Dynamic Combustion Chamber

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Dynamic Combustion Chamber™

A HYDROGEN TECHNOLOGIES, LLC. PRODUCT

EXECUTIVE SUMMARY

There are two fundamental issues with traditional fossil-fuel boiler systems used in commercial, industrial, and power end-markets (“CI&P”). First, the greenhouse gases (“GHG” such as CO2, NOx, and SOx) from these coal, natural gas, diesel, and oil-fired systems contribute heavily to the world’s ever increasing GHG emissions profile. And second, the current installed base of CI&P boilers are largely aged and inefficient — with efficiencies as low as 50% on 40+ year old equipment. Meanwhile, new product offerings fail to fully address the inherent inefficiencies, cost and emissions related issues.

We developed the DCC™ from a clean sheet of paper to be the boiler of the future. It maximizes thermal efficiency, minimizes operating headaches, and emits absolutely no greenhouse gases or other pollutants.

By combining pure hydrogen and oxygen gas in an exothermic reaction, the DCC™ achieves previously unattainable fuel efficiencies greater than 95%. It is a closed loop fuel system (when using an electrolyzer) with no smokestack that is free of all current air and emission regulations.

This adds up to a boiler that produces high quality process steam at prices that already compete with best-in-class natural gas boilers. We make no assumptions of speculative future technology which may or may not become reality. This white paper was written to give customers and partners of Hydrogen Technologies, LLC (HT) a look behind the curtain at the first-principles physics that govern the DCC™’s performance, and the economics it enables.

PROBLEM:

GHG Emissions

Are boiler emissions really a big-picture climate change risk?

Burning coal, natural gas, diesel or fuel oil for everyday thermal needs (hot water, space heating, industrial steam, and power processes) accounts for over 20% of all global greenhouse gases emitted each year. As developed economies and industrial geographies like India, China and Southeast Asia grow, there will be an ever-increasing call on fossil fuel-based boilers. Meanwhile, the underlying CI&P boiler market is slated to grow between 5-7% per annum over the next 10 years. Despite net zero sustainability goals for global political bodies, Fortune 1000 corporations, and asset managers alike, little progress has been made in solving the issues of GHG emissions related to our thermal energy needs.

Steam is a pervasive energy medium in Commercial & Industrial applications (not to mention electricity production). US industry burns, 37% of the fossil fuels burned by industry alone are burned to produce steam. All major industrial energy users devote significant proportions of their fossil fuel consumption to steam production: 57% for Food Processing, 81% for Pulp & Paper, 42% for Chemicals, and 23% for Petroleum Refining. Eliminating emissions related to our thermal energy needs is critical to our global net zero goals. For example: a single 1Mwe (6T/hr) coal-fired boiler (running at 100% capacity) produces the same emissions as 5,000 passenger vehicles per year.

PROBLEM: Efficiency

What limits the efficiency of conventional boiler systems?

The problems related to fossil-fuel powered boilers are release of harmful GHG emissions, inefficient energy conversion in the form of waste heat and gas, and an increase in total cost of operation over time.

In addition to fossil fuel-based boilers, the market has produced alternative low or zero emission boilers. However, these alternatives (like 'Hydrogen-Ready' boilers and Electric Boilers) are fraught with their own challenges around reliability, O&M cost, total cost of ownership and overall emissions profile.

Most natural gas boilers can already accept a fuel mix up to 20% pure hydrogen. Further, many large boiler manufacturers are marketing dual-fuel or 100% hydrogen boilers for residential and limited commercial applications. All these designs burn hydrogen in the presence of air, which generates emissions requiring ventilation via a smokestack. The existence of this smokestack is responsible for efficiency losses and GHG emissions which cannot be designed around.

