Green Fortress Engineering

# *DISTRIBUTED HYDROGEN GENERATION AND STORAGE*

**Lecture Presentation**
***Hydrogen Days 2020***
**Prague, Czech Republic**

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# Green Fortress Engineering

At Green Fortress, we are revolutionizing Hydrogen Production and Storage with our proprietary technology.

*NSF Funded*

- Local Energy (H2) availability by gasification of waste
- Generate pure Hydrogen at meso-scale (5 to 240 kg/day)
- Store Hydrogen in solid-state microporous silicon (8 bar, 120 $^{o}$C)
- **NINE** (9) US Patents – all are issued & active:

**8,691,115 8,456,562 9,416,326 8,845,772**

**8,518,856 7,721,601 7,833,418 8,673,811 10,093,875**

$H_2$ GENERATION

STORAGE

# Product: **BMSG** BioMass Super Gasifier

**Any Feedstock**

**High Efficiency**

**Tar-free Syngas**

**Non-labile Biochar**

*First Pilot Plant "Stalk Stoker"*

*FUNDING AGENCIES*

USDA

DEPARTMENT OF ENERGY · UNITED STATES OF AMERICA

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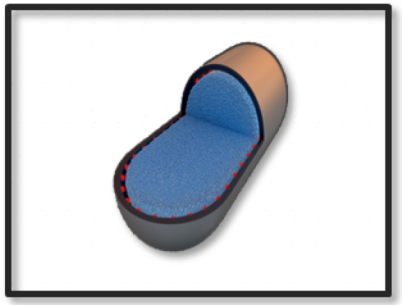
# Product: **H2US** Hydrogen ($H_2$) Ultra Storage

**Low Cost**

**High Density**



*$H_2$ Storage Vessel*

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# Secrets of the GFE BMSG Gasifier
## Indirectly Heated Pyrolytic Gasification

**Typical dry wood Syngas I-HPG composition:**

**4.9% H2 21% CO2 9.5% N2 57.2% CO 5.1% CH4**

**Plus Soot and Tar**

**Energy Content = 3.23 kWh/m3**

**I-HPG GFE Super gasifier syngas composition:**

- **45% H2 45% CO and 10% mix of H2O, CO2 N2**
- **Both methods produce syngas with same energy content**

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# More Secrets of the GFE BMSG Gasifier

- **How can this be?**
- **Anaerobic gasification at 850 to 1000 degrees C**
- **Both methods produce syngas at the same energy content**
- **GFE BMSG gasifier produces clean syngas**
- Soot and tar-free syngas having low or no maintenance
- Re-examination of gasifiers for Syngas (or H2) production
- GFE BMSG Gasifiers are available for testing or examination

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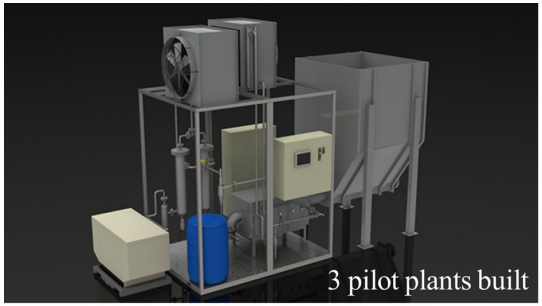
# BMSG Characteristics

- Syngas composition: $H_2$=0.45 CO = 0.45 {$N_2$+$H_2O$+$CO_2$} = 0.10
- Energy content of syngas: **3.25 kWh/m³**.
- Biochar content: 0 to 30% (higher with dry feedstock)
- Chemical energy efficiency (with CHP): **71%**
- Daily System capacity turn down ratio**: 0.5-24 TPD**
- Feedstock input: **1 to 144 MT/day**
- Tar content: **0**
- System economic payback (at 10 cents/kWh): **4 years**
- Emissions from SI-ICE genset: meets US EPA limits
- Restrictions: no halogenated plastics: no PVC; no Teflon
- Patents: **4**

