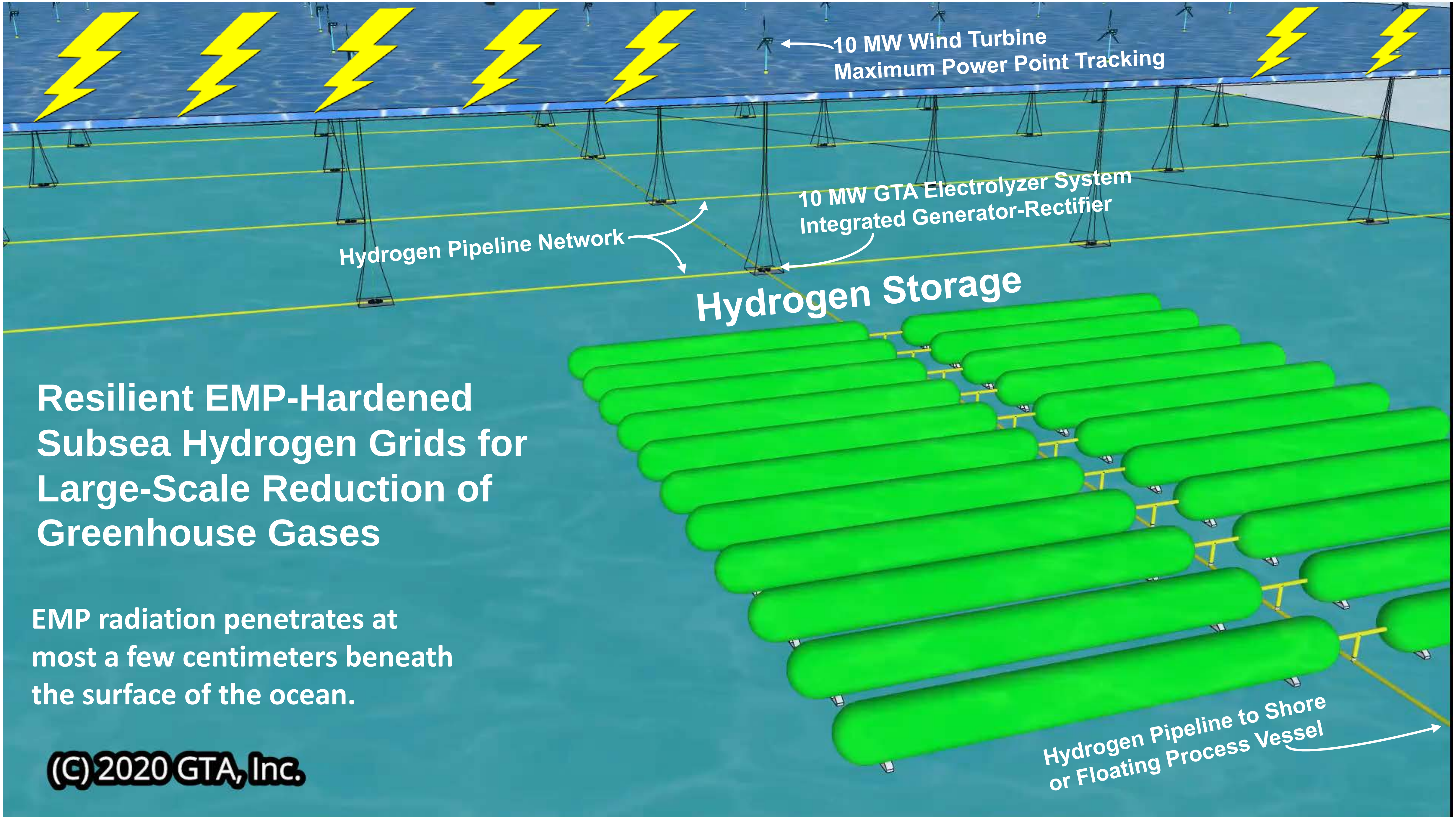