Smokestacks can also be eliminated with electric boilers, but there are some fundamental issues with this approach. These include but are not limited to:

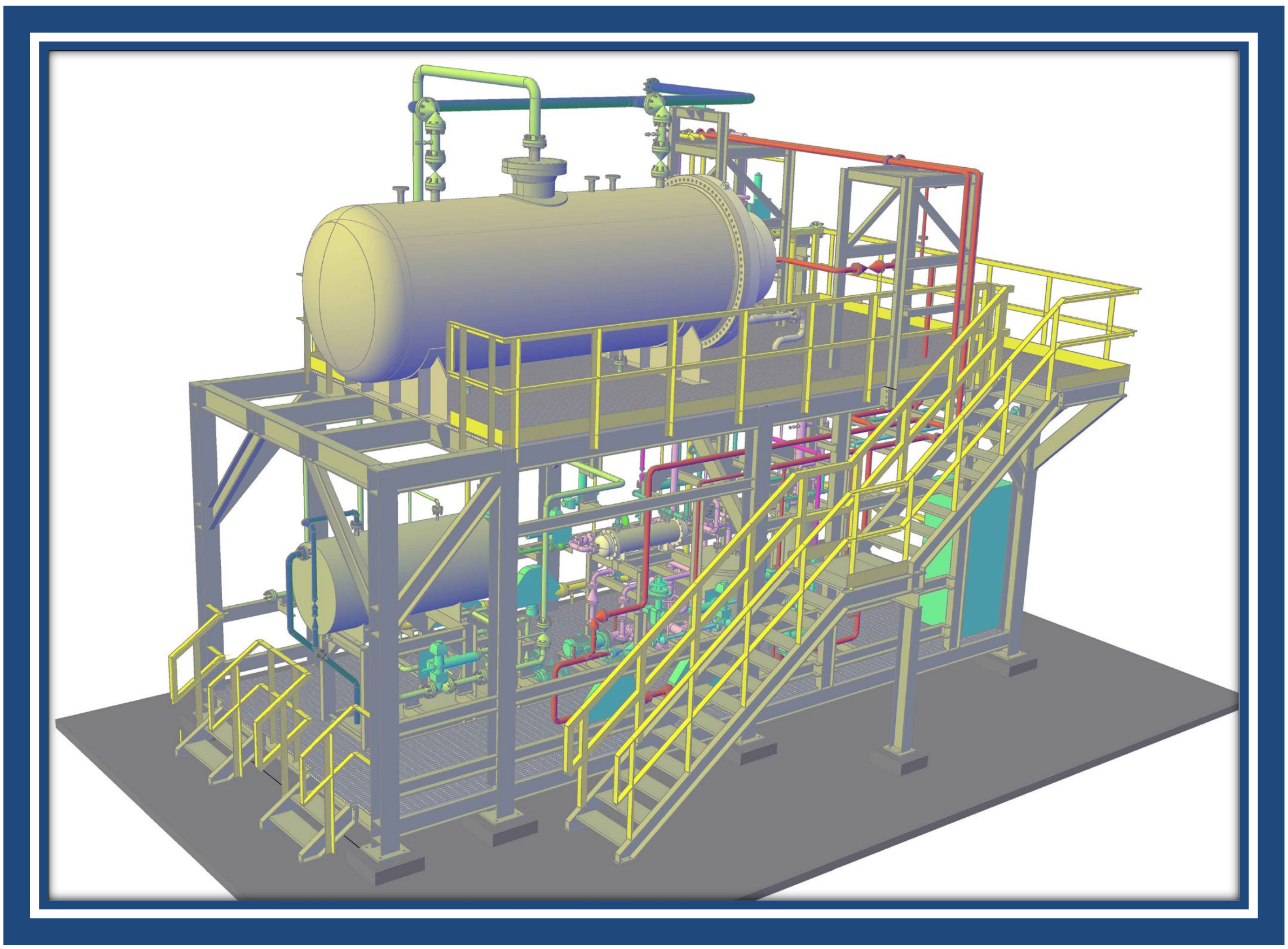
1) Addition of high-output transformers
2) Fouling of internal electrical components
3) Process water purity
4) Peak power requirements & peak demand charges

Even in hydrogen-ready or very efficient natural gas boilers, fuel is combined with outside air, necessitating a smokestack. That smokestack has a fundamental negative effect on efficiency.

SOLUTION:

The clean H_2 steam DCC™ boiler is a unique zero-emissions hydrogen boiler — a bold step in the evolution of hydrogen technology.

The Dynamic Combustion Chamber (DCC™) is the only zero-emissions hydrogen boiler. This design produces clean process steam without generating any air pollutants. It does not require a smokestack or any energy-dissipating exhaust system. It is greater than 20% more efficient in fuel usage than most currently deployed steam boilers.