**CLEANER THAN:**
**Combustion**
**Incineration**
**Pyrolysis**
**Enzymes**

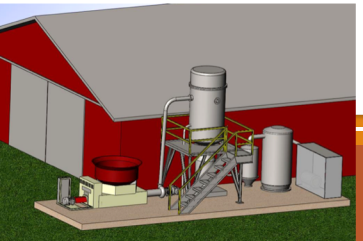


# BMSG Finance

* CAPEX: $ 391,000

* Payback: **4 years** at 0.12$/kWh electric, or **2.5** years at 0.23 $/kWh

* Carbon-based feedstock
  - biomass/crop waste
  - packaging waste
  - scrap wood & sawdust
  - old pallets
  - cardboard/paperboard
  - plastics
  - food waste
  - landscape trimmings



| Biomass CHP System Cost Analysis | | | | | |
|---|---|---|---|---|---|
| **EXPENSES** | **BASIS** | **AMOUNT ($)** | | **ASSUMPTIONS** | **VALUE** |
| Biomass CHP system (60 kW) | one-time | $350,000 | | Fuel usage (1000 kg/day) | 2.0 |
| Pre-processing equipment | one-time | $24,000 | | Biomass energy (MJ/kg) | 18 |
| Shelter for hopper and operator | one-time | $9,000 | | Electrical efficiency | 24.00% |
| Installation | one-time | $8,000 | | Electrical energy (MJ/day) | 8640 |
| Operator Labor & Fuel | daily | $15 | | Electrical power (gross kW) | 100 |
| Feedstock | per ton | $10 | | Internal power (kW) | 40 |
| Maintenance Labor | monthly | $250 | | Net electric power (kW) | 60 |
| Maintenance/Spares Costs | monthly | $100 | | Percent biochar | 30.00% |
| Insurance | yearly | $500 | | Percent mineral ash | 5.50% |
| Depreciation (for term only) | yearly | $50,000 | | Heat efficiency | 50.00% |
| Opportunity costs - feedstock | per ton | $0 | | Net heat power (kW) | 50 |
| Finance costs | per year | $0 | | CHP efficiency | 74.00% |
| Ash spreading | monthly | $200 | | Lifetime (years) | 20 |
| | | | | Depreciation term (years) | 7 |
| **COST / COST AVOIDANCE** | **BASIS** | **AMOUNT ($)** | | Purchase terms: | cash |
| Electricity | kWh | $0.12 | | Interest rate (if financed) | 6.00% |
| Heat | kWh | $0.025 | | Payments/year (if financed) | 12 |
| Biochar | per ton | $120 | | | |
| Mineral fertilizer | per ton | $40 | | | |
| | | | | | |
| **SAVINGS - DAILY** | **BASIS** | **AMOUNT ($)** | | **SAVINGS - LIFETIME** | **AMOUNT ($)** |
| Electricity | daily | $172.80 | | **Expenses** | **$1,138,500** |
| Heat | daily | $30.00 | | **Savings** | **$2,035,240** |
| Soil augmentation (biochar) | daily | $72.00 | | **Total Net - Lifetime** | **$896,740** |
| Mineral fertilizer | daily | $4.00 | | **Payback time (years)** | 3.96 |
| **Total** | **daily** | **$279** | | **Return on Investment** | **79%** |

$H_2$ GENERATION

STORAGE

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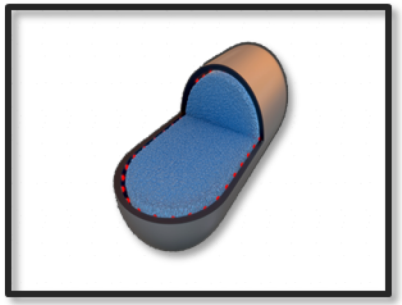

*$H_2$ Storage Vessel*

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# H2US Unique Selling Points

**Low pressure high density storage** of H2 (8 bar; 37g/L)

Low parasitic energy cost of storage (much lower than compressed H2)

Storage density greater than that of liquid H2 (ca. 29g/L)