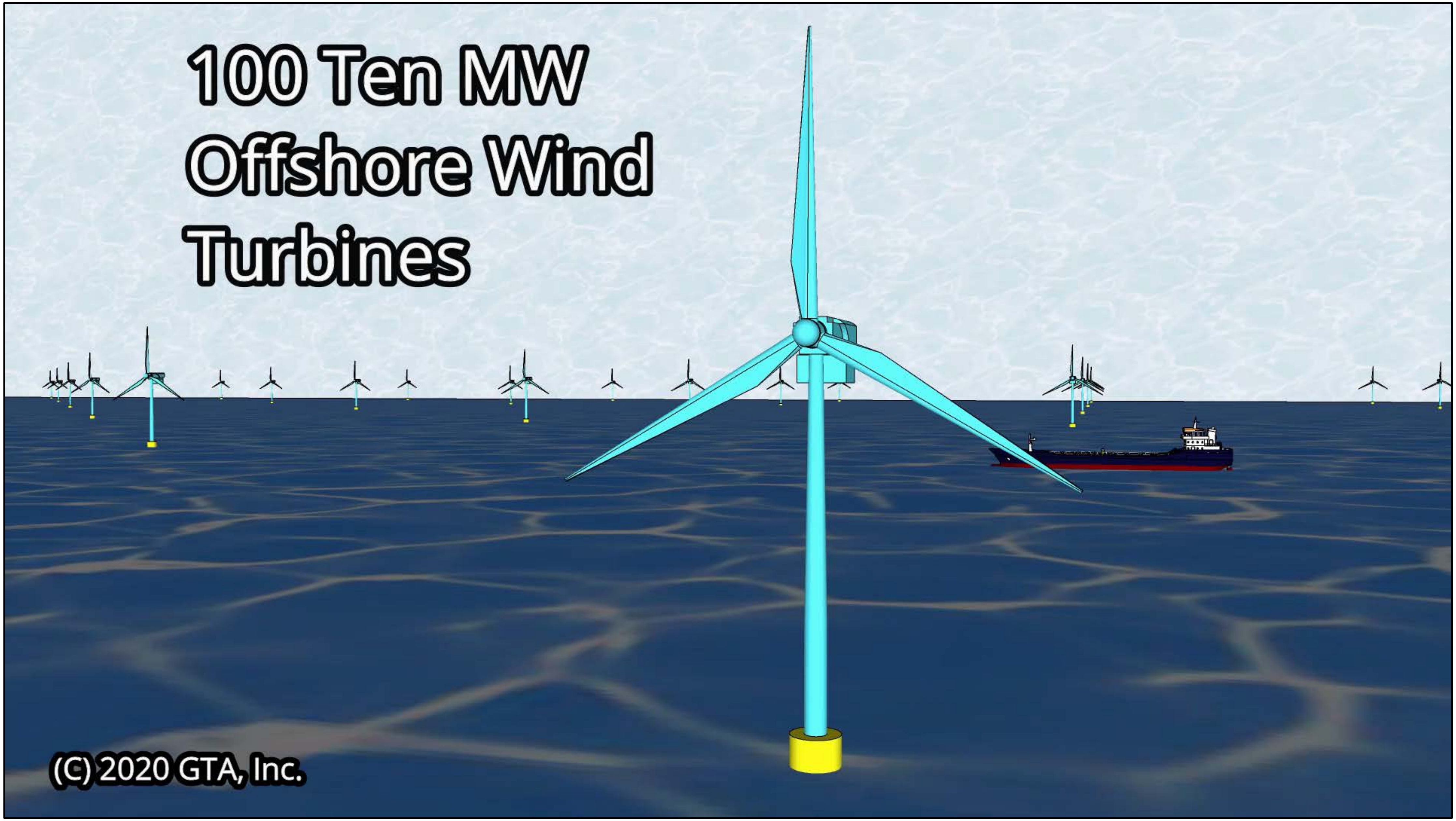

