The Blackstone Method: Large-scale green hydrogen production & distribution using the zinc redox pair

Technical summary

June 2020

BLACKSTONE
GREEN ENERGY INC.

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Abstract

Blackstone Green Energy, Inc.[1] ("BGE") has developed two patent-pending[2] technologies (collectively, "Blackstone Method") for emissions-free production and distribution of green hydrogen[3] for as little as $1.00/kg, using zinc ore, zinc powder, and zinc oxide. The Blackstone Method is a combination of solar, chemical, and zinc hydrolysis reactions that split water molecules to produce green hydrogen and zinc oxide, and then dissociating the latter to zinc powder for reuse in multiple production cycles.

By reusing the zinc redox pair, the Blackstone Method allows us to produce green hydrogen:

- inexpensively;
- for a wide variety of industrial uses;
- on a scale required to power vehicles;
- to generate micro-grid, off-grid, and mobile electricity.

The Blackstone Method is projected to produce green hydrogen well below the Department of Energy's recent target Gasoline Gallon Equivalence (GGE) price of $2.68 per/kg, and could remain profitable for as little as $1.00/kg.

Zinc-to-hydrogen production loop

Vaporizing the zinc content in ore together with water in a hydrolysis reactor produces green hydrogen and zinc oxide as a by-product of the water splitting. [4] The zinc redox pair is reused multiple times by dissociating the zinc oxide to elemental zinc powder in a two phase process using heat and bio-mass in a solar powered vacuum furnace at around 1600° C and dissolving any residual zinc oxide in an acidic electro-winning cell depositing zinc powder at the cell's cathode. The zinc powder is reused to produce more green hydrogen.

End of the tube truck

The attrition rate of zinc oxide during dissociation governs the number of reuses of the zinc redox pair. The greater the number of times the redox pair is reused, the greater the amount (and profitability) of green hydrogen produced. Shipping 20 tons of zinc oxide or powder to hydrogen dispensaries is far less expensive than hydrogen delivery by tube-truck due to DOT weight restrictions of 3700 lbs. of hydrogen per truckload. For example, reuse of the zinc redox pair ten times for hydrogen production produces 35 times more green hydrogen per truckload than can be delivered by tube truck.

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[1] Blackstone Green Energy, Inc. is an Idaho corporation formed July 8, 2016. BGE is a wholly owned subsidiary of Blackstone Mining Company, Ltd., is an Idaho corporation (DUNS 065842765), originally organized in 1899 and reincorporated as successor-in-interest in 1987. The company was initially founded by former Idaho Governor James H. Hawley.

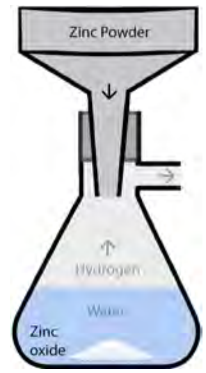
[2] J. Hawley, for Blackstone Green Energy, Inc. (2020), *Solar-hydrolytic method for on-site production, distribution, and storage of green hydrogen fuel, zinc powder, and zinc oxide using carbon-neutral technology*. United States Patent and Trademark Office, Provisional Patent Application File No. 62391773; J. Hawley for Blackstone Green Energy, Inc. (2020), *Method for producing green hydrogen fuel, zinc powder, zinc oxide, polymetallic matte bullion, and potable water from zinc ore.* United States Patent and Trademark Office, Provisional Patent Application File No. 62920870.

[3] Green hydrogen refers to hydrogen produced by zero-emission, carbon-neutral energy sources. Since the Blackstone Method produces hydrogen by using concentrated solar power to perform zinc hydrolysis (i.e., water splitting), the method is considered a green technology.

[4] See patent drawings, pp. 7-10.

The Blackstone Method also reduces the capital and operating costs of hydrogen dispensaries by eliminating the cost of electricity used to power hydrogen electrolyzers where 4.5 units of electrical energy is required to produce 1 unit of hydrogen. The same holds true for solar and wind power, the latter being the least efficient due to down time and transmission losses to the power grid. In contrast the Blackstone zinc redox pair can be reused multiple times dramatically reducing the cost of hydrogen production.