Rapid refill 5kg H2 in 3.5 min at 8 bar and 200 degrees C

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# H2US Performance Metrics

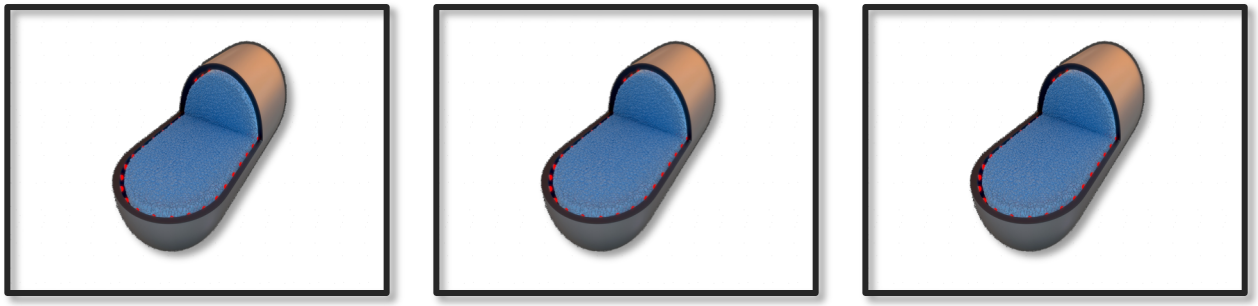
- Gravimetric storage density (system): **5.8%** w/w
- Volumetric storage density (media): **37** g/liter *(700 bar compressed is 24 g/l)*
- Fill **5 kg** in **3.5** minutes with **8** bar at 200 C
- Specific cost (at maturity): **7.72** $/kWh
- Recharge energy (round trip): **2.5** kWh/kg
- Levelized Cost of Storage (system): **80** $/MWh
- Silicon is abundant: **#2** element in Earth's crust
- Patents on hydrogen storage in porous silicon: **4**
- Scales from Smart Dust to Grid Level Storage: **μg→Mg**

**BETTER THAN:**
**Cryogenic Liquid**
**Compressed Gas**
**Any Battery at all**

Funding from the
National Science Foundation

# H2US Finance

| Hydrogen Sponge Storage System Cost Analysis | | | | | |
|---|---|---|---|---|---|
| **EXPENSES - Hydrogen** | **BASIS** | **AMOUNT ($)** | | **ASSUMPTIONS** | **VALUE** |
| H2 Storage System (5 kg) | one-time | $5,352 | | System size (kg) | 25 |
| Hydrogen cost (per kg) | daily | $8 | | FC Energy per kg H2 (kWh) | 15.0 |
| Operator Labor & Fuel | daily | $25 | | FC energy cost (daily - USD) | $200 |
| Installation | one-time | $200 | | FC Energy total (daily - kWh) | 375 |
| Maintenance Labor | yearly | $250 | | Lifetime (years) | 20 |
| Maintenance/Spares Costs | yearly | $100 | | Depreciation term (years) | 7 |
| Depreciation (for term only) | yearly | $11,479 | | Purchase terms: | cash |
| Fuel Cell system | per kW | 2,400 | | | |
| | | | | | |
| **COST AVOIDANCE - Battery** | **BASIS** | **AMOUNT ($)** | | | |
| Electricity | kWh | $0.12 | | | |
| Battery | $/kWh | $1,500 | | **SAVINGS - LIFETIME** | **AMOUNT ($)** |
| Battery Life | years | 4 | | **Expenses ($H_2$ system)** | **$1,628,865** |
| Operator Labor (swapping) | daily | $ 138 | | **Savings (vs. Batteries)** | **$3,191,437** |
| Depreciation (over battery life) | yearly | 140,625 | | **Total Net - Lifetime** | **$1,562,572** |
| Electricity consumption | daily | $45.00 | | | |
| Heat | daily | $0.00 | | **Payback time (years)** | **1.1** |
| **Total** | **daily** | **$45.00** | | **Return on Investment** | **96%** |



Each 5 kg module equivalent to 20 liters petrol

* CAPEX: $1080/kg

* Payback: **1.1 years** at 8$/kg $H_2$, or **0.2** years at 1.12 $/kg (BMSG)

Versus Batteries:

- FASTER
- SMALLER
- CHEAPER
- LONGER LASTING
- RECYCLES
- SAFE

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# Beachhead Markets

## H2US

- Fork lifts
- Service vehicles (airports)
- Drones
- Delivery fleets
- Light-duty cars & trucks

## BMSG

- Warehouse $H_2$ production
- Factory waste-to-energy
- Farm operations
- City landscape collection
- Remote operations

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# THANK YOU

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PRESENTER:

Randall Gatz, Ph.D., Business Development Executive

President: Peter J. Schubert, Ph.D.