10 MW Wind Turbine
Maximum Power Point Tracking
10 MW GTA Electrolyzer System
Integrated Generator-Rectifier
Hydrogen Pipeline Network
Hydrogen Storage
Resilient EMP-Hardened Subsea Hydrogen Grids for Large-Scale Reduction of Greenhouse Gases
EMP radiation penetrates at most a few centimeters beneath the surface of the ocean.
Hydrogen Pipeline to Shore or Floating Process Vessel
(C) 2020 GTA, Inc.



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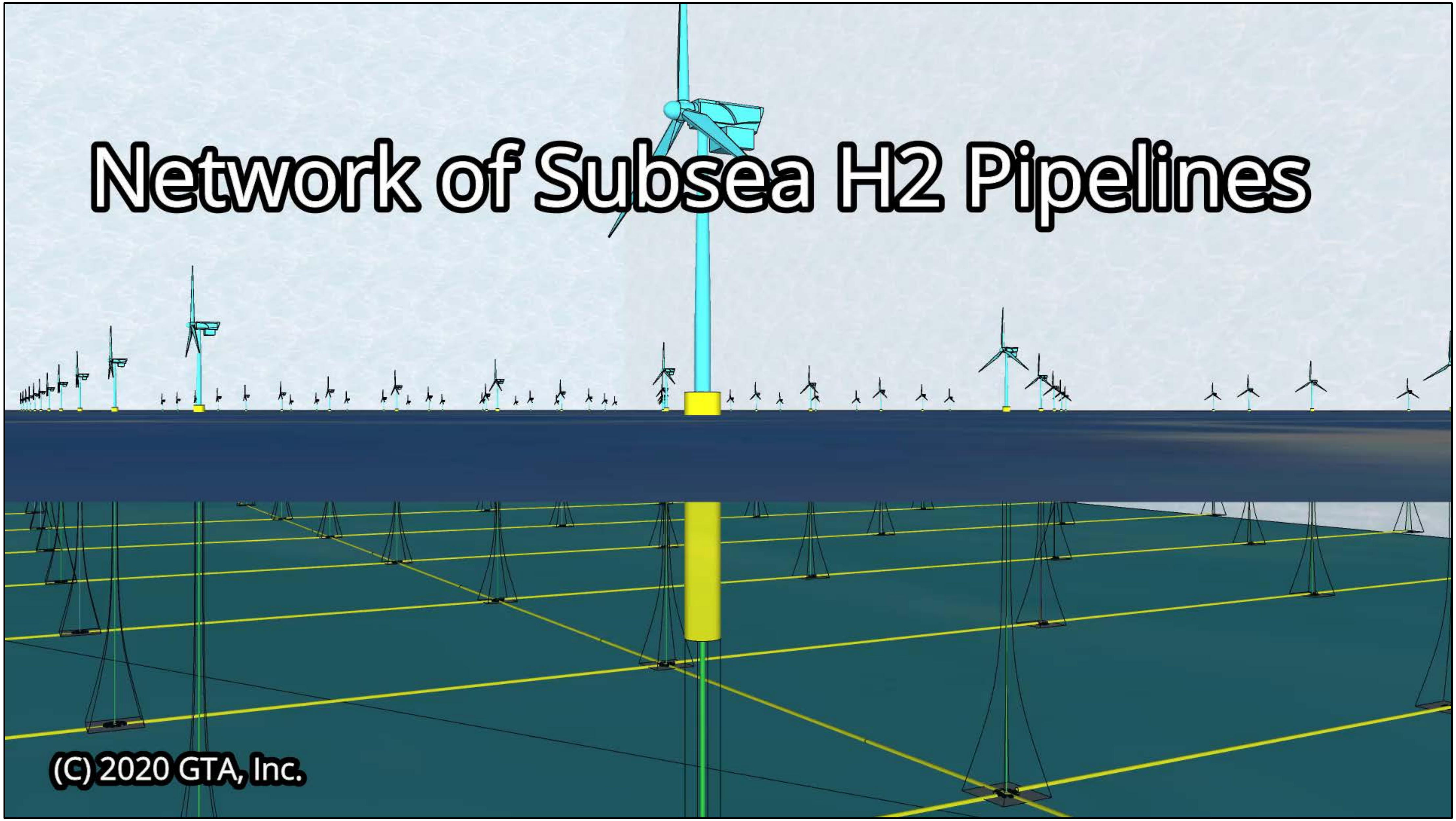
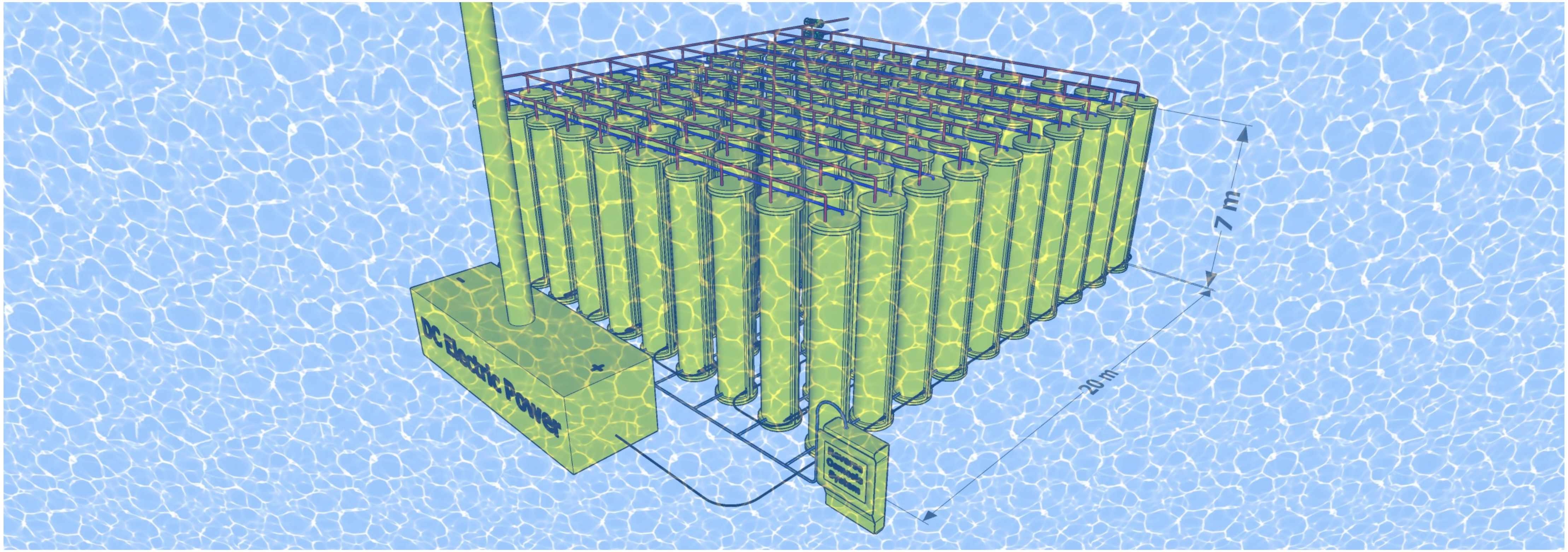