Zinc Hydrolysis



The science of zinc hydrolysis

The Blackstone Method is based on the scientific principles of water splitting well known for more than 100 years. In 2005, scientists from the European Union and Israel developed the "SOLZINC" method for storing solar energy in zinc oxide and dissociating it to zinc powder to produce hydrogen by hydrolysis at the point-of-use.

In contrast, the Blackstone Method converts zinc-rich ore to green hydrogen producing zinc oxide and polymetallic matte bullion as a by-product of the hydrolysis reaction. The zinc oxide is dissociated to zinc powder at regional centers and shipped to local hydrolysis reactors for production and dispensing of green hydrogen. (USPTO Patent Pending #62391773)

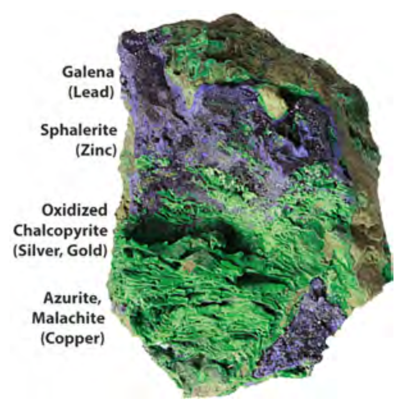
Location Map

Source of zinc ore

BGE's parent company, Blackstone Mining Co., Ltd. ("BMC"), has previously developed about 256,000 tons of hydrogen-compatible, stockpiled, and near surface polymetallic ore containing commercial amounts of zinc, copper, lead, silver, and gold at its Blackstone Mine[5] ("Property") in southwestern Idaho. The Property consists of five federally patented claims (100 acres),[6] which BMC owns in fee simple title. BMC has leased the Property to BGE for purposes of perfecting the Blackstone Method of green hydrogen production.

Hydrogen-compatible ore is defined as containing a minimum 3 percent zinc (60 lbs.) sufficient to generate enough green hydrogen to supply off-grid power for zinc oxide, and matte bullion production at the Property. Matte bullion is an amalgam of copper, lead, silver, and gold the sale of which is expected to offset the cost of green hydrogen and zinc oxide production at the Property and local hydrogen dispensaries.

Blackstone Hydrogen-Compatible Ore



Verification and implementation

The cornerstone of the Blackstone Method is the proven science of water splitting and zinc hydrolysis to produce green hydrogen and zinc oxide. The SOLZINC project proved the viability of commercial use of the zinc redox pair for hydrogen production. BGE plans to build a laboratory scale pilot processing plant to determine optimum time and temperatures for hydrolysis, fuming, and dissociation, the volume of hydrogen, zinc oxide, and matte bullion produced from hydrogen-compatible ore. The results will be used to prosecute the BGE patent pending filings and construct an on-Property facility capable of producing enough zinc oxide to support the green hydrogen distribution example on the next page ("Yuma Center").