# ABSTRACT

Carbon-based waste streams can be converted to pure hydrogen using a new technology suitable for scale at farms or villages. Hydrogen can be stored using a small, low-energy compressor feeding a hydrogen-microporous silicon storage system. It is possible to synthesize microporous silicon hydrogen storage media from the mineral ash residue resulting from gasification of agricultural waste. The overall result is distributed generation and storage of hydrogen using waste materials at low cost. From an input of lignocellulosic biomass of 3.5 MT/day comes a steady stream of 99.999% pure hydrogen at 6 kg/hour at a cost below 2 USD/kg. When stored in solid-state microporous silicon media the system-level specific storage is 5.8 percent with a volumetric density of 39 g/liter, at a cost of 7.72 USD/kWh. When compared to bulk, mature, wholesale prices for hydrogen at 4 USD/kg the capital and operating expense of such a distributed system pays for itself in 4 years. At retail prices for hydrogen, the system is much more attractive economically, and this is the model which is now possible with the combination of hydrogen generation from waste biomass and low-energy storage based on microporous silicon. It is well-known that long-distance transport of biomass to centralized facilities is cost prohibitive, however the technologies introduced herein enable profitable operations at a local scale. When arranged in a corridor along transportation routes where hydrogen fuel is used, or adjacent to facilities using fuel cell materials handling or short-haul commercial vehicles, **local farms and villages can support clean transportation technology from crop waste or landscape trimmings**.

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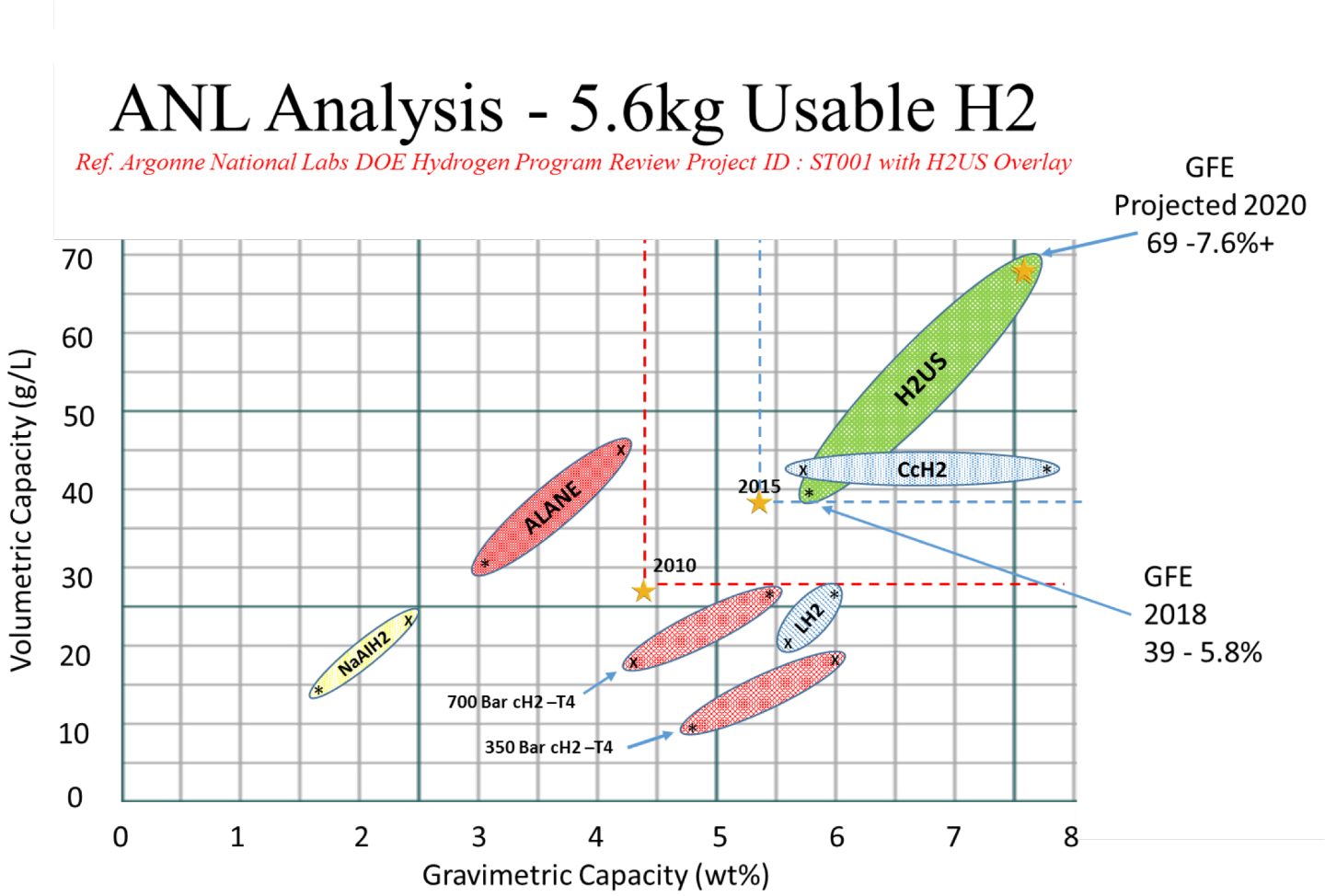