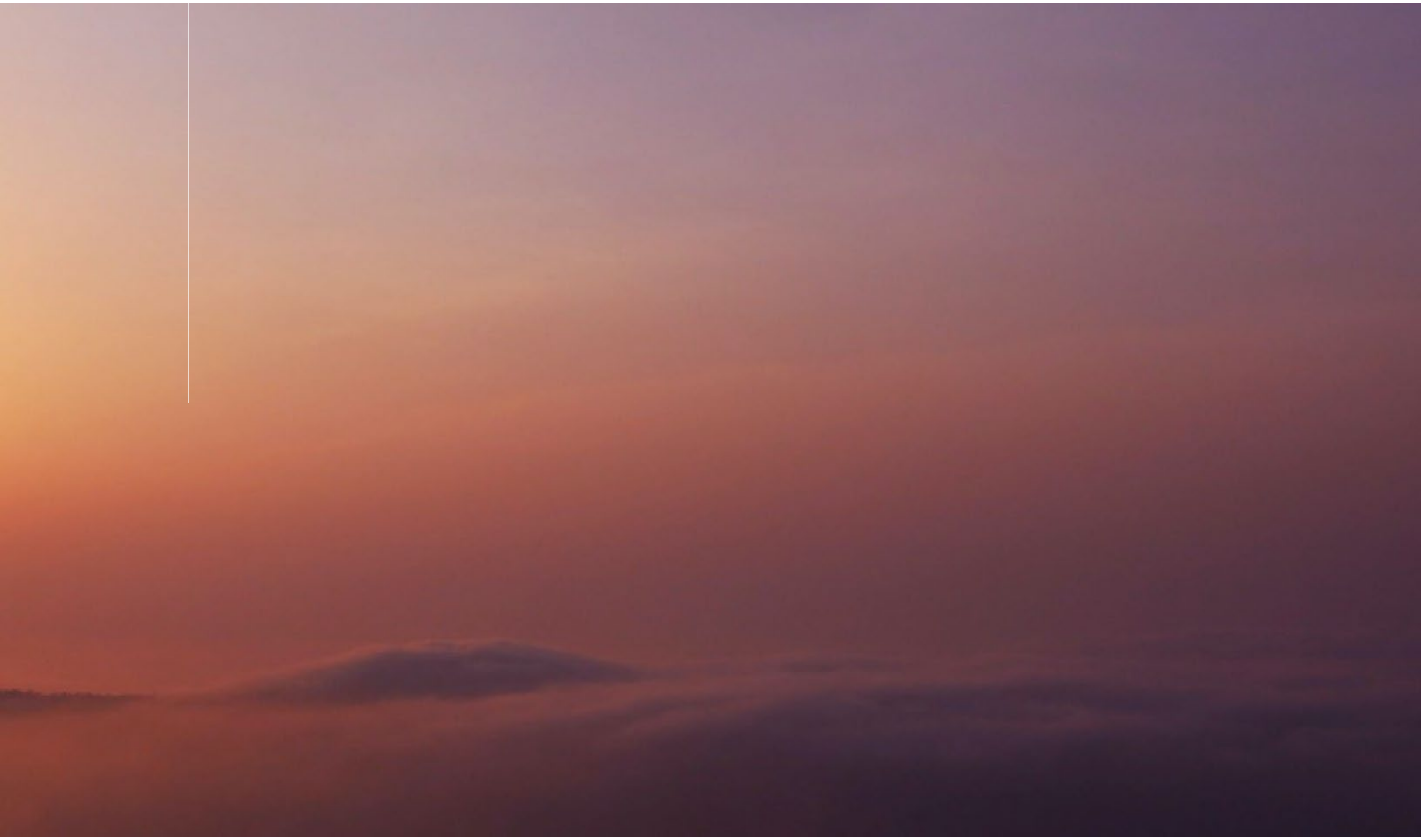
WHAT IS THE PROCESS?

The DCC™ is the most efficient way to use hydrogen to create high-temperature steam or hot water.

The DCC is designed to burn essentially pure hydrogen in oxygen, to create super heated steam in the burner section. The superheated steam then enters the heat exchange section transferring its energy to the shell side process water.

Unlike conventional boilers, the DCC™ does not use atmospheric air for combustion. Without atmospheric air and carbon combustion, the system is free of CO_2, N_2, CO, SO_x, NO_x, etc. and thus needs no flue stack.In fact, the combustion water is condensed and either recovered for re-use or sent to a drain.

