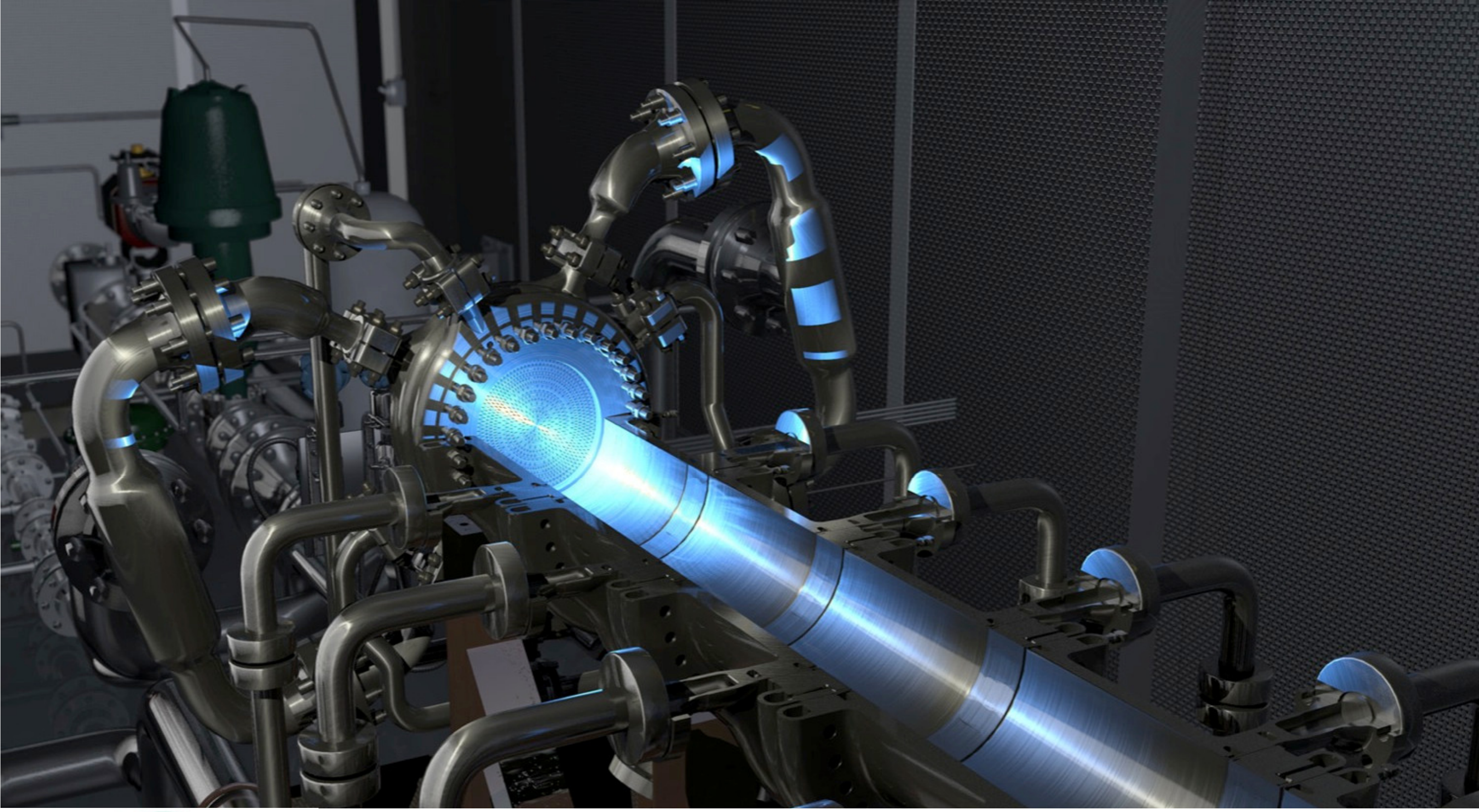


CLEAN ENERGY SYSTEMS
Direct Steam Generation Technology

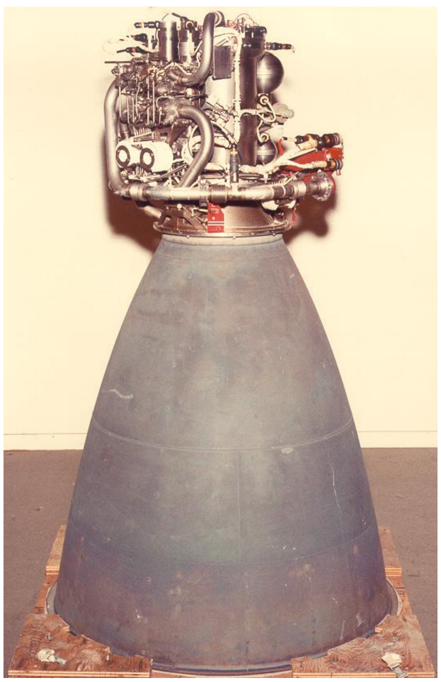
NEW APPLICATION FOR PROVEN TECHNOLOGY

It *is* Rocket Science!