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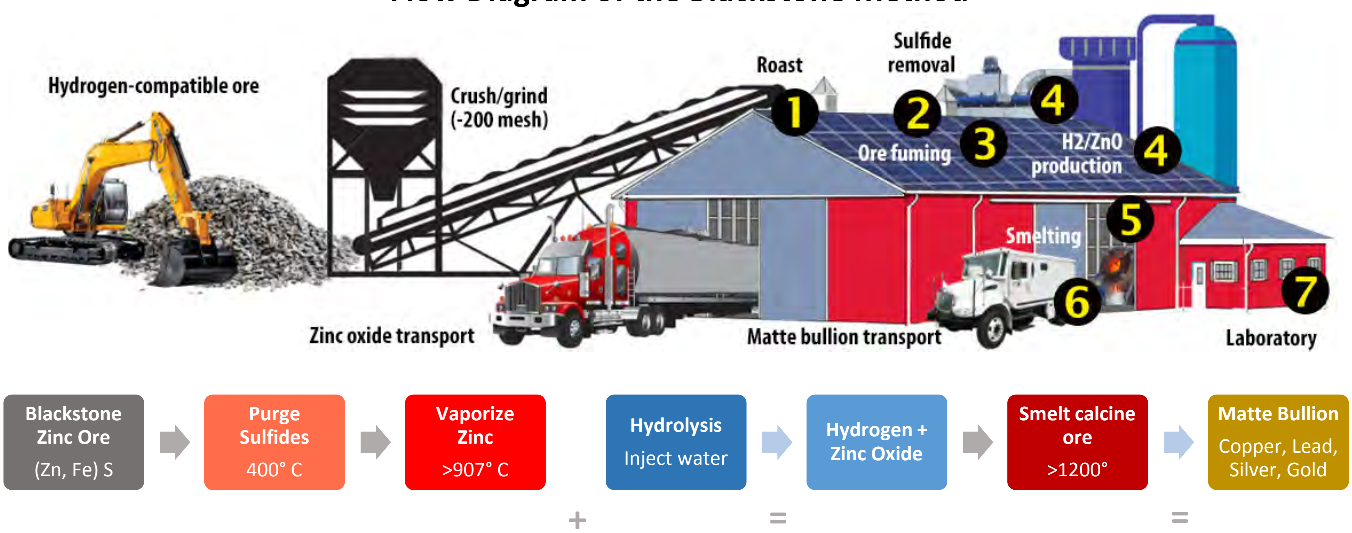
[5] The patented claims are situated in the Bennett Mountains, sections 13, 14, and 15, T.2 S., R.10 E., Boise Meridian, approximately 85 miles southeast of Boise, Idaho. Access is via Elmore county road #68, six miles south of U.S. Highway 20. The claims are designated as the Kentucky, Ohio, Iowa, Illinois, and Oregon Lode Mining Claims (Mineral Survey No. 1662), as described in Book 15 of Patents at page 407, et seq., in the Office of the County Recorder, Elmore County, Idaho. The claims were originally patented in 1903. The Property lies at an elevation of approximately 5,800 feet and extends along the crest of a low granite ridge that rises about 1,000 feet above the Camas Prairie valley to the north. Surface development consists of a 100' x 600' open pit located near the eastern end of the patented claims (private property with mineral and water rights).

[6] Under the *1872 General Mining Act,* a patented claim is one in which the federal government has passed title to the claimant. The patent gives the owner exclusive title to the locatable minerals along with title to the surface. In other words, the patent holder owns the land as well as the minerals on the land and below the surface. A patented mining claim is equal to 20 acres and is granted in perpetuity.

The Blackstone Method: Step by Step

1. Finely ground hydrogen-compatible zinc ore (-200 mesh) is roasted at a temperature above 400° C in a closed circuit rotary kiln to remove the sulfur content of the polymetallic ore.
2. The fumes are evacuated to a calcium oxide (lime) scrubber and converted to calcium sulfate as fertilizer or sulfuric acid for digesting zinc oxide not dissociated by heat.
3. The roasted ore is then fired in a two-stage, graphite-lined electric kiln powered by a hydrogen-fueled, three-phase generator at temperatures equal to or above 907° C, the point at which zinc boils.
4. The zinc vapors collect in a pneumatic-filtered hydrolysis reactor (similar to a bag house) where they are mixed with water, liberating the hydrogen molecule and creating zinc oxide as a by-product of the exothermic reaction. The hydrogen is used at the Property to supply off-grid power.
5. Following the hydrolysis reaction sodium carbonate and borax glass are added to the ore (calcine) and the kiln temperature raised to above 1200° C. melting the mixture.
6. The molten mass is tapped from the kiln and poured into molds as polymetallic matte bullion composed of commercial amounts of primarily copper, lead, silver, and gold.
7. The slag (borax glass) is analyzed for residual high temperature metals content and reprocessed for additional values or recycled as an aggregate for construction materials.