Network of Subsea H2 Pipelines
(C) 2020 GTA, Inc.

10 MW GTA Subsea Electrolytic Hydrogen Production

100 × 100 kW Electrolyzers



Each cylindrical component is a 100 kW modular unit. The units are connected in series.

Subsea Offshore Oil and Gas Operations at the Seafloor

Subsea operations performed at the seafloor are more complex and potentially more dangerous than the operation of GTA subsea electrolyzers.

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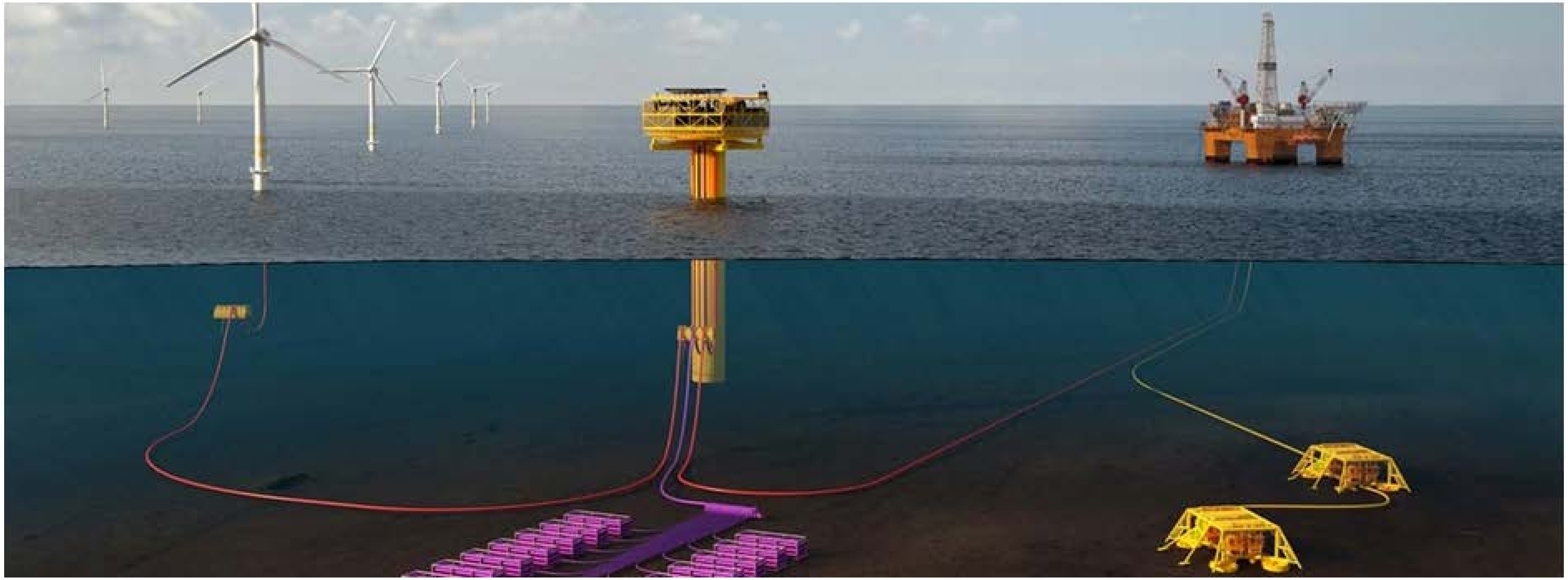
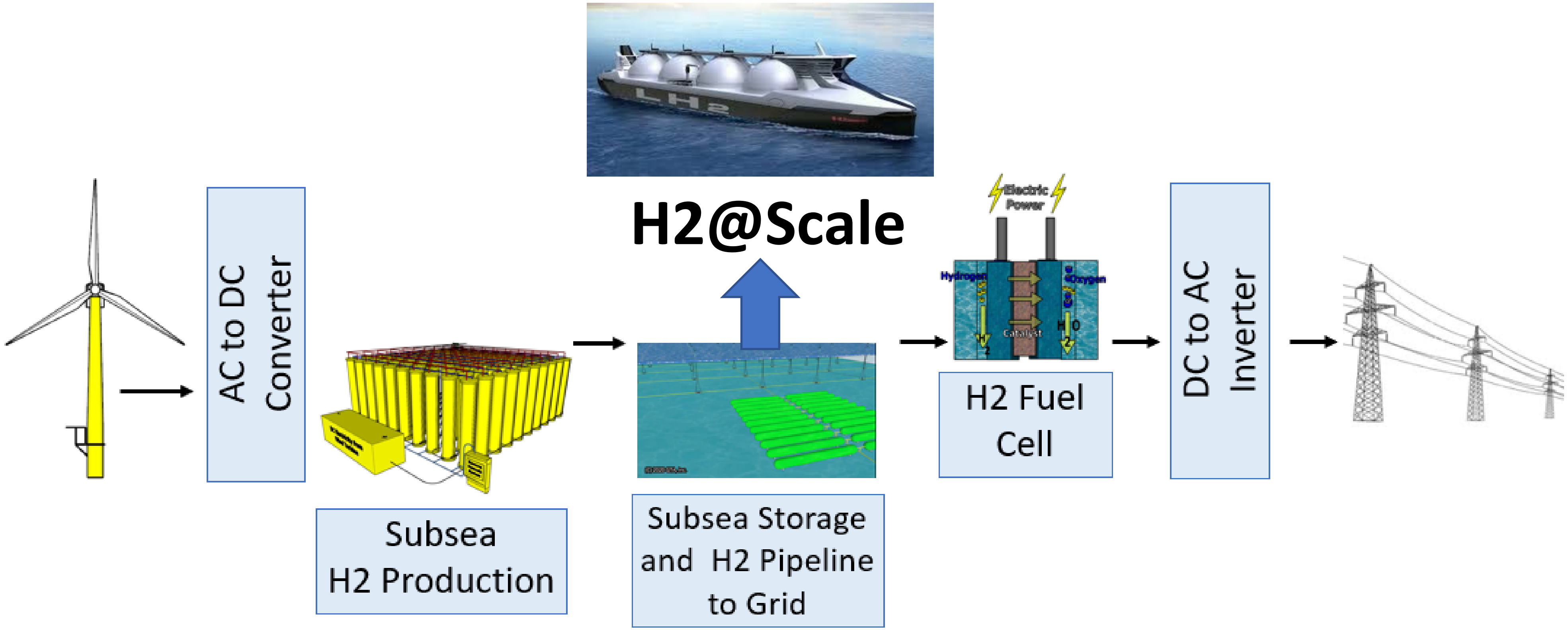
Deep Purple Project Collaboration



The Deep Purple offshore concept. Energy system management, electrolysers and fuel cells are located in the yellow device in the middle of the image. The hydrogen storage tanks are purple. Photo by TechnipFMC.