The Clean Energy Systems' (CES) mission of "Power without Pollution" was developed by German rocket scientist Rudi Beichel who immigrated to the US in 1945 during "Operation Paperclip." Rudi maintained a successful career as an engineer, eventually working with Aerojet for over 40 years.

By 1993, Beichel had assembled an informal team of scientists, engineers, and businessmen committed to developing his idea, ultimately leading to the founding of CES.

In the pursuit of making power without pollution a reality, CES has continued to develop zero emission oxy-combustion power cycles, receiving over 30 patents and investing over $125 million in technology development.



A prominent example of the application of CES' platelet technology is the oxidizer/ fuel injector for the NASA Space Shuttle Orbital Maneuvering System Engine. This Aerojet-developed rocket engine sported a spotless, 100% reliability record over the 30 year lifespan of the Space Shuttle program.

Oxy-fuel Combustion

At the core of CES' technology is an oxy-fuel combustion system adapted from the same principles of rocket propulsion technology that powered the Space Shuttle.

CES combustors burn gaseous and/or liquid fuel with pure, gaseous oxygen at near-stoichiometric conditions in the presence of recycled or even untreated steam assisted gravity drain (SAGD) produced water. The custom-designed combustors utilize a wide variety of fuels, such as natural gas, associated or produced gas, syngas, refinery residues, landfill gas, bio-digester gas, etc.

The primary products of the oxy-fuel combustion process are steam and CO_2, and CES has developed a cycle which separates the CO_2 from the steam, ensuring no green house gases (GHGs) are emitted. Furthermore, while the produced CO_2 may be sequestered, it may also be used in enhanced oil recovery (EOR) operations. The oxy-fuel combustion process also produces clean water, all while drastically reducing emissions.

CES' Combustors vs Conventional Burners

Unlike conventional burners, CES' oxy-fuel combustors do not rely on turbulent flow within the burner for mixing of the reactants, thus effectively removing the constraints of volumetric flow requirements. Instead, CES' combustors achieve intimate mixing via proven *platelet technology*, allowing for numerous individual injection orifices. This characteristic allows CES' combustors to achieve significant turn-down capabilities – from 35% to 100% of thermal input with no adverse effect on performance or efficiency.

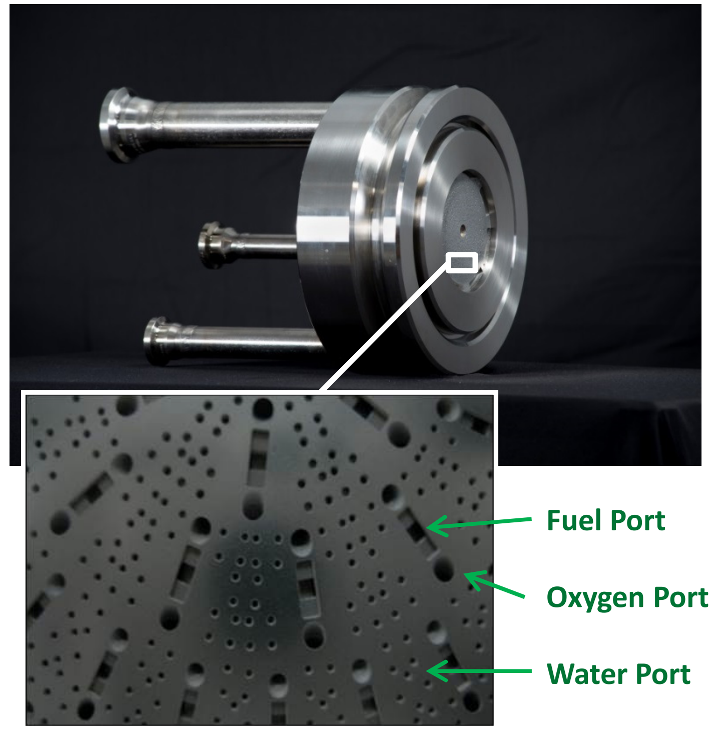
Direct Steam Generation

CES' Direct Steam Generators (DSGs) provide a safe, reliable method for blended steam and CO_2 production. The DSG400 burner utilizes platelet technology to intimately mix gaseous fuel with oxygen in the presence of water producing extremely intense compact combustion.

