Advanced exhaust heat recovery systems for energy-efficient ships

Dr. Eric Maxeiner, Echogen Power Systems

Electric & Hybrid Marine World Expo
Amsterdam, The Netherlands
June 23, 2015

imagination at work

ECHOGEN power systems

Echogen Power Systems

Echogen is the industry leader in development of supercritical CO_2 heat recovery systems.

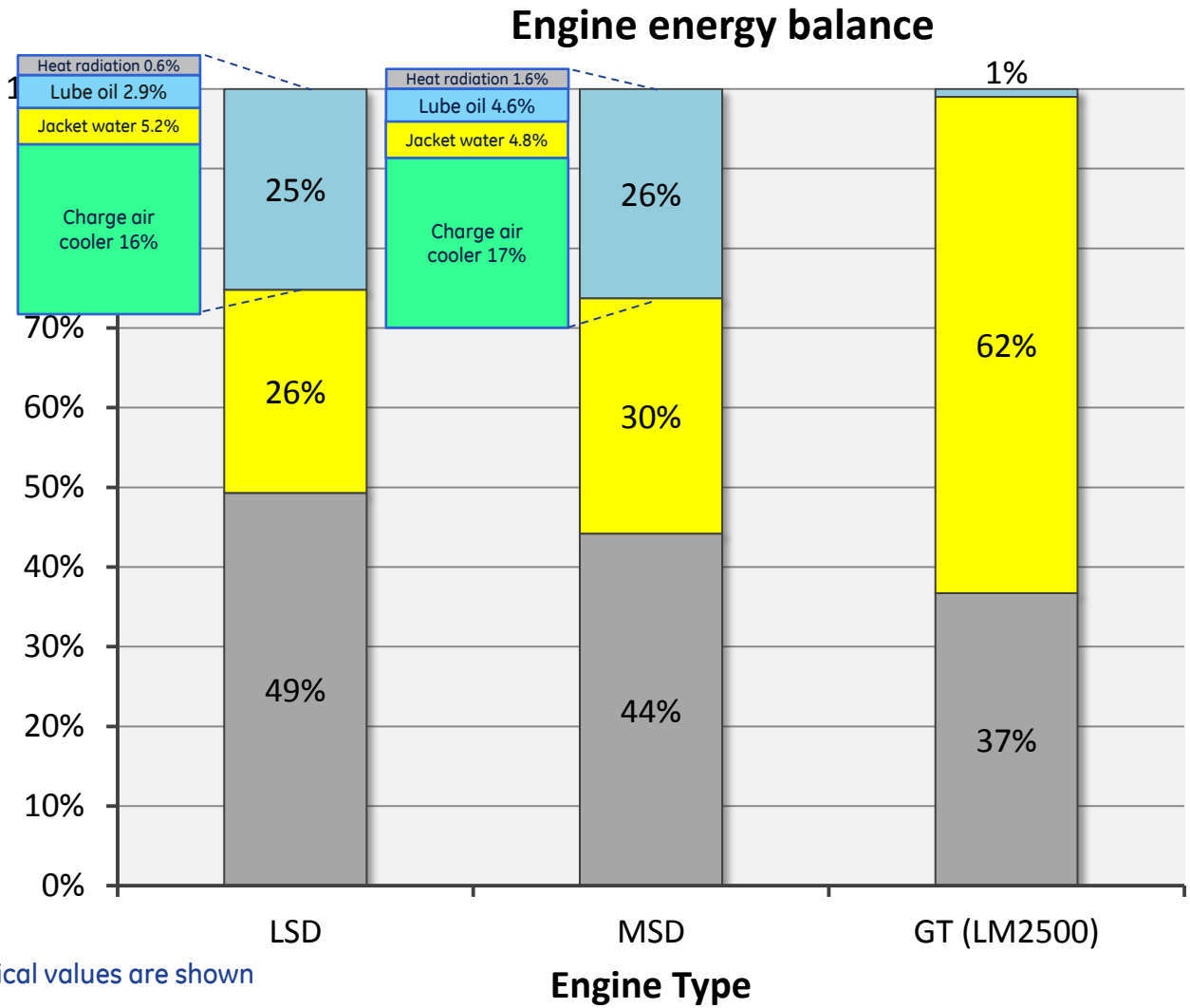
2007	*Echogen founded*
2011	*Partnership with Dresser-Rand; development of EPS100 8 MW engine begins*
2013	*Partnership with GE Marine; development of EPS30 1.5 MW engine begins*
2014	*EPS100 completes factory testing*
2015	*Looking for EPS100 and EPS30 commercial pilot sites*