The purity of the DCC™ combustion steam greatly enhances the post-boiler heat recovery via feed water pre-heating. This is because pure steam has a higher dew point than water vapor diluted by incondensable gases such as N_2 and excess O_2. In condensing air-fired boilers, there may be water disposal issues due to the dissolved CO_2, NO_x, SO_x, and even particulate matt-er originating in the combustion air.



APPLICATIONS

High quality clean process steam is largely consumed and utilized in Commercial, Industrial and Power applications. Commercial applications and markets are primarily focused on steam boilers for space heat, hot water, and Combined Heat & Power applications. Industrial applications are primarily focused on high-quality process steam related to Food and Beverage, Chemical & Petrochemical, Textiles, Pulp & Paper, Metals & Mining industries as well as other large consumers of heat and steam. For example, steam and hot water play an integral role in Food and Beverage processing including sterilization, disinfecting, pasteurization, reducing microbiological bacteria, cooking, curing and drying.

Within the Power and Utility space, the DCC™ can be combined with a turbine genset for power generation or Combined Heat and Power applications. It can also be used as part of a building or district energy system. Combined with electrolysis, hydrogen storage, and a turbine, the DCC™ can have significant advantages over other energy generation alternatives. Hydrogen's ability to be a store of energy and be separate (via storage) from the DCC™ system allows customers to take advantage of favorable power pricing during off-peak hours or when renewable power sources generate excess power supply to produce the hydrogen and oxygen input fuel.

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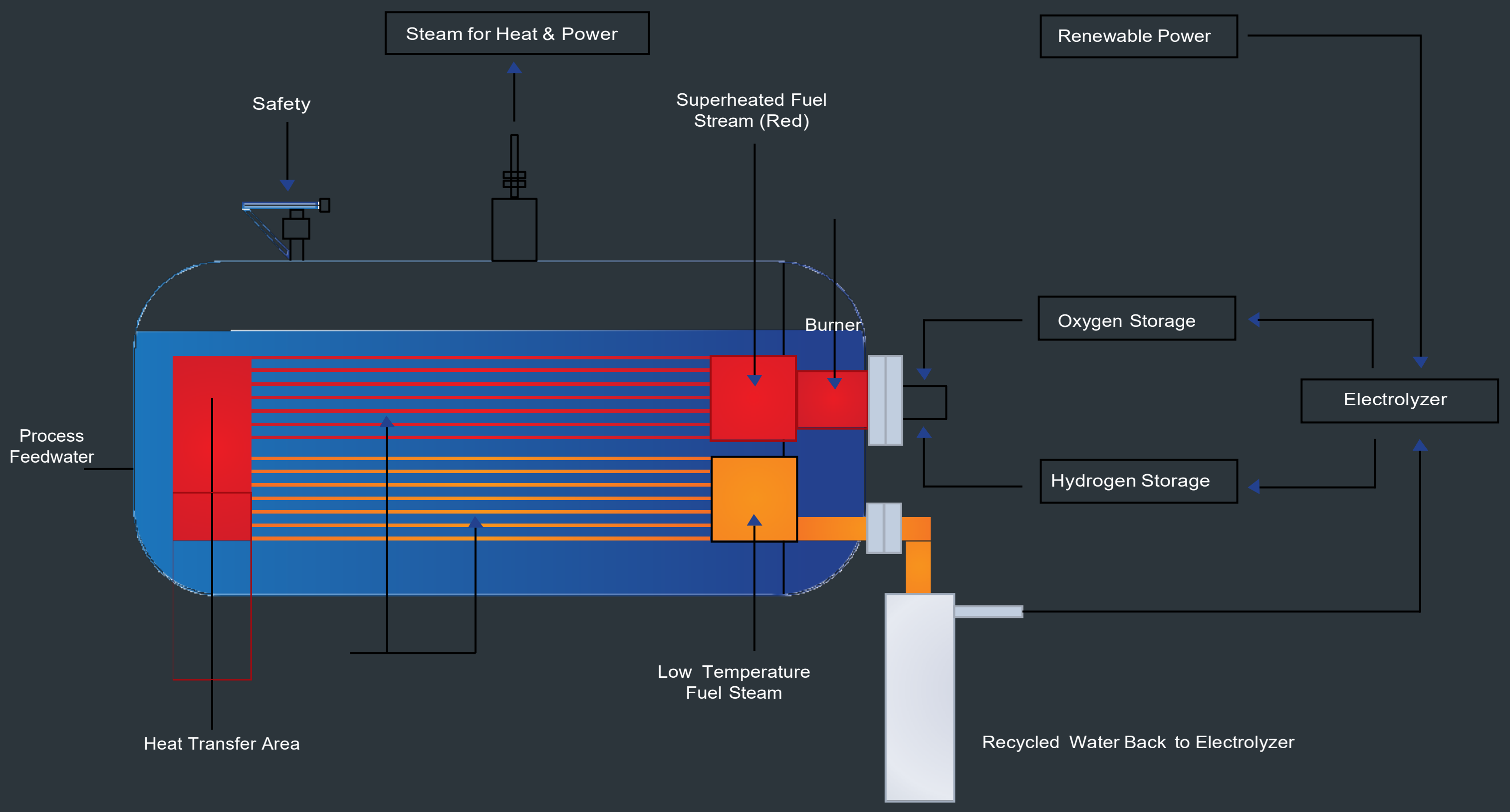
A Schematic of the Dynamic Combustion Chamber™