Flow Diagram of the Blackstone Method



Blackstone Method economics

The price of zinc oxide and powder drive the cost of green hydrogen production by hydrolysis. Using the Blackstone Method the zinc redox pair is essentially free, the cost offset by the sale of matte bullion from processing hydrogen-compatible ore at the Property. BGE's two patents-pending technologies detail the production and distribution of zinc oxide and powder using regional centers for the dissociation of zinc oxide to elemental zinc powder and distributing the latter to local dispensaries for on-site green hydrogen production. Dispensaries return the zinc oxide produced by their on-site reactors to the regional center for dissociation to zinc powder, and the production-distribution cycle is repeated.

The Blackstone Method divides green hydrogen production and distribution into three segments. The first is the shipping of zinc oxide produced at the Blackstone Property to a regional center for dissociation to zinc powder. The second is distribution of the zinc powder to local hydrogen dispensaries. The last phase is the return of zinc oxide from local hydrolysis reactors to the regional center for dissociation to zinc powder. The zinc powder is then reshipped to the dispensaries to complete the production-distribution loop (see "Yuma Center" example).

Yuma Center production loop
The example assumes 23 hydrogen dispensaries, each with its own hydrolysis reactor for producing green hydrogen on site. Zinc powder is transported from a central dissociation center to local dispensaries for on-site hydrogen production. The zinc oxide by-product is returned to the regional center for dissociation to zinc powder which is returned to the local stations to complete the green hydrogen production loop.

Both zinc powder, and zinc oxide can be shipped in bulk (up to 40,000 lbs.) to and from local hydrogen dispensaries and the dissociation center by common carrier with no restrictions other than weight as opposed to hydrogen tube-trucks which are restricted by law to 3,700 lbs. of hydrogen on US highways. Forty thousand pounds of zinc powder will produce about 5,700 kg of green hydrogen or if the zinc redox pair is reused ten times 57,000 kg.

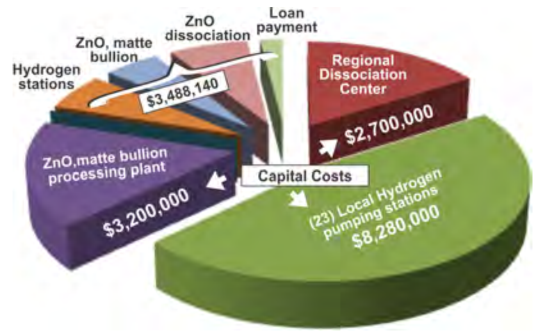
Yuma Dissociation Center

Yuma Center components
A regional dissociation center's basic components include a 1000 kW solar array with three-phase power inverters, eight vacuum furnaces with electro-winning cells, zinc oxide storage, zinc powder storage, and a stand-by hydrolysis reactor for fueling backup hydrogen powered electrical generators. Components for local stations include an on-site hydrolysis reactor, type 4 storage tank, hydrogen dispensing system, hydrogen fueled standby electrical generator, and material handling equipment for the zinc redox pair. About 3.2 kg of zinc powder will yield 1 kg of hydrogen from a hydrolysis reaction or 1,280 kg of zinc powder will produce about 400 kg of green hydrogen per station or 2,800 kg if the zinc redox pair is reused ten times. Reuse of the redox pair is governed by attrition from materials handling and incomplete zinc oxide dissociation reactions typically about 8 percent per cycle using solar thermal heat. Digesting unconverted zinc oxide in acidic electro-winning cells is expected to reduce zinc oxide dissociation losses to under 2 percent per production loop.

Distributed energy resources
In addition to commercial use, the Blackstone Method can provide green hydrogen fuel for micro-grids, mobile power systems, and off-grid generators by scaling on-site zinc hydrolysis reactors to the amount of hydrogen needed. The Blackstone Method has the potential to replace fossil fuel use with locally produced green hydrogen at a significantly less cost than natural gas steam reformation (brown hydrogen) or electrolysis, resulting in pollution free generation of electrical energy for a variety of power grids and a reduction in utility costs plus the ability to provide electricity for off-grid communities or anywhere power is unavailable.