Plans for the future…

- *Introduce additional EPS engine sizes*
- *Naval installations*
- *Industrial and nuclear applications*

365 Water St., Akron, OH USA

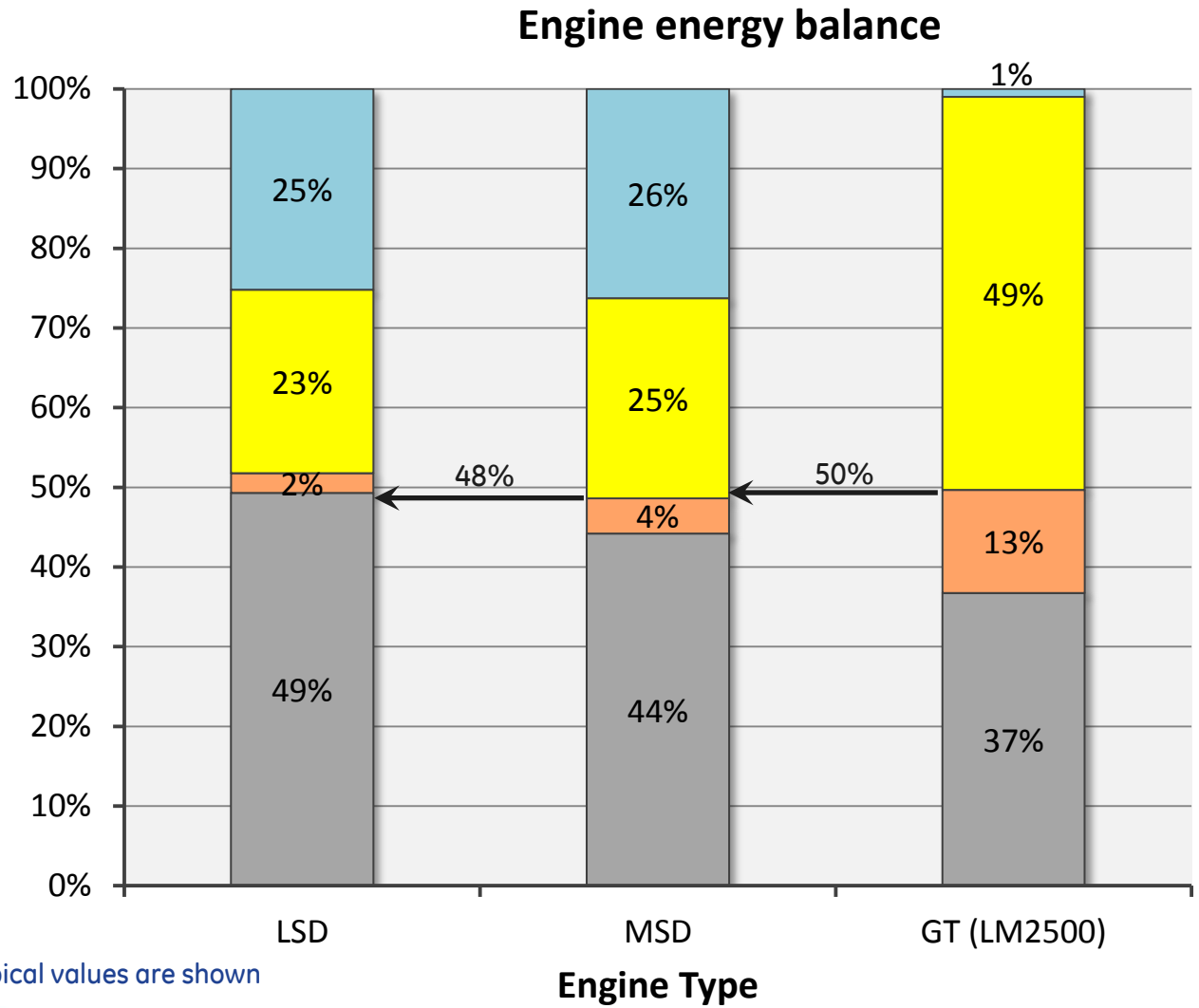
Exhaust heat recovery (EHR)