SIZING, INPUTS, AND OUTPUTS

The DCC™ comes in three sizes.

For larger steam or power applications, the DCC™ can be set in series or customized for larger output.

1) DCC™ 3000

a) 26'11" L x 18'6" W x 25'1" H footprint

b) Produces 3,000 kg/hr steam

- i) Utilization Horsepower: 265hp
- ii) Heat Output: 8.9 MMBtu/hr
- iii) Steam Output: 6,600 lb/hr steam

c) Consumes ~ 62 kg/hr Hydrogen

d) Outlet Pressure: 165 PSIG

2) DCC™ 6000

a) 26'11" L x 20'0" W x 25'7" H footprint

b) Produces 6,000 kg/hr steam

- i) Utilization Horsepower: 530hp
- ii) Heat Output: 17.8 MMBtu/hr
- iii) Steam Output: 13,200 lb/hr steam

c) Consumes ~ 123 kg/hr Hydrogen

d) Outlet Pressure: 165 PSIG

3) DCC™ 28000 *

a) TBD footprint

b) Produces 28,182 kg/hr steam

- i) Utilization Horsepower: 2,500hp
- ii) Heat Output: 83.1 MMBtu/hr
- iii) Steam Output: 66,000 lb/hr steam

c) Consumes ~ 615 kg/hr Hydrogen

d) Outlet Pressure: 600 PSIG

* Available 4th Q 2022.

COMPETITIVE LANDSCAPE

We've established that there are no zero-emissions Hydrogen boilers besides HT's DCC™ However, the DCC™ exists in the broader context of fossil fuel boilers and non-Hydrogen zero-emissions technologies. All cost figures in this section are levelized, to provide an even playing field for comparison.

While the DCC™ itself is greater than 95% efficient, it exists in a "Hydrogen Cycle" including an electrolyzer in most applications. This hydrogen cycle is currently 83% efficient but is expected to rise to ~93% efficiency with next-generation electrolyzer technology. Considering large investments in balance-of-plant outside the DCC™, levelized cost of process steam at the IEA standard 6c/kWh is still only $35/k lb of steam produced*. Factors positively influencing this figure include low O&M expenditure, high inherent uptime, and long lifetime of componentry. At 3¢/ kWh, which many industrial power purchase agreements can accommodate, that cost of steam drops to ~$18/k lb.

Coal's resilience as a boiler fuel surprises many outside the industry. Coal boilers aren't inherently efficient or reliable, and they can be subject to heavy carbon taxation. However, the "mine and burn" nature of the fuel enables extremely low variable operating costs. As carbon taxes grow this decade, new coal boiler construction has nearly evaporated in the developed world, and old coal boilers will increasingly be converted to run natural gas or get decommissioned entirely. As it relates to the DCC™, the equation governing replacement is a function of emissions regulations and lifecycle. An example coal boiler might produce process steam at $12/k lb with $50/ton carbon taxes, but that cost skyrockets to skyrockets to $26/k lb with Canada's new $133 tax. This assumes that the given regulatory body hasn't mandated they be decommissioned by a certain date and/or even allows for the installation of a new coal fueled boiler system.