The attemperation chambers cool the resultant superheated, high-pressure mixture of steam and CO_2 by the injection of water which produces additional steam and controls the combustion chemistry kinetics. The water is injected at high-pressure through the formed platelet liner of the attemperation chambers. These chamber liners contain two separate circuits. The first routes the injection water through the liner orifices to facilitate cooling of the hot gas stream; the second directs coolant along the length of the liner for active cooling of the internal attemperation chamber walls.

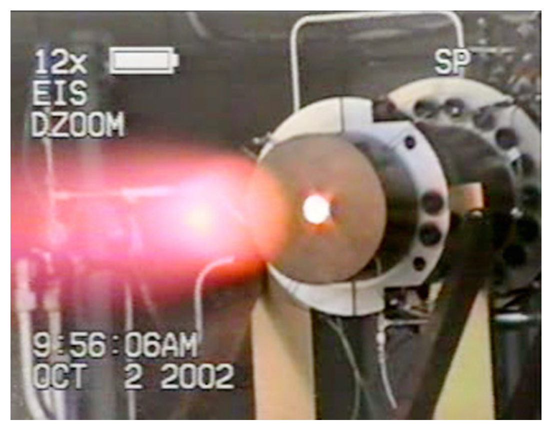
The final attemperation chamber is capable of increased water injection capacity in order to allow for the control of steam quality exiting the DSG.

DSG400 Platelet Burner

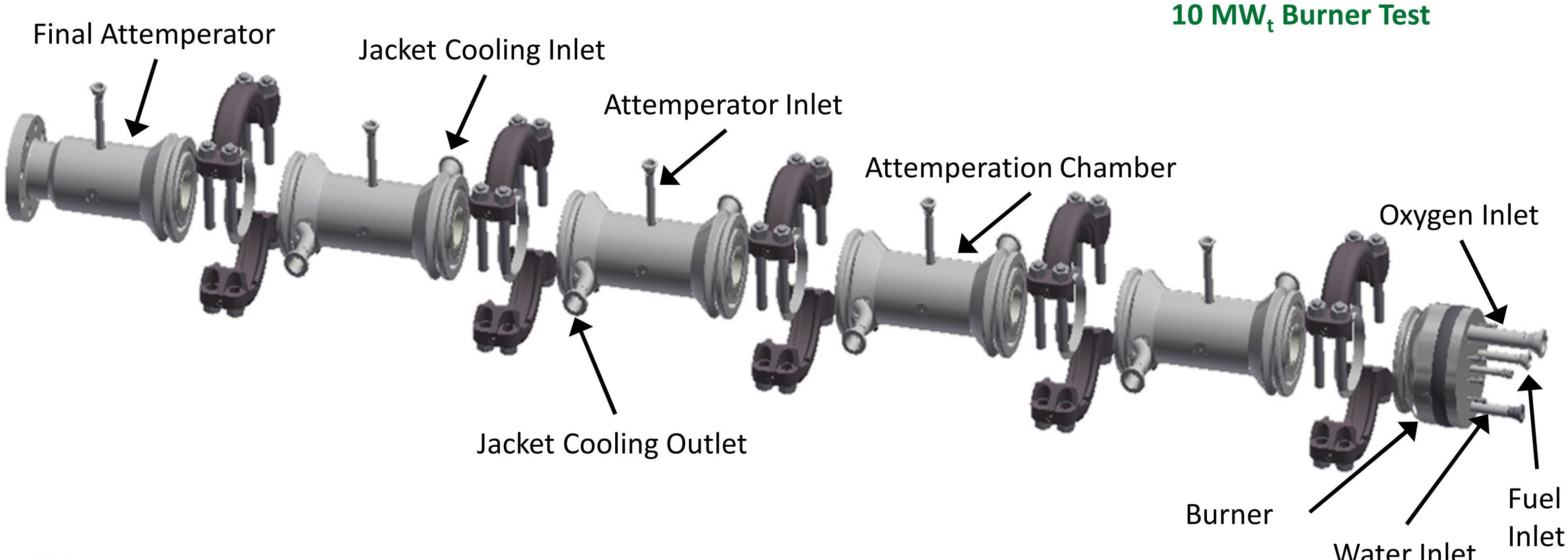


DSG Burner Face Detail

STEAM & CO_2 PRODUCTION



10 MW_t Burner Test



PLATELET TECHNOLOGY

Overview

Platelet technology is a design philosophy and manufacturing process first developed by Aerojet in the mid-1960s, with significant contribution from a number of CES' original founders, current employees, and consultants. CES continues to advance the development of this critical technology.