LSD: low speed diesel,
$T_{exhaust} \approx 250^{o}C$
MSD: med speed diesel,
$T_{exhaust} \approx 350^{o}C$
GT: gas turbine,
$T_{exhaust} \approx 550^{o}C$

Note: typical values are shown

Exhaust heat recovery (EHR)



LSD: low speed diesel,
$T_{exhaust} \approx 250^{o}C$
MSD: med speed diesel,
$T_{exhaust} \approx 350^{o}C$
GT: gas turbine,
$T_{exhaust} \approx 550^{o}C$

EHR helps bridge the thermal efficiency gap

Note: typical values are shown

EHR delivers power with no additional fuel consumption

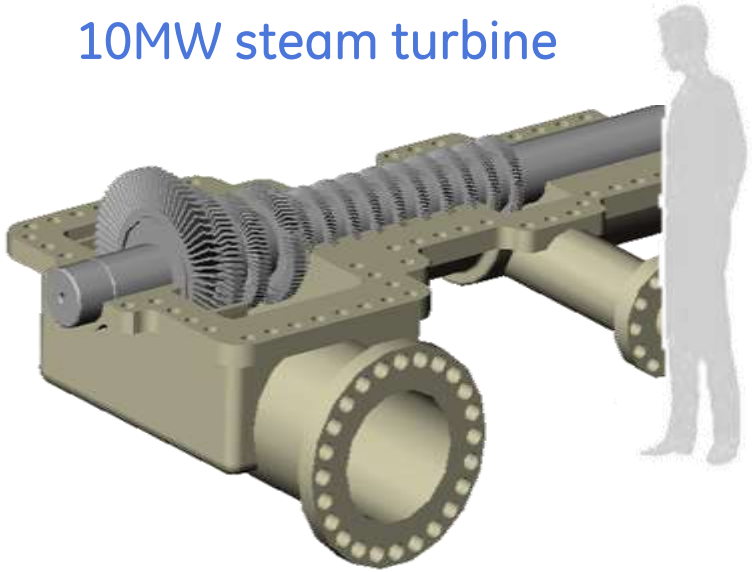
Marine benefits of EHR

- Improved fuel economy
  - Increases output with no added fuel consumption
    - Up to 10% for diesels, up to 35% for gas turbines
  - No other existing or emerging technology has comparable reduction in fuel consumption
- Complement to gas turbines
  - EHR takes advantage of high exhaust temperature & flow rate
  - Reduced size, maintenance and vibrations over diesels
  - Gas turbine with EHR has lowest emissions of any commercially available power plant
- Flexible shipboard applications
  - Applicable to wide range of engines (diesels and gas turbines)
  - May also provide ship steam, heating or cooling
- Military advantages
  - Increased vessel range
  - Lower stack temperatures (reduced signature, protect topside equipment)

Supercritical CO_2 (sCO_2)

10MW sCO_2 turbine

10MW steam turbine



Supercritical CO_2 (> 31°C, 74 bar) has properties of both liquid and gas. There is no distinct phase change when moving in/out of supercritical region.

Advantages of CO_2

Stable, non-flammable, non-corrosive working fluid

Efficient working fluid – density of a liquid with the viscosity and compressibility of a gas

Simple, in-stack waste heat exchanger single pressure and no boiling!