System Concept



The proposed large-scale hydrogen production system avoids offshore platforms, high-voltage inter-array and export cables, and large power transformers. Transport of energy as hydrogen in pipelines is at least eight times less expensive than transport as electricity in metal cables (B. D. James et al., 2019).

Operation, Materials Compatibility, Subsea Stability, Maintenance/Servicing

- **Remote autonomous operation**
- **GTA electrolyzers have no moving parts**
- **Polyethylene has virtually 100% stability in sea water [1]**
- **Potassium hydroxide is a thermal stabilizer for polyethylene [2]**
- **Nickel electrode/alkaline electrolyzers rarely need servicing [3]**

[1] International Standard ISO 22404, “Plastics — Determination of the aerobic biodegradation of non-floating materials exposed to marine sediment — Method by analysis of evolved carbon dioxide”, September 2019.

[2] N. P. Cheremisinoff, *Handbook of Engineering Polymeric Materials*, p. 84, Marcel Dekker, New York, 1997.

[3] B. Kroposki, J. Levene, K. Harrison, P.K. Sen and F. Novachek, “Electrolysis: Information and Opportunities for Electric Power Utilities”, Technical Report, NREL/TP-581-40605, September 2006.

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Techno-Economic Features

- Electrolyzers that are anchored at the sea floor are shielded from extreme weather and EMP events.
- Hydrostatic pressure at the sea floor is leveraged for production of pressurized hydrogen without mechanical devices.
- Cool water at the sea floor is leveraged for “free” cooling.
- Subsea electrolysis is simpler and safer than the operations of the offshore gas and oil industry.
- An international trained workforce is already in place.

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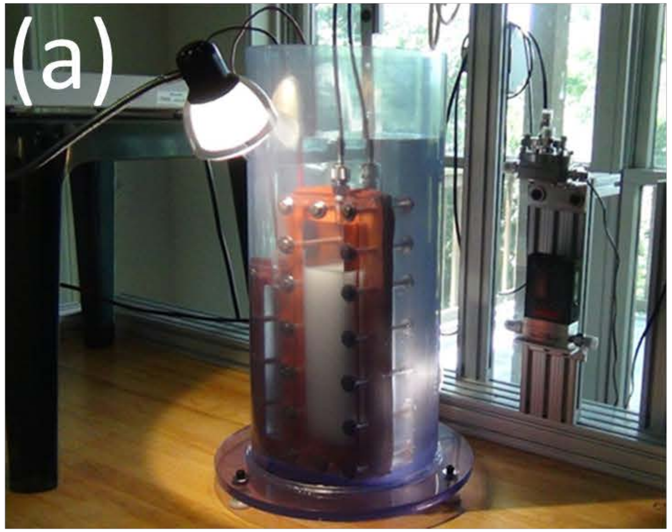
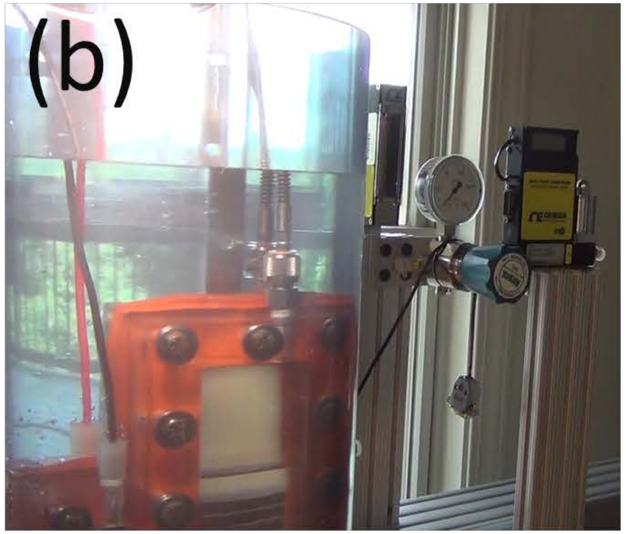
GTA Pressure Balanced Offshore Hydrogen Wind Farm

- **Offshore hydrogen wind farms comprise fields of multi-gigawatt offshore wind turbines that power pressure-balanced electrolyzers that are anchored at the sea floor.**
- **The turbines are not electrically connected to the utility grid, thereby eliminating high-voltage cables and large power transformers.**
- **Hydrogen stored at the sea floor may be sent to a utility company for grid balancing or sold in the H2@Scale market.**