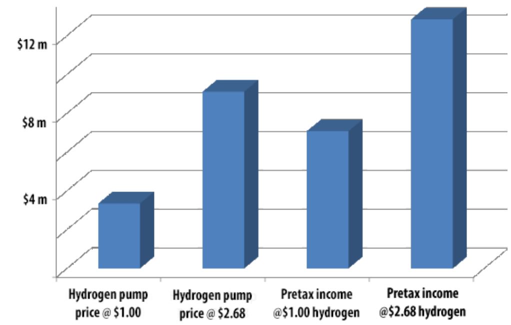
The metallic silver by-product is a core element for the manufacture of solar panels, being the highest electrical and thermal conductor of all metals. It is heavily used in solar panels (typically 20 grams per panel) or about 6 percent of a panel's cost. Copper is used five times more in renewable energy systems than in traditional power generation. Rather than selling the Blackstone copper matte bullion to refiners at an approximate 15 percent to 25 percent discount to market it may be prove to be more cost-effective to market the bars directly to green energy equipment manufacturers.

Chart 1: Pro Forma Operating Expenses



Zinc oxide and copper matte bullion produced at the Blackstone Property are the base components for the cost effective manufacturing of green hydrogen. Chart 1 shows pro forma operations using the Yuma Center example. Chart 2 compares estimated pretax income based on the sale of green hydrogen at $1.00/kg and $2.68/kg. The latter is a recent Department of Energy Gasoline Gallon Equivalence (GGE) target price for hydrogen.

Chart 2: Pretax Income Projections

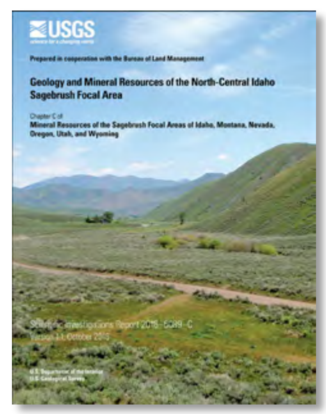


Blackstone hydrogen-compatible ore

The Blackstone complex was named for the black sphalerite mineralization (zinc sulfide) that apexes along a 1.5 mile east/west strike line delineating at a polymetallic ore body, 60' to 180' wide at the surface, consisting primarily of zinc, copper, lead, manganese, silver, and gold.

Numerous geological studies of the Blackstone, most recently by the USGS,[7] trace the origins of the ore deposit to intrusions from the Idaho batholith, a massive granitic chamber about 1.5 miles below the surface. Exploratory drilling, mining, magnetometer surveys, microscopic thin sections, and geochemical analysis indicate an extensive ore body at the Property, extending into the batholith with polymetallic ore values increasing with depth.[8]

USGS Report



Only a fraction of the Blackstone ore body has been explored and mapped. As of June 2020, the stockpiled, near-surface proven, and probable reserves [9] equaled about 256,000 tons of hydrogen-compatible polymetallic ore averaging 8.5 percent zinc (170 lbs/ton), 4.5 percent copper (90 lbs/ton), 23 ozs/ton silver, .106 ozs/ton gold and 1.5 percent lead (30 lbs/ton).

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[7] U.S. Department of the Interior, U.S. Geological Survey (2016), "Geology and Mineral Resources of the North-Central Idaho Sagebrush Focal Area," in *Mineral Resources of the Sagebrush Focal Areas of Idaho, Montana, Nevada, Oregon, Utah, and Wyoming*, Scientific Investigations Report 2016-5089-C.

[8] Robert Bell (1930), "Another Butte in Southern Idaho?" *Northwest Mining Truth;* Frank Johnesse (1932), *Report on the Revenue Group of Lode Mining Claims in the Volcano Mining District, Elmore County, Idaho* (Research report); Rhesa Allen (1940), *Geology and ore deposits of the Volcano district, Elmore County, Idaho* (M.S. thesis); Rhesa Allen (1952), "Geology and mineralization of the Volcano District, Elmore County, Idaho," *Economic Geology;* Richard DeLong (1986), *Geology of the Hall Gulch plutonic property, Elmore and Camas Counties, Idaho* (M.S. thesis); Earl Bennett (2001), *The geology and mineral deposits of part of the western half of the Hailey 1°×2° Quadrangle, Idaho,* U.S. Geological Survey Bulletin 2064-W.