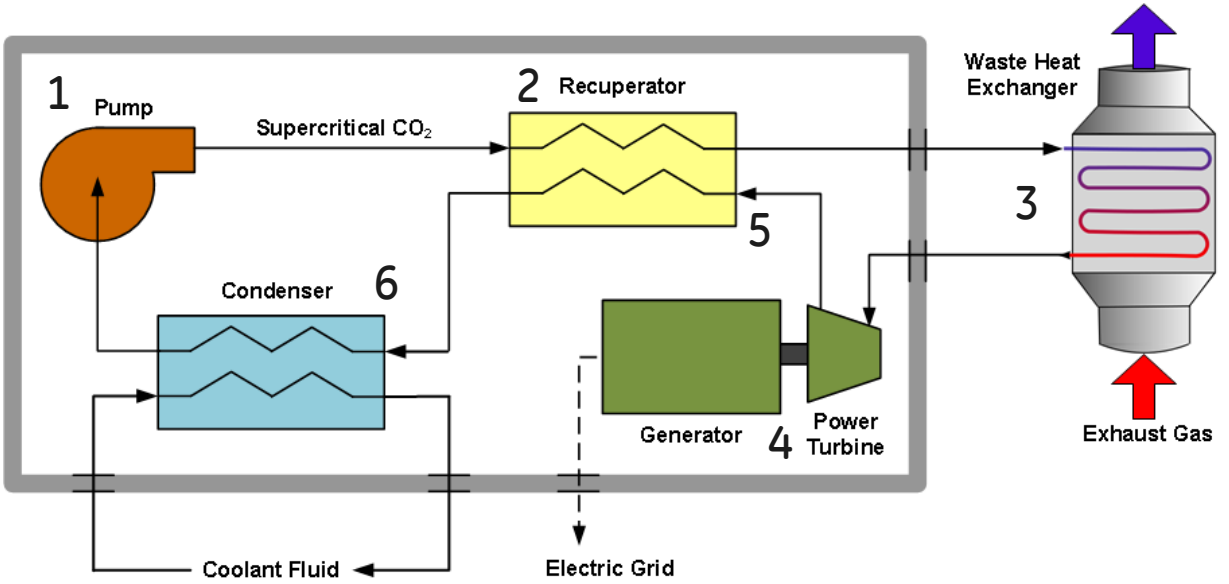
Flexible operations – CO_2 can remain in heat exchanger at all times

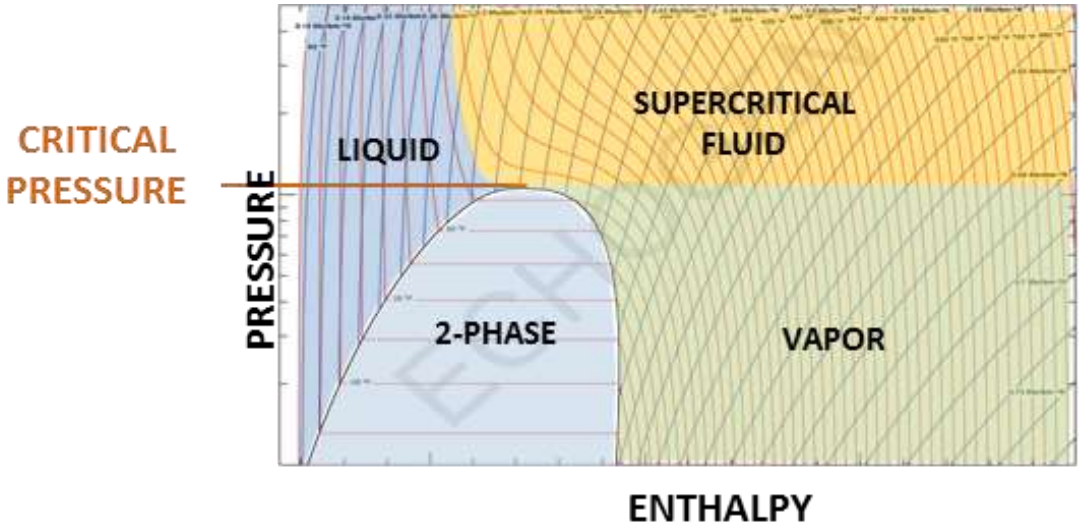
Compact, closed loop system -- minimal operations & maintenance (O&M) support

Competitive thermal-to-electric power conversion efficiency with typically lower capital cost vs. steam or ORC technologies