SAE J2719 Fuel Cell Grade Hydrogen		GTA Electrolyzer H_2
	SAE J2719 Limits µmole/mole	GTA Sample µmole/mole
H_2O (ASTM D7649)	5	279*
Total Hydrocarbons (Methane) -C_1 Basis (ASTM D7892)	2	0.48
O_2 (ASTM D7649) with O_2 getter	5	9.4
O_2 (ASTM D7649) native O_2 content	5	3472
He (ASTM D1946)	300	10
N_2 & Ar (ASTM D7649)	100	40
CO_2 (ASTM D7649)	2	2.3
CO (ASTM D5466)	0.2	0.023
Total Sulfur	0.004	0.00082
Formaldehyde (ASTM D7892)	0.01	0.0012
Formic Acid (ASTM D5466)	0.2	<0.003
Ammonia (ASTM D5466)	0.1	<0.02
Total Halogenates	0.05	0.015

*No attempt was made to remove water vapor or CO_2.

Technology Validation at National Renewable Energy Laboratory

- **Native hydrogen purity: >99.6%; sufficiently pure for most H2@Scale industrial applications.**
- **One-step O2 removal: < 10 ppm O2; near fuel cell grade hydrogen, SAE J2719 standard.**
- **Within standard for remaining SAE J2719 analytes**
- **Conversion efficiency, 75%**

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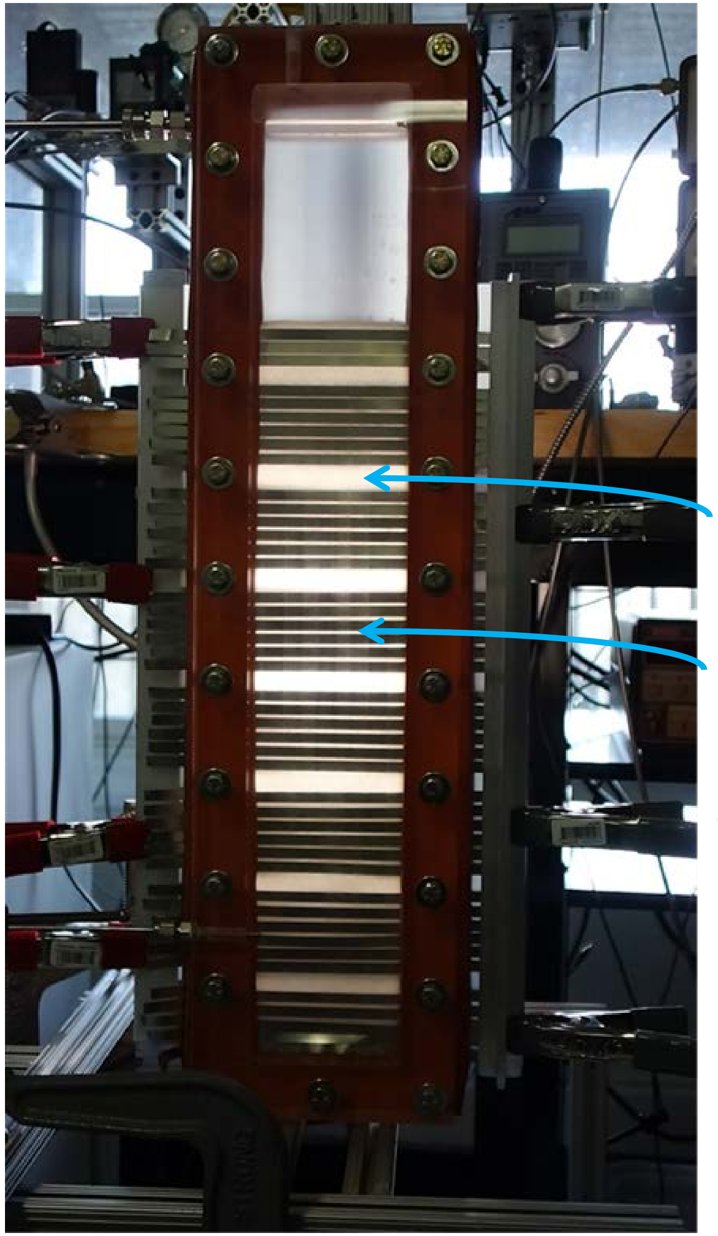
TRL 4