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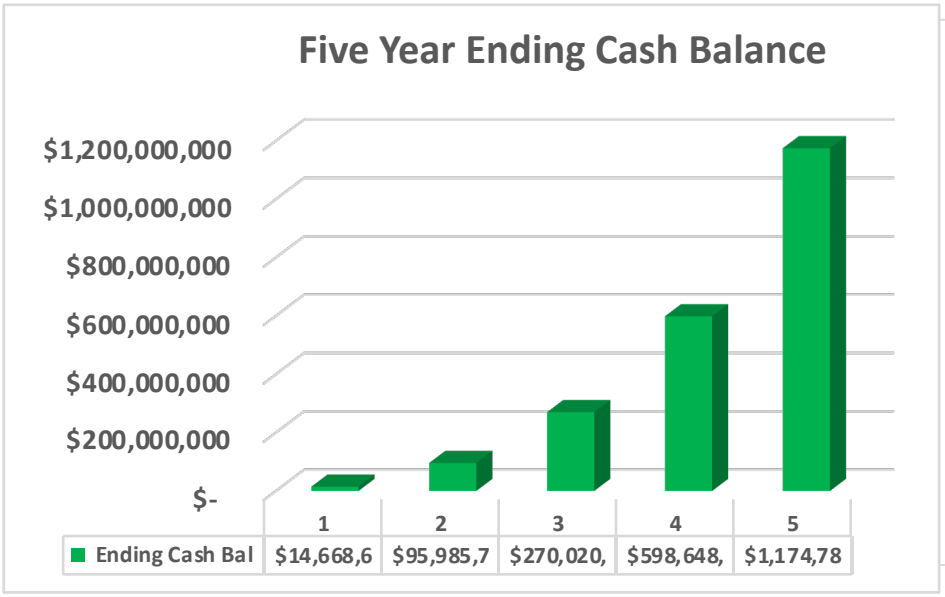
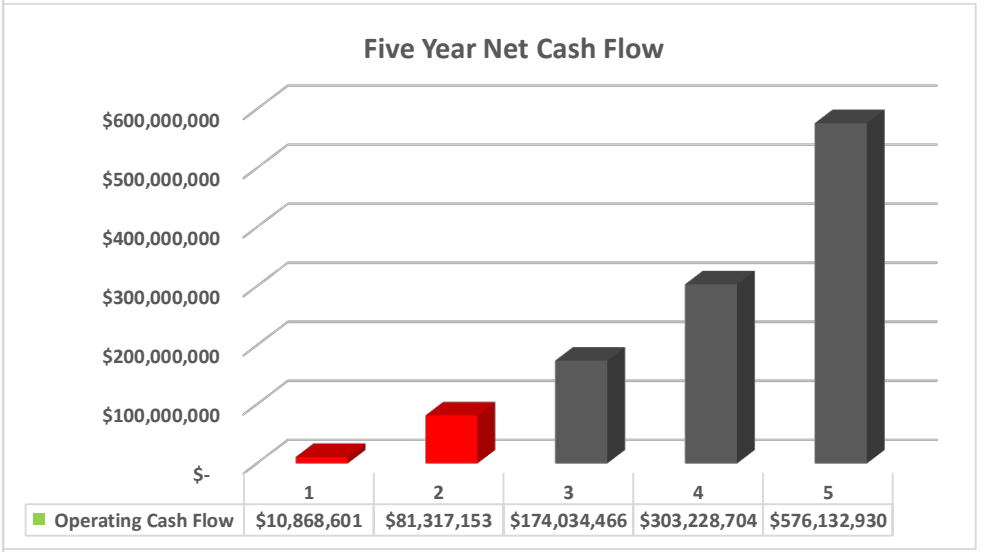
## Five Year Financials