Natural Gas Boilers afford a 25% reduction in greenhouse gas emissions while still ingesting a "zero-process" fuel like coal, and are the current industry standard.

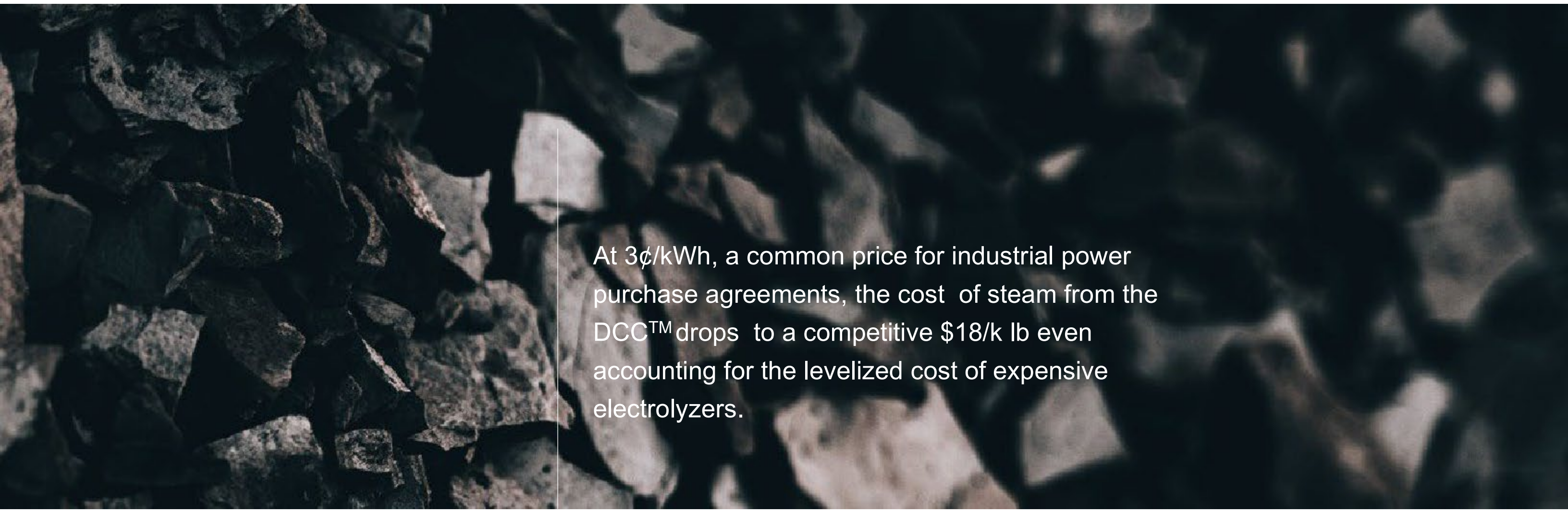
https://www.energy.gov/sites/prod/files/2014/05/f15/tech_brief_true_cost.pdf

In particularly strict air districts, NOx emissions standards have been temporarily circumvented by running multiple sub-50hp boilers in series. At a $50/ton carbon tax, best-in-class natural gas boilers can make a pound of process steam at $16/k lb. At $133/ton, that cost rises to almost $25/k lb in parity with current zero- emissions steam from the DCC™. This too assumes a continued allowance for the use of natural gas, which has already been banned from use by 40 cities and municipalities in California. Seattle, New York, and Denver have banned it in new building construction.

Electric boilers at the megawatt scale exist, but are so fraught with operational issues that they are not considered feasible by the majority of the industrial market. The first problem to overcome is the demand charges, grid service fees, and even availability of high-voltage hookups for the transformers required at this scale. If installation is possible, the primary operational concern is the fouling of internal electrical components which shortens service life. To prevent this, water purity must be upgraded and constantly monitored. Even so, periodic de-scaling of the boiler will be required, reducing uptime. Finally, there is no ability outside of massive lithium-ion batteries to de-couple an electric boiler from the whims of electric utility pricing. Beyond pricing, simple availability of peak power may result in untenable demand charges.