The sCO_2 Power Cycle

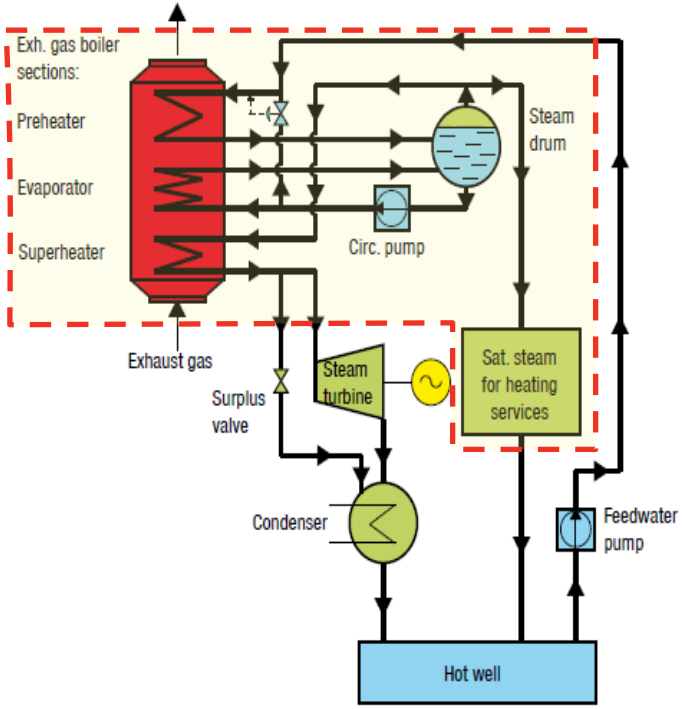
1. Liquid CO_2 is pumped above critical pressure.
2. Supercritical CO_2 is preheated in a recuperator.
3. Recovered waste heat is added at the waste heat exchanger.
4. High energy sCO_2 is expanded in the turbine, driving the generator.
5. Excess heat after expansion is recuperated
6. Expanded sCO_2 is condensed to a liquid at the cooling system. Coolant can be air or water.