The process allows for the fabrication of uniform structures containing complex, precise 3D flow passages and features. It also facilitates the unique ability to control the oxy-fuel combustion process and maintain combustor component cooling while in close proximity to 3,300°C flame fronts.

How It's Made

Thin sheets of metal are photochemically etched with specific design patterns to produce "platelets." Individual platelets are then accurately assembled, or "stacked," and joined via a diffusion bonding process.

The result is a monolithic structure containing complex internal passages which allow for reactant and coolant flow control, manifolding, and filtering. The process enables precise mixing of fuel and oxygen, as well as higher operating pressures and temperatures than are achievable with traditional burners.

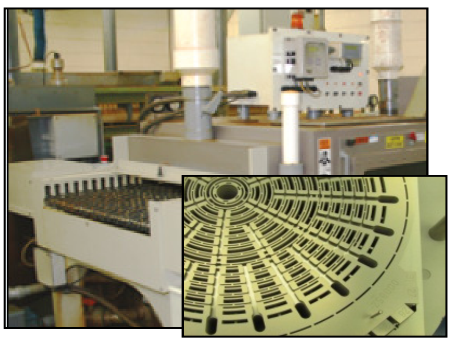
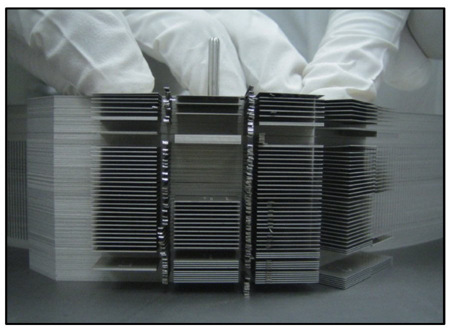


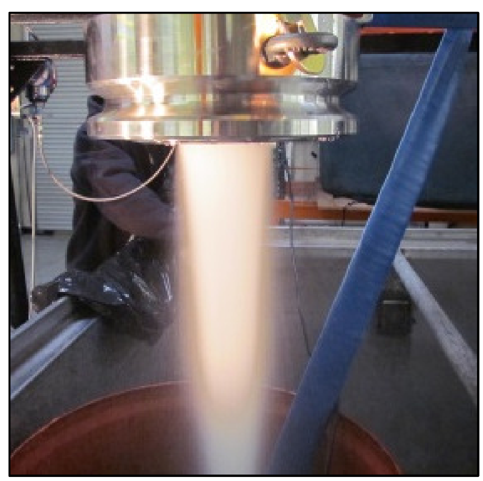
Photo-Etching Creates Unique Platelet Designs