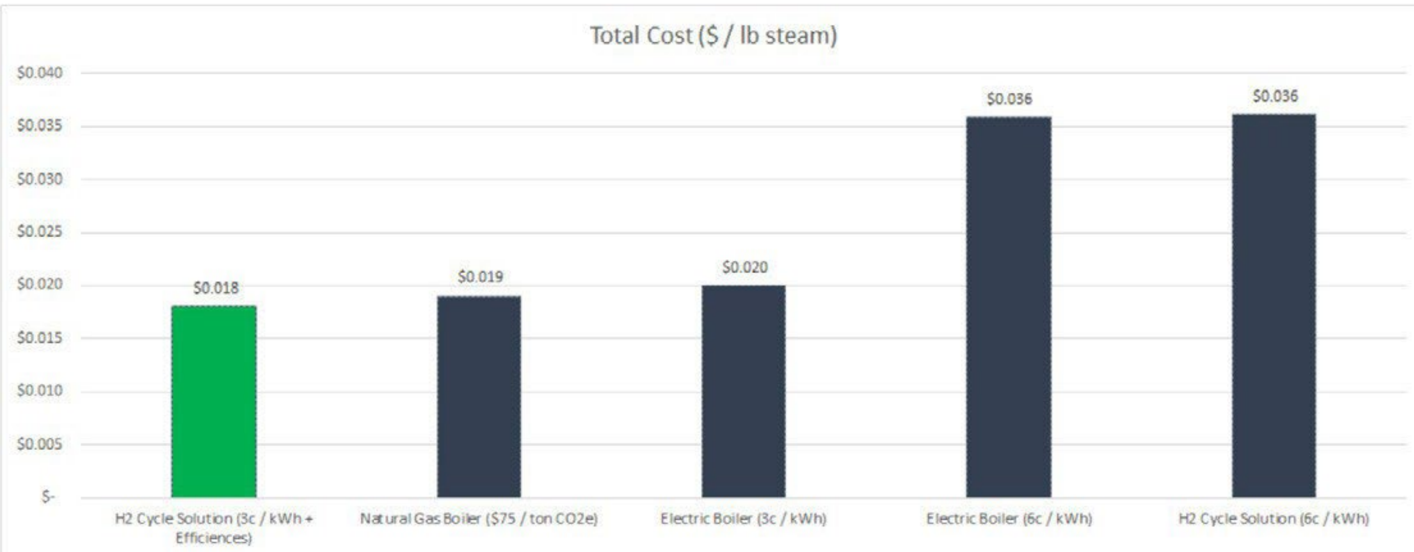
Biomass boilers are very interesting for the right geographic location and set of customer priorities. So long as carbon taxes are not applied, and NOx/SOx regulations also inapplicable, biomass boilers can make steam cheaply. In some jurisdictions, the growth of trees for biomass is even considered carbon-negative due to the lifetime carbon consumption of those trees. However, carbon emissions accounting for wood biomass remains suspect, as burning biomass emits more CO_2 than fossil fuels per energy unit generated. In these cases, $15/k lb process steam is possible.

However, outside of the pacific Northwest and other highly productive timberlands, accomplishment of less than $100/ton high- quality biomass is not feasible at scale. Furthermore, biomass boiler life is expected to be shorter than a natural gas or DCC™ lifespan. We are confident the DCC™ will have a 25+ year useful life because only the steam produced from the H_2-O_2 exothermic reaction reaches the heat transfer surfaces. In contrast, a biomass boiler life is expected to be only 10-15 years. Given progressive air districts' intolerance of NOx from natural gas boilers, we predict it's only a matter of time before biomass boilers are subject to the same restrictions, introducing expensive taxes or scrubbing equipment.



COMPARITIVE

Boiler Operating Cost Comparison



Note: H_2 Cycle Solution (3¢ / kWh + Efficiencies) accounts for projected at-volume manufacturing deflation and projected efficiency of Electrolyzer technologies.

Boiler Emission Comparison

OPERATION AND REGULATION

The flexibility of steam generator technology has been proven, and its durability tested, for over 200 years.

Steam boilers are known for their ability, with proper maintenance and good chemistry, to perform for decades. In fact, boilers exhibit the longest life cycle of any heat and/or power generating equipment. Utility boilers have been known to operate for more than 50 years.