- No platinum group metals
- Electrodes are nickel ribbon wires
- Electric current is restricted to individual electrodes and is uniformly distributed across the face of the separator (Patent EP 2917386)
- Minimizes high-current thermal runaway and corrosion



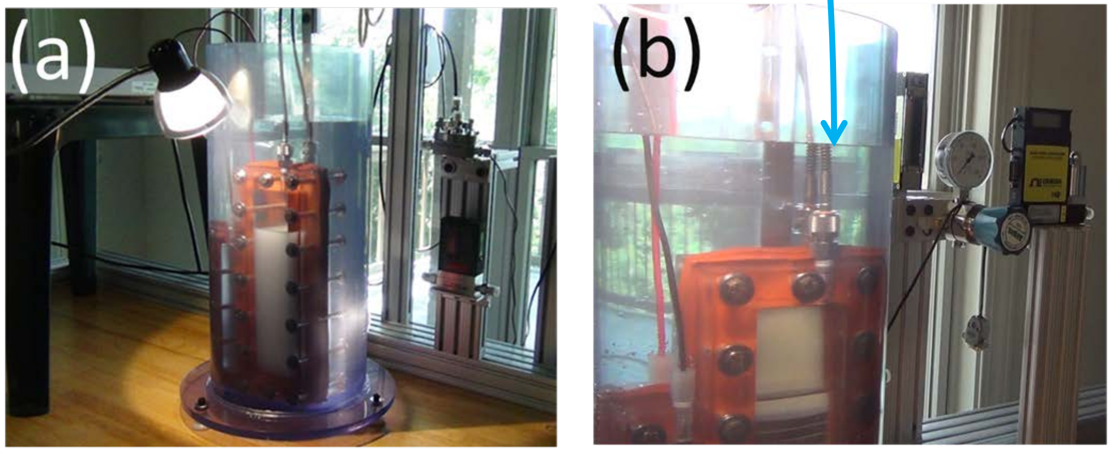
Photograph of the electrolyzer that was validated at the US DOE National Renewable Energy Laboratory: 61 cm tall × 15 cm wide × 7 cm deep.

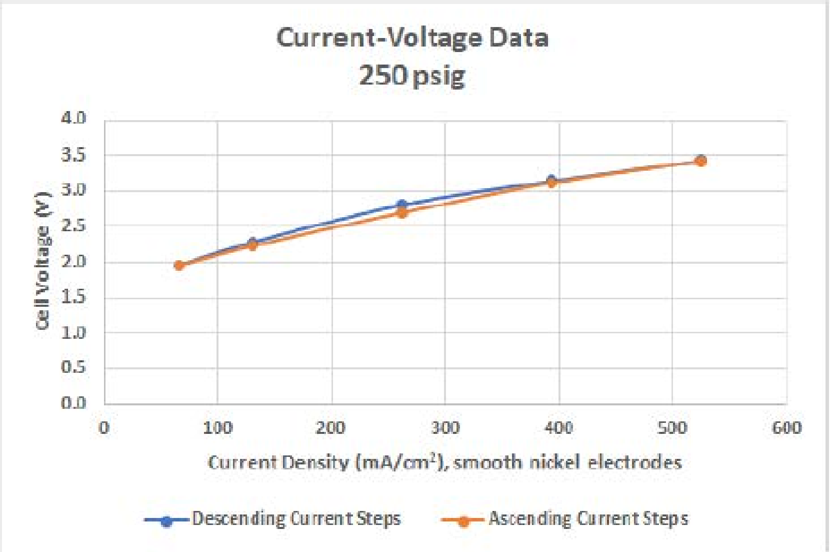
Porous polyethylene membrane separator

Pluralities of independent cathode and anode electrodes on opposed sides of the membrane separator. Uniformly segments electric current across the face of the separator.

TRL 5

Operational electrolyzer submersed in Atlantic Ocean seawater





Cell Voltage vs. Current Density. The absolute currents were 5, 10, 20, 30 and 40 A across a 76 cm^2 porous polyethylene separator. The electrolysis cell was operated in constant-current mode. Voltage values were sampled once per minute for 10 minutes. Each data point per current step is the average of the 10 samples. One-half inch steel end-plates were used to buttress the cast acrylic cell for operation at 250 psig.

Left: Electrolysis cell behind safety shield pressurized to 250 psig. Right: electrolysis cell, similar to that shown on the left, without buttressing plates and operation at or near ambient pressure.

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