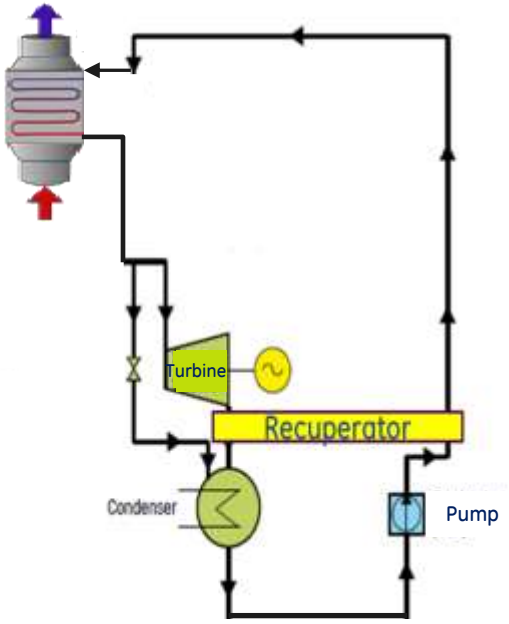


Comparison of steam and CO_2

Steam System



CO_2 System

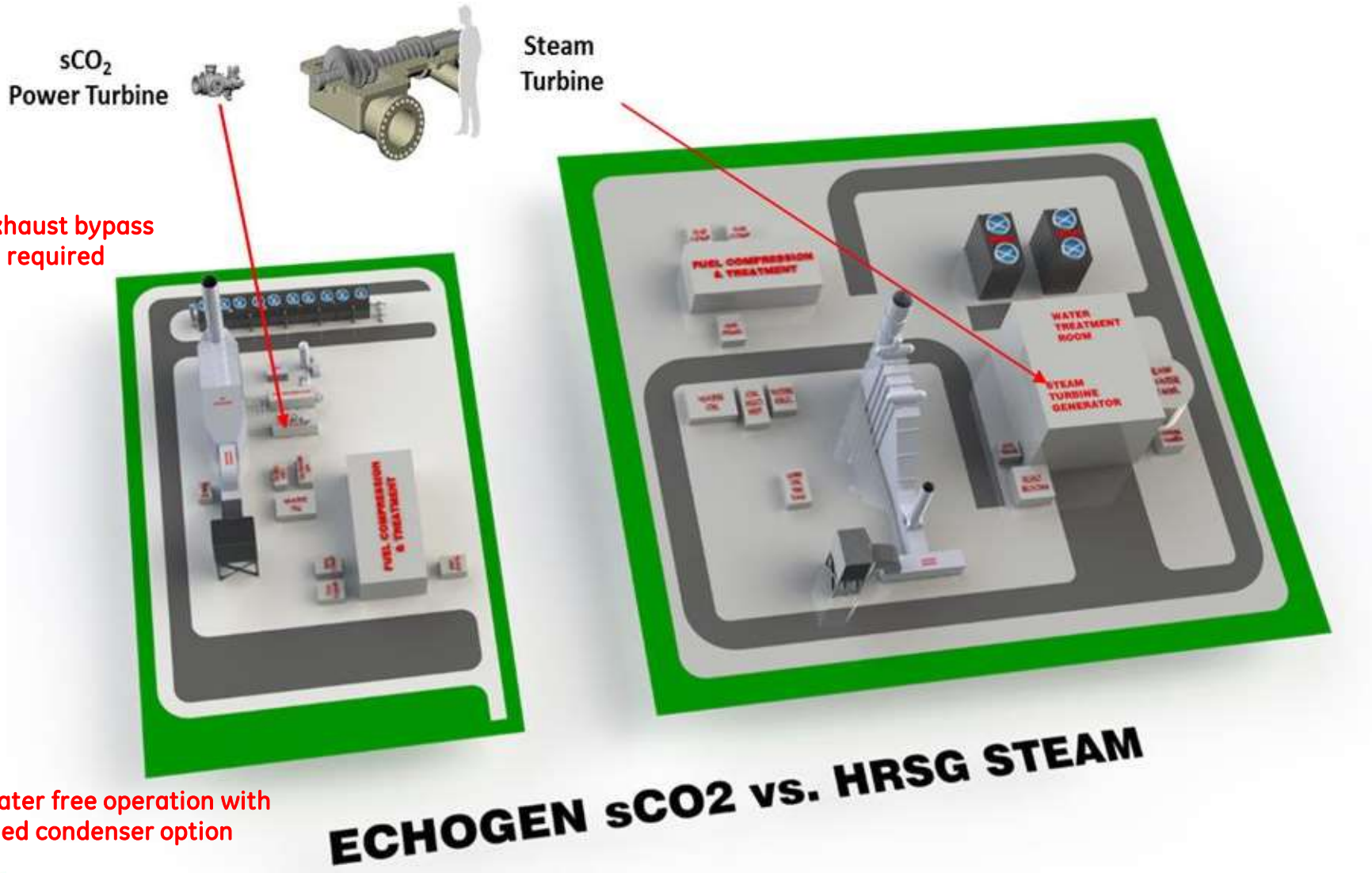


- No steam drum
- Single-pressure heat exchanger
- No "pinch point" design constraint
- No corrosion
- No water chemistry
- More compact
- Similar efficiency