REGULATORY DRIVERS

Government and corporations alike are driving to reduce GHG emissions. Concerns regarding GHG emissions and their impact on global warming have prompted the introduction of Government regulations and worldwide Inter- Government coordination (COP21).

Fossil fuel boilers are carbon intensive and are nearly ubiquitous in commercial and industrial heating markets where almost 85% of all installed boilers are emitting harmful greenhouse gases and air pollutants (CO_2, NOx, SOx, etc.).

Current and future carbon pricing schemes or tax assumptions are beginning to be included into customer's economic analysis for their fossil fuel boiler systems. Because boilers are a 20- and 30-year investment decision, forecasting any future carbon price is just as important as what current policies or prices are set. For example, Canada has introduced a phased-in carbon tax, beginning at $50 / ton in 2022, ultimately rising to $133 / ton by 2030. The use of carbon pricing tools provides strong tailwinds to the comparative economics of clean energy technologies including the use of our DCC™.

More stringent than economic mechanisms, many countries and local jurisdictions are outright banning the sale of new fossil-fuel based boilers. In particular, the United Kingdom and many localities on the West Coast of the United States (California, Washington state, Oregon) have already passed legislation banning the sale of new fossil fuel boilers in the future.

May 14, 2020 EPA Approved San Joaquin Valley Unified Air Pollution Control District. https://www.epa.gov/sips-ca/epa-approved-san-joaquin-valley-unified-air-district- regulations- california-sip

NOx limit by 2023: https://www.nationwideboiler.com/boiler-blog/understanding-air-permitting-for-boilers-in-california.html

California has the most stringent air emissions standards in the US, and is the fifth largest economy in the world. It is also the only State that can write its own air pollution related laws and standards. When the Clean Air Act passed, Congress required the Environmental Protection Agency to grant California an exemption, since the state was already developing innovative laws and standards to address the state's major air pollution issues. The DCC™ when operating with pure hydrogen and oxygen is completely emissions- free, releasing only heat and water through its combustion process. The DCC™ is fully endorsed by the largest air district in California, the San Joaquin Valley Unified Air Pollution Control District*.

By contrast, even the cleanest natural gas boilers face an impending regulatory crackdown in California. All boilers over 20 MMBtu/hr must comply with a 5 ppm NOx limit by 2023*. It is worth noting that Hydrogen-enabled boilers operating without a closed loop system can still trip this NOx limit, leaving industrial consumers to choose between electric boilers or HT's DCC™ solution.

California is not alone in the growing push to mandate new- construction boiler emissions standards. Between the current administration's climate priorities*, the ambitious Paris Climate Accords*, and the typical regulatory fallout from follow-on states* after California innovates, we believe restrictions on boiler emissions will only grow.

Biden climate plan: https://www.washingtonpost.com/climate-environment/2021/04/20/biden-climate-change/

Paris: https://unfccc.int/process-and-meetings/the-paris-agreement/the-paris-agreement

Follow-on states: https://news.climate.columbia.edu/2020/09/28/californias-continuing-climate-leadership/

SAFETY AND PERMITTING

Permitting is always site-specific. However, there are several globally applicable elements worth mentioning. The DCC™ itself is comparable in size to best-in-class natural gas boilers. Systems coupled with renewable energy-powered electrolysis and storage can have the non-boiler components located off-site, with connections via pipelines. Hydrogen regulations are evolving, but the FCEV industry is illustrative of what can be expected for stationary applications. Drivers of Toyota Mirais, for example, sit directly atop 10,000 psi H2 storage tanks in an application where impacts are possible. There is no reason to believe H2 storage will not be permitted below structures, so long as sufficient separation from O2 is allowed (separate tankage).

The DCC™ has no potential to emit, eliminating the need for air permitting. Locations like California will also require additional permitting such as the California Environmental Quality Act (CEQA). Additional safety needs may need to be addressed because hydrogen is considered an acutely hazardous material due to its flammability. Hazardous Materials Management Plans (HMMP) must be part of an onsite consequences plan while those facilities under Federal Law that store 10,000 lbs or more of hydrogen must also develop a Risk Management Plan (RMP). These plans must follow Process Safety Management (PSM 29 CFR1910.119) and have a Risk Management Plan (RMP40 CFR68).

CEQA: https://opr.ca.gov/ceqa/

HYDROGEN TECHNOLOGIES

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