Platelets Accurately Stacked in Clean Room Environment

Diffusion Bonding Forms Monolithic Part

Secondary Operations Complete Platelet Device



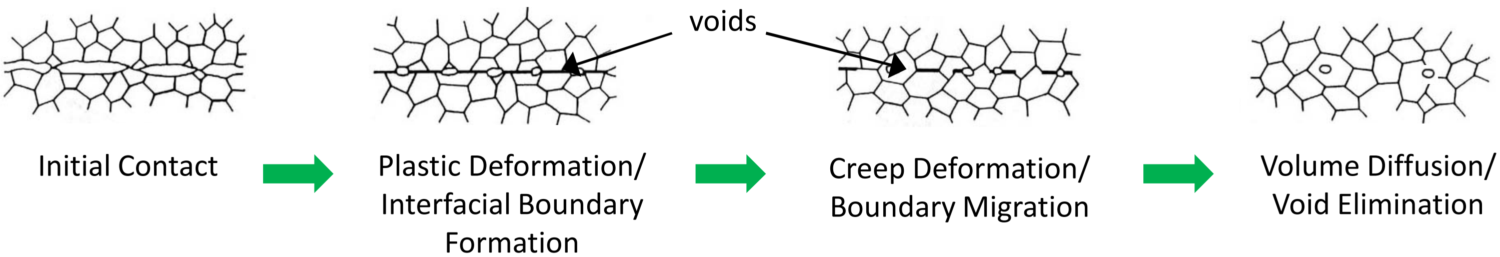
Cold Flow and Proof Tests

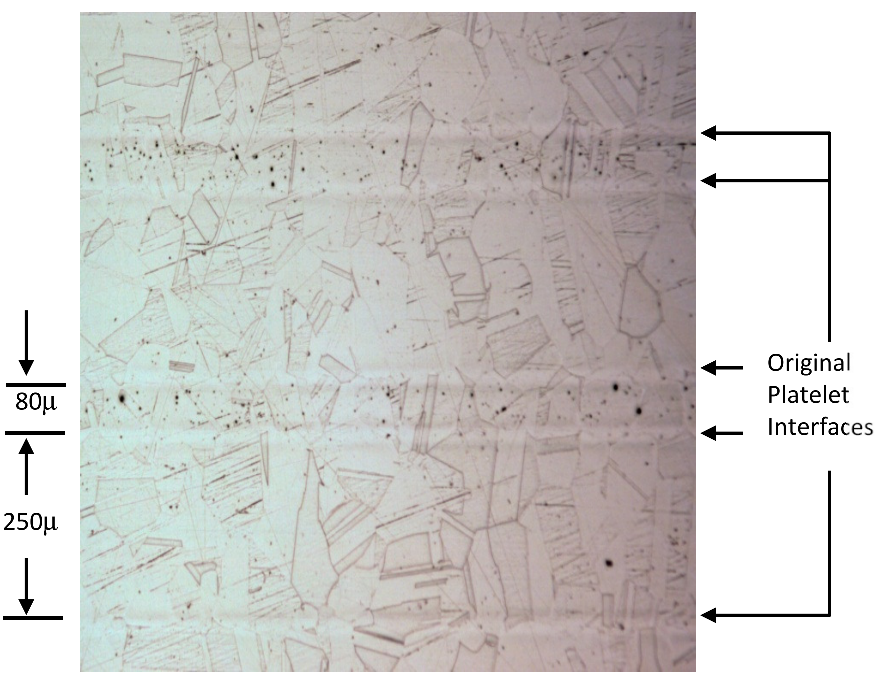
Diffusion Bonding

Diffusion bonding is a solid state process (*i.e.* no melting takes place) which produces a monolithic, helium leak-tight joint. When performed in accordance with CES' specifications, no macro-scale deformation occurs during the bonding process, leaving the as-fabricated platelet features intact while maintaining parent material strength through the formation of bonds at the atomic level.

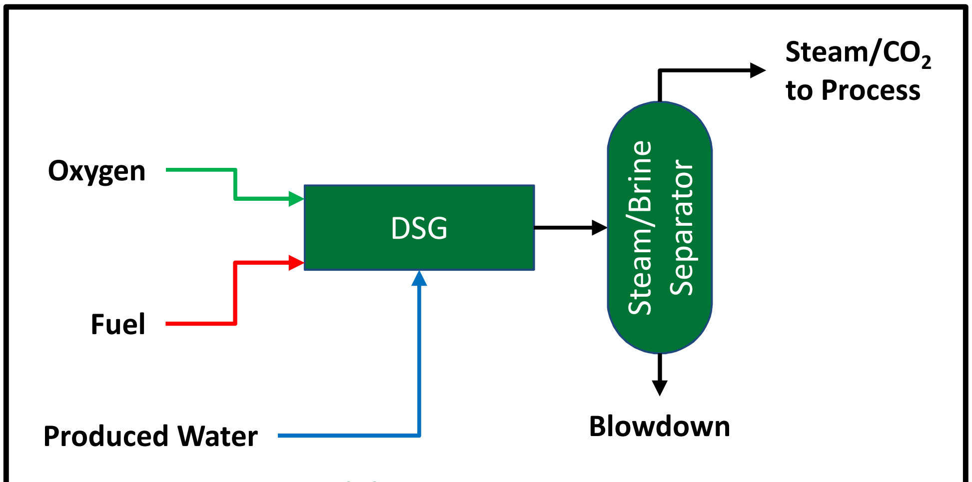
During the process (illustrated below), the mating surfaces of the platelets are forced into intimate contact due to local plastic deformation at elevated temperatures, at which time elemental diffusion across the platelet interface begins along with grain boundary migration. All surface layers of the platelets are joined through inter-diffusion, and the original interfaces and boundaries are fully coalesced, creating a singular device. No other current fabrication process is capable of producing the detail and accuracy achieved by the CES diffusion bonded platelet process.

Stages of Diffusion Bonding





Micrograph of diffusion bonded 300 Series stainless steel showing grain boundary migration across original platelet interfaces, evidence of a true monolithic structure.