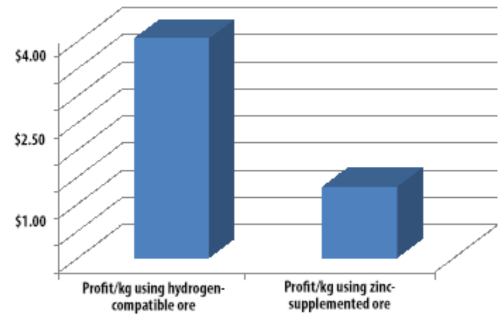
[9] Richard Kucera, Ph.D. and Andrew Egan, B.Sc. (2015), *Certification of Proven Ore Reserve Values: Blackstone Mine Project, Elmore County, Idaho.* Based on the results of exploratory drilling, the Property contains 35,500 tons of proven reserves valued at $214.8 million at 2015 metals prices and 186,000 tons of probable reserves of a similar grade adjacent to the proven ore block. Consistent with the guidelines set forth in *SEC Industry Guide 7,* probable reserves were not valued in the certification. The Property also contains an additional 3.2 million tons of probable reserves approximately 1,600 feet west of the proven block. To date, less than one percent of the Property has been explored.

A minimum of 3 percent zinc content is required for processing hydrogen-compatible ore. Less than that amount will produce insufficient hydrogen for off-grid electrical power at the Blackstone.

Supplementing zinc ore

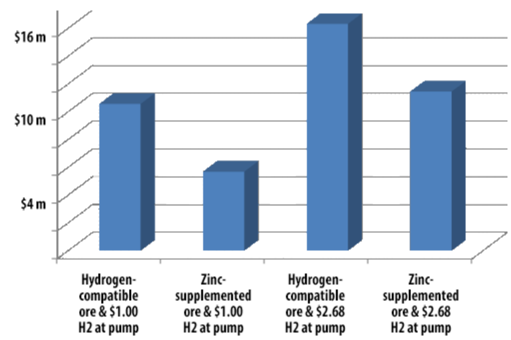
In the unlikely event there is insufficient hydrogen-compatible ore to support commercial production of hydrogen and zinc oxide at the Property, BGE would purchase zinc from the commodities and scrap markets to supplement the 3.7 million tons of proven and probable lower-grade reserve ores. These contain a minimum of 10 lbs. zinc, 5 lbs. lead, 4 lbs. copper, 2.11 oz. silver, and .078 oz. gold. At recent commodities prices, a ton of the lower-grade ore has a value of about $240 assuming the zinc is marketed as zinc oxide.

Chart 3: Matte Bullion Values



Purchasing zinc to supplement the amount in the lower grade ore increases the cost of zinc oxide production at the Blackstone by reducing the revenue from matte bullion sales. Chart 3 sets forth the estimated matte bullion value difference between hydrogen-compatible ore and zinc supplemented lower grade ore. Chart 4 sets forth gross income for the Yuma Center example using hydrogen-compatible and zinc supplemented matte bullion where green hydrogen retails for $1.00/kg or $2.68/kg.

Chart 4: Projected Gross Income



Property life

The approximate 256,000 tons of hydrogen-compatible ore at the Property is projected to support green hydrogen production for the 23 dispensing stations in the Yuma Center example for 18 years. The volume of the lower grade ore would provide hydrogen production indefinitely, though not as profitable.

Based on the width, length, projected depth, and the metallic composition of the reserve ore the Property could contain as much as 500 million tons of hydrogen-compatible ore. If true, the complex contains enough zinc to supply zinc oxide for multiple dissociation centers and hydrogen dispensing stations well into the foreseeable future.