| Five Year CAGR | 112.93% |
|---|---|

| Annual Summary | 2020 | 2021 | 2022 | 2023 | 2024 |
|---|---|---|---|---|---|
| Beginning Cash | $ 50,000 | $ 14,668,601 | $ 95,985,754 | $ 270,020,220 | $ 598,648,924 |
| Revenues | $ 17,450,000 | $ 102,950,000 | $ 217,600,000 | $ 414,900,000 | $ 763,800,000 |
| Expenses | $ 6,581,399 | $ 21,632,847 | $ 43,565,534 | $ 86,271,296 | $ 187,667,070 |
| Operating Cash Flow | $ 10,868,601 | $ 81,317,153 | $ 174,034,466 | $ 303,228,704 | $ 576,132,930 |



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# Potential Challenges

## H2US

- Timid adoption
- Long sales cycles
- Disruptive Regulations
- Battery breakthroughs

## BMSG

- Long Sales Cycles
- Regulatory Changes
- Loss of Tax Credits
- Lower energy cost

# Green Fortress Engineering
## Fund Raising

- Seeking $3,100,000 in equity
  - For commercialization of the H2 Ultra Storage and to complete the beta testing and certifications of the Biomass Super Gasifier
- Pre-money valuation at $6,000,000
  - Based upon the number of patents (9) and patent applications (2) we have, NSF funded work to date on the H2US project, the near market readiness for the BMSG systems, and our revenue projections.
- Additional equity free dollars
  - other grants in 2019 & 2020.

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## COMPETITION

## H2US

Competitive Analysis

| Competitor | Strength | Weakness | GFE Response | Advantage GFE |
|---|---|---|---|---|
| Cella - Alane | • Cartridge based System<br>• Stable with long shelf life | • Co-Combustion with Diesel = carbon emissions<br>• High Pressure<br>• Not rechargeable | GFE's H2US is a low pressure, emissions free solution. Rechargable | ✓ |
| Luxifer Gas Cylinders - G-Stor H2 | • Light Weight for High Pressure system | • High Pressure<br>• Moderate density<br>• Large Foot Print | GFE's H2US is a compact, high density, low pressure solution | ✓ |
| Toyota Miria H2 Storage | • Early adoption<br>• Fixed internal market | • High pressure<br>• Moderate density<br>• Limited application dual tank system<br>• Proprietary | GFE's H2US is a Low pressure, high density, single tank system that can be used in many applications. | ✓ |
| BMW CCH2 | • Stores H2 gas at lower temp at 350 bar.<br>• 50% more H2 storage capacity than typical 700 bar tanks | • High Pressure<br>• Moderate density<br>• Large Foot Print | GFE's H2US is a compact, high density, low pressure solution | ✓ |

## BMSG

Community Power Corp.

All Power Labs

Flux-I Bio-Power