G^2S^2 Process Overview

PER UNIT CAPABILITIES:

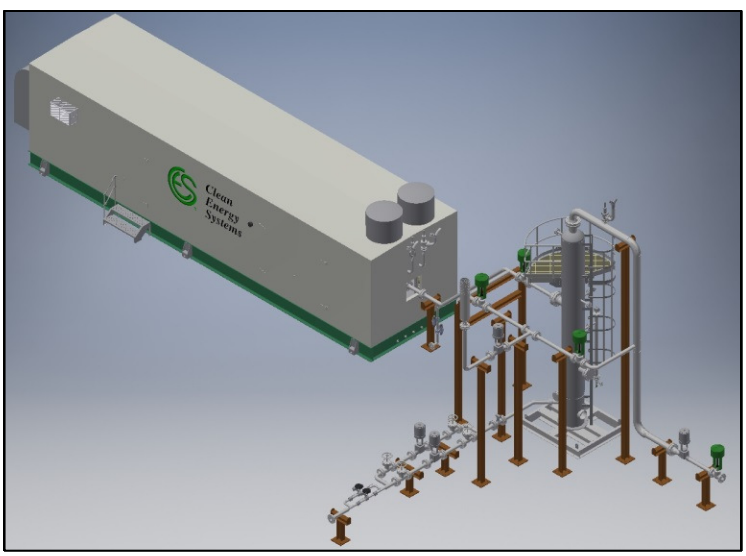
- 10 – 350+ MW_{th}
- 2,000+ Bbl/hr CWE
- 10,500+ kPa
- 1,000+ °C

Steam Separator at CES Test Facility

G^2S^2 PACKAGE

Coupling the DSG with a traditional steam separator allows produced water (traditionally a hydrocarbon recovery by-product with elevated concentrations of dissolved solids) to be used as the feed water source for steam production. This package, referred to as a G^2S^2 assembly, provides a compact, efficient, and economical solution for *in situ* light- and heavy-oil production employing steam and CO_2 injection, particularly where clean water sources are limited.

The G^2S^2 system reduces total operating costs for heavy-oil production by reducing or eliminating water treatment costs required for conventional once-through steam generators (OTSGs). By utilizing all sensible and latent heat to generate downhole steam, the G^2S^2 package offers improved thermal efficiency over typical OTSGs.



G^2S^2 Package layout

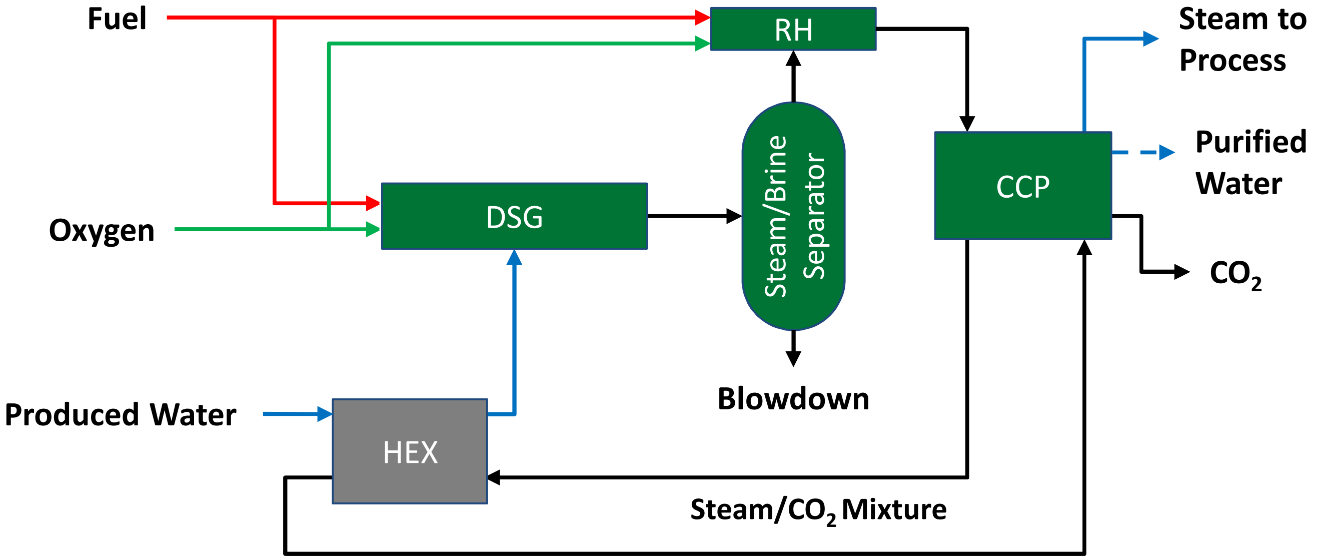
CES' INNOVATIVE MODULAR DESIGN APPROACH PROVIDES CUSTOMIZABLE, FLEXIBLE SOLUTIONS FOR *IN SITU* HYDROCARBON RECOVERY OPERATIONS.