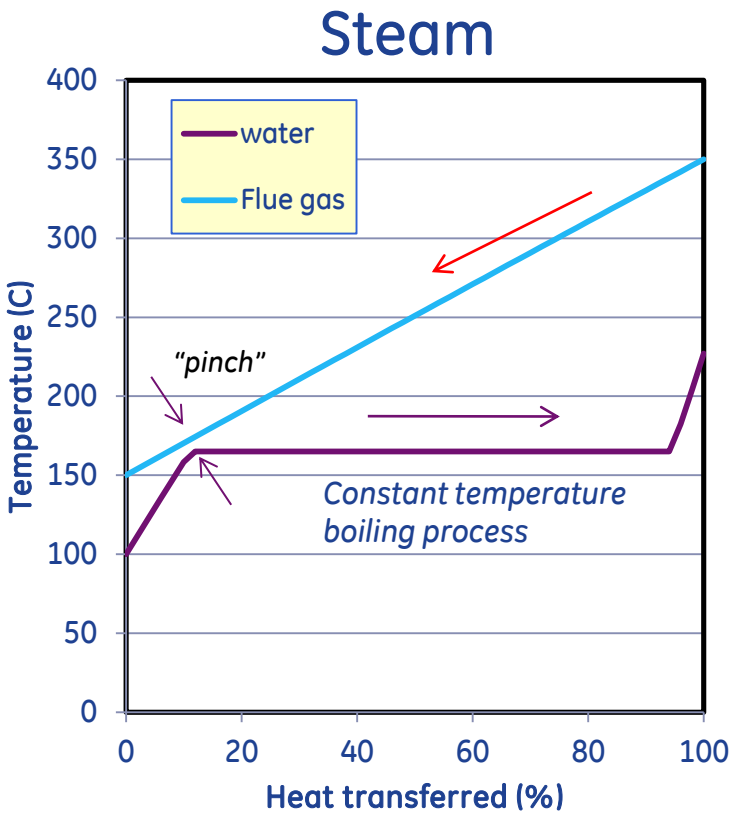
Note: exhaust-only systems are shown

Steam is the current industry standard for heat recovery.
We believe CO_2 will be the new standard very soon.

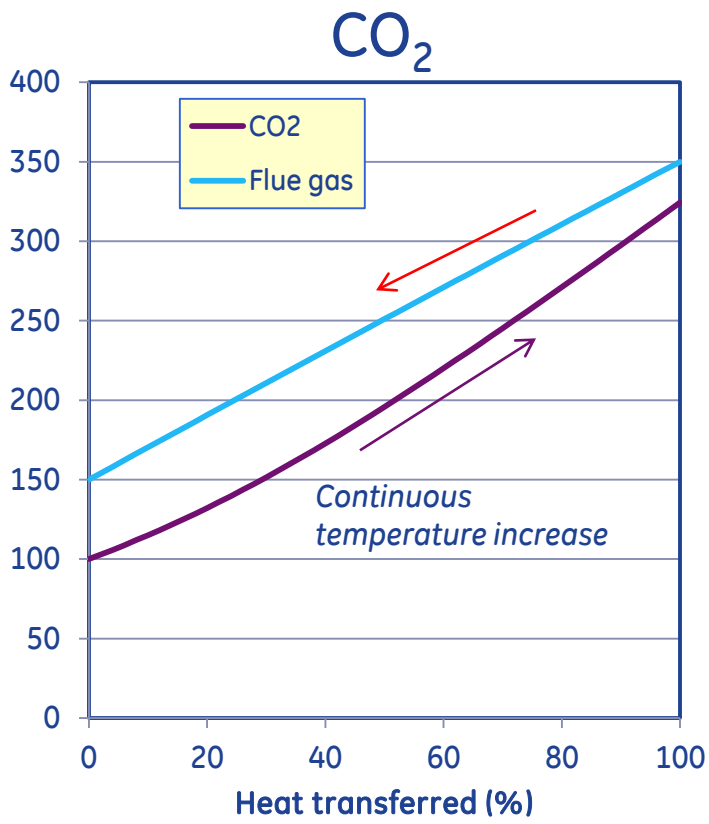
Land-based: 25-50% Reduction in Plant Footprint vs. Steam



Single-phase exhaust heat exchangers



- Phase change (evaporation) causes discontinuous temperature rise
- "Pinch point" requires multi-stage heat exchanger with multiple pressures to fully heat



- CO_2 remains supercritical and thus does not have "pinch point"
- Heat exchanger can be smaller and simpler than typical boiler

Key Markets

DRESSER-RAND Technology License

Oil & Gas

Gas Transmission, LNG
Offshore Platform, FPSO
(Gas Turbine, Gas Engine)

Power Generation

- - - Fossil Fuel - - -
(Gas Turbine, Diesel)

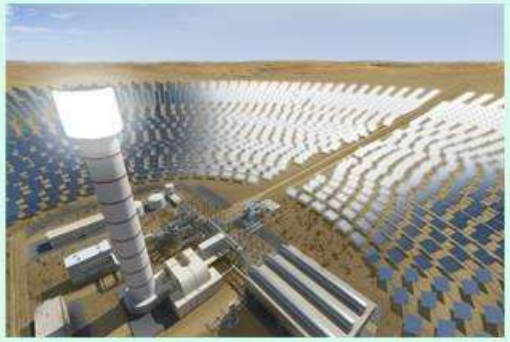
Marine

Cruise Ship, LNG, Naval
(Gas Turbine, Diesel)

GE Marine Technology License

Oil & Gas

Mechanical Drive
(Gas Turbine)



Power Generation

Alternative/Renewable
(Biomass, CSP, Nuclear)