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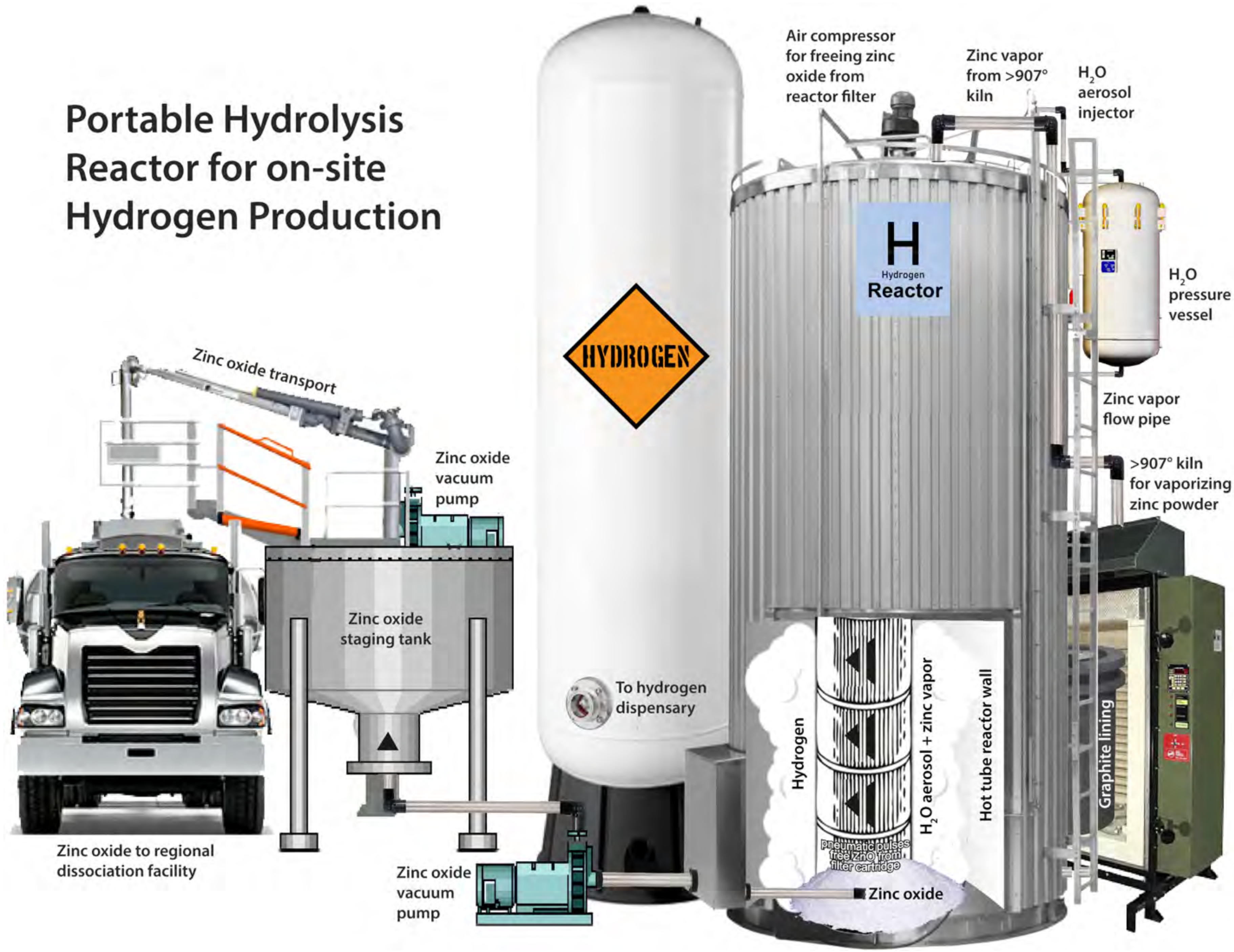
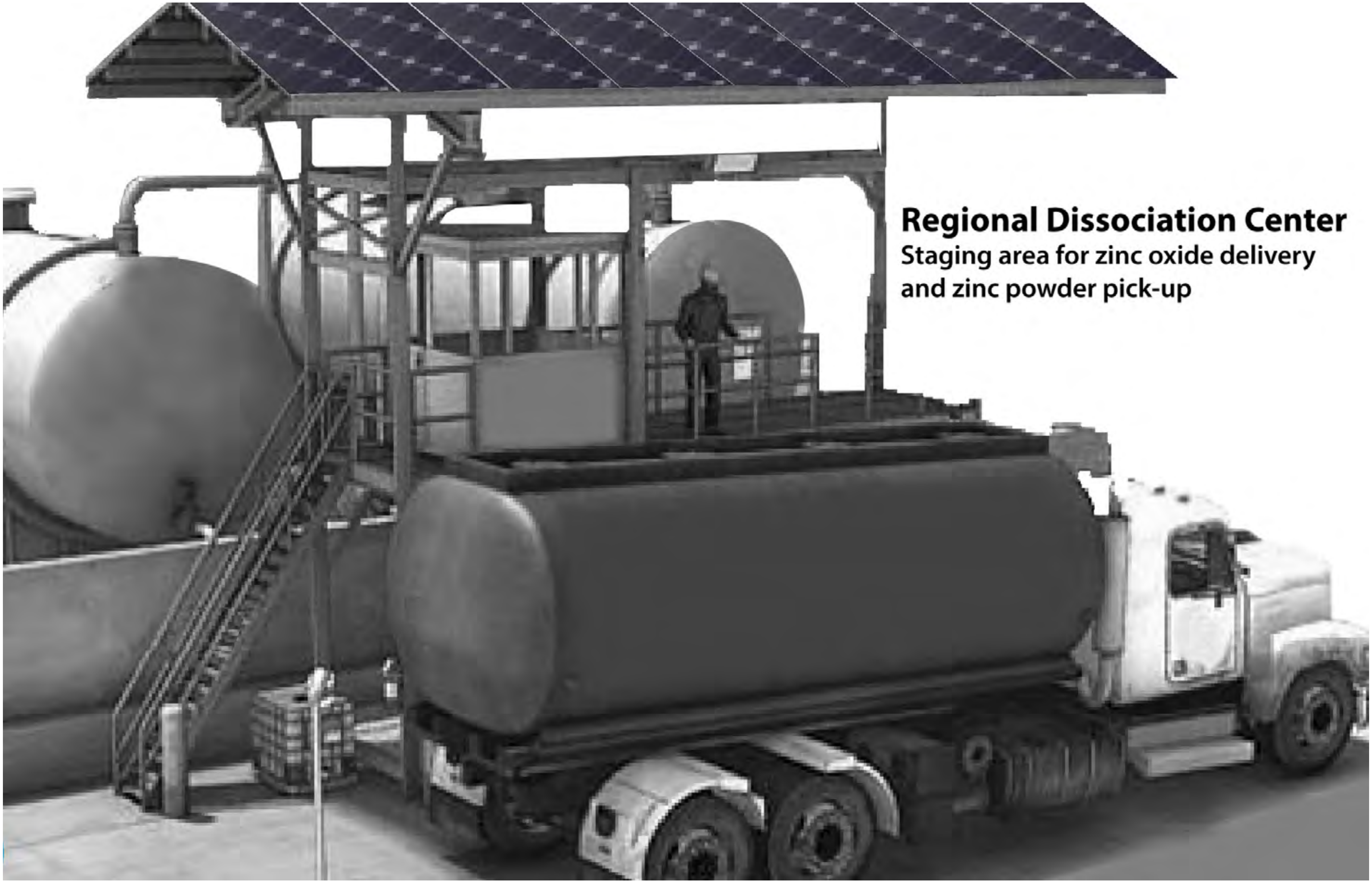
Portable Hydrolysis Reactor for on-site Hydrogen Production





Regional Dissociation Center

Staging area for zinc oxide delivery and zinc powder pick-up


>1300° to 1800° hot Wal Solar or electrical receiver reactor for dissociating zinc oxide to elemental zinc powder (biomass required at lower temperatures)
Zinc oxide from staging area
Solar array converted to 3-phase electrical current (approx. 60 kWh)
>2000° vacuum furnace for dissociating zinc oxide to zinc powder
Type 1 Reactor
Zinc oxide reactor loading bins
Type 2 Reactor
Regional Dissociation Center

Blackstone Method Production & Delivery Cycle