20 MW_{th} DSG Chamber Assembly with Integrated Attemperation

ADVANCED G^2S^2 PACKAGE

The G^2S^2 assembly may be combined with other CES technologies to provide customized outputs. The Advanced G^2S^2 package couples the DSG and Steam Separator to an in-line platelet Reheater (RH) and Carbon Capture Plant (CCP) in order to facilitate the separation of clean steam and pressurized CO_2. This compact, modular design allows for direct reservoir injection of steam and CO_2 in controlled flows and ratios. The CCP utilizes Compact Platelet Heat Exchangers (CPHX), produced by CES' HEXCES division, to allow high pressure operation while significantly reducing system size.

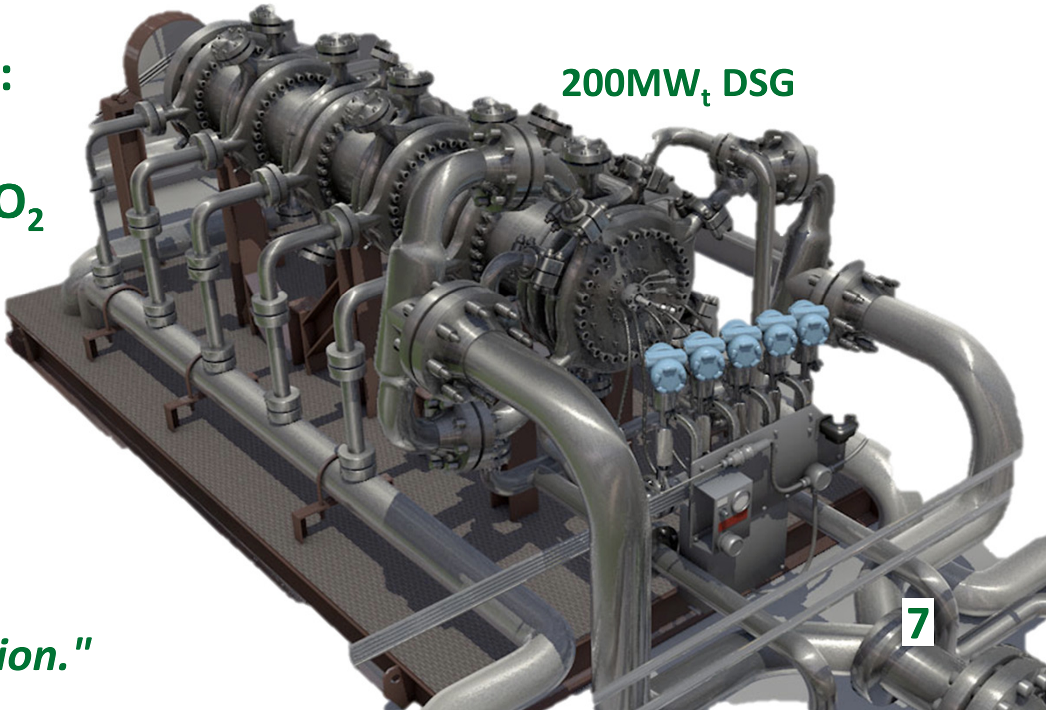
CES Carbon Capture Plant Heat Exchangers



G^2S^2 with CCP Process Overview

PER UNIT CAPABILITIES:

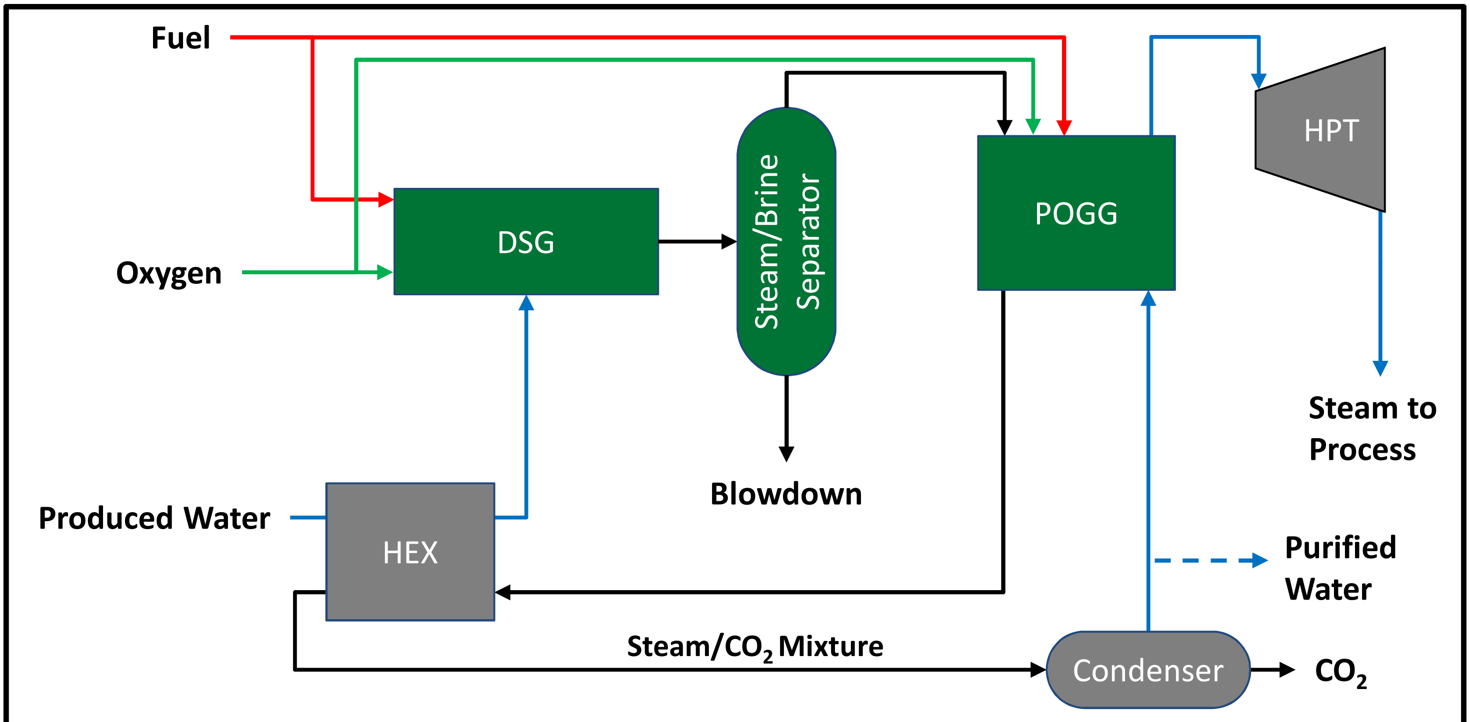
- 10 – 350+ MW_{th}
- Separated Steam & CO_2
- 2,000+ Bbl/hr CWE
- 10,500+ kPa
- 1,000+ °C



200MW_t DSG

"Power without Pollution."

For applications with high power demand, CES' standard G^2S^2 package may be combined with a Pressurized Oxy Gas Generator (POGG), producing clean steam at supercritical conditions and a separate CO_2 stream. The steam may be routed through a traditional high-pressure steam turbine (HPT) for power generation; the resulting exhaust stream may then be used for other processes, such as hydrocarbon recovery.



G^2S^2 with POGG Process Overview

STEAM, CO_2 & POWER

PER UNIT CAPABILITIES:

- 10 – 350+ MW_{th}
- Separated Steam & CO_2
- 12+ MW_e
- 2,000+ Bbl/hr CWE
- 10,500+ kPa
- 1,000+ °C

PACKAGING

CES' DSGs and other technology packages are delivered in compact, transportable, and environmentally-protected enclosures, which house all required equipment, piping, electrical wiring, and control systems.

Key Features

- Typical Dimensions: 4 x 4 x 14 meters
- Compliant with ASME, CSA, Canadian Building Codes, and registered with ABSA.
- Fire suppression and gas detection system approved by the National Fire Protection Association (NFPA)
- Allen Bradly PLC /control system
- Tolerance of wind loads up to 160 km/hr
- Noise emissions reduced to less than 85dB(A) within one meter during operation
- Overhead bridge crane for servicing the equipment
- Color PTZ camera system
- Climate control system for personnel and equipment
- Spill containment basin

200 MW_t DSG Installed at CES Test Facility

"Power without Pollution."

Want more information?

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