-to-Gas***
- **18-Month Term | 12-Month Test/Data Collection Period**
- **10 Tons GHG Reduction (100 Tons possible)**

Technology Development Opportunities

Compact, High Reliability Electrolysis

- PEM electrolysis attractive for efficiency and packaging
  - Potential additional OPEX/reliability benefits from low maintenance
- Challenges remain for system cost, input water purification needs, stack lifetime
- Multiple R&D opportunities
  - Low-cost PEM stack (capital and manufacturing), High pressure electrolysis, System simplification/cost reduction

Hydrogen Cooling

- Current state-of-the-art in T20 – T40 cooling is cost prohibitive for small scale
  - Pre-cooling of hydrogen can improve user experience (fill times) at all infrastructure scales
- Solution for home/fleet market must be compact, low cost, and highly reliable
  - Must scale well to low-utilization applications
- Expansion of allowable temperature range in fueling standards can help
  - More low-cost and reliable technologies available to be developed for higher precooling temperature

High Temperature Resistant Compressed Hydrogen Storage System (CHSS)

- Current CHSS technology limits fueling rates at all hydrogen temperatures
  - Significant reductions at high ambient temperature conditions
- Higher temperature CHSS materials would change the landscape for fueling options
- Many materials to target – liner, binders, overwrap

Market and Industry Development

Government and Regulatory

- Standards development for fleet and home/community H_2 fueling
  - Ambient Temperature Fueling standards – in progress
  - Vehicle Fueling Appliance focused safety standards
- Continue and expand programs for distributed H_2 infrastructure
- Develop funding sources for industry protocol and standards development
- Provide framework / space for industry collaboration and planning
  - Harmonized industry vision to accelerate vehicle and infrastructure rollout

Incentivizing Early Adoption

- Expand incentive programs to include small scale distributed H_2 fueling
  - Battery EV charger incentives as template
- Fund and/or promote fleet demonstration and deployment projects
  - Extend funding/rebate programs to commercial as well as private customers

Industry Tools

- Widely available advanced vehicle storage (CHSS) and fueling models
  - Provide technology developers with tools to assess stratification impacts, new protocols and CHSS types
  - Similar industry benefits to HyRAM, HDSAM – vetted and open tools and resources

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