Industrial

Cement, Steel
(Process)

DOOSAN Technology License

Echogen Technology Timeline

15KW Lab Unit

Available

EPS100 – 7,500 kW

Future products:

EPS200 – 15 MW

EPS7 – 500 kW

5KW Lab Unit

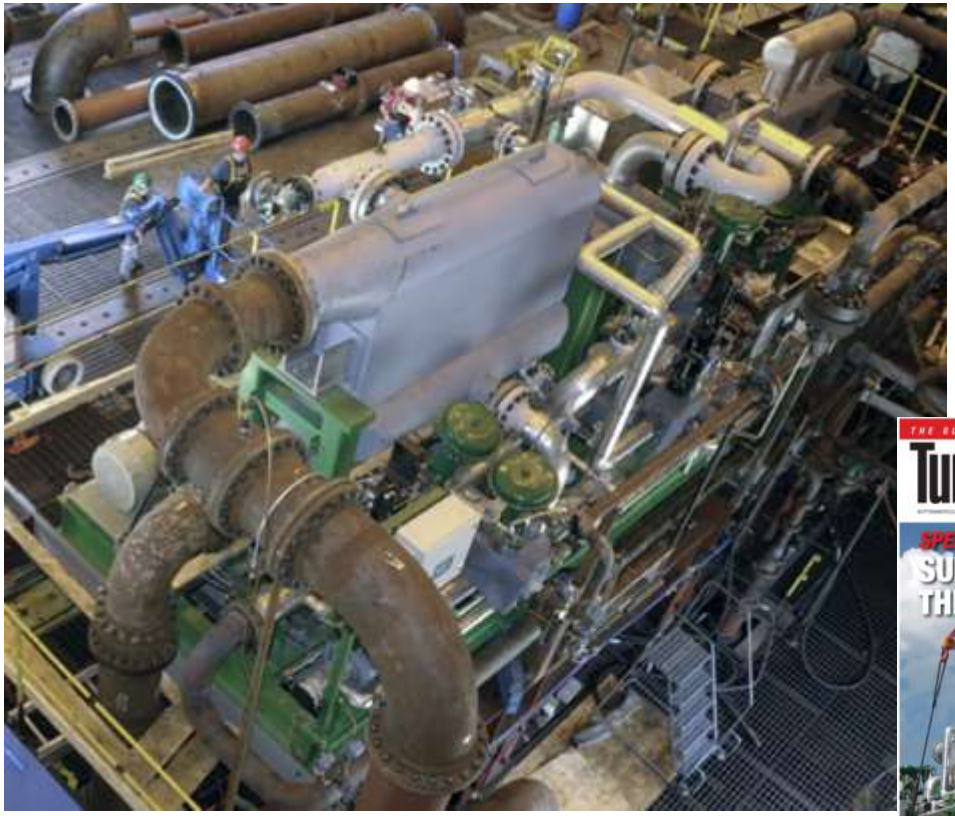
Demo Unit (250 kW)

Available 2016

EPS30 – 1,500 kW

2007 2008 2009 2010 2011 2012 2013 2014 2015 2016

Echogen EPS100 (7.5 MW)



Largest CO_2 power loop in the world; currently in negotiations for first commercial installations

EPS100 Testing – Key Accomplishments

- ✓ Phase I : Validation of components - completed
- ✓ Phase II: Full speed no load - completed
- ✓ Phase III: Performance - completed
- ✓ Phase IV: Endurance Run – complete

- System control and stability fully demonstrated
- Component performances meet or exceed expectations
- Turbopump run to max conditions
- Generator speed control stability demonstrated
- Power turbine electrical output = 3.1 MWe (max power at test stand conditions, limited by steam available)
- 270 hours turbo-pump run time
- 120 hours power turbine run time

EPS30 Marine System

Ship-specific solution currently being developed by Echogen

- Marine license with GE Marine
- 1.5 MW output (gross), 480V, 60 Hz
- Compatible with large medium-speed diesels and small gas turbines

Builds on prior Echogen technology development

- Single-shaft, dual-coil HX architecture
- Hermetically-sealed turbomachinery/alternator
- Seawater cooled (via closed freshwater loop)

ABS Approval-in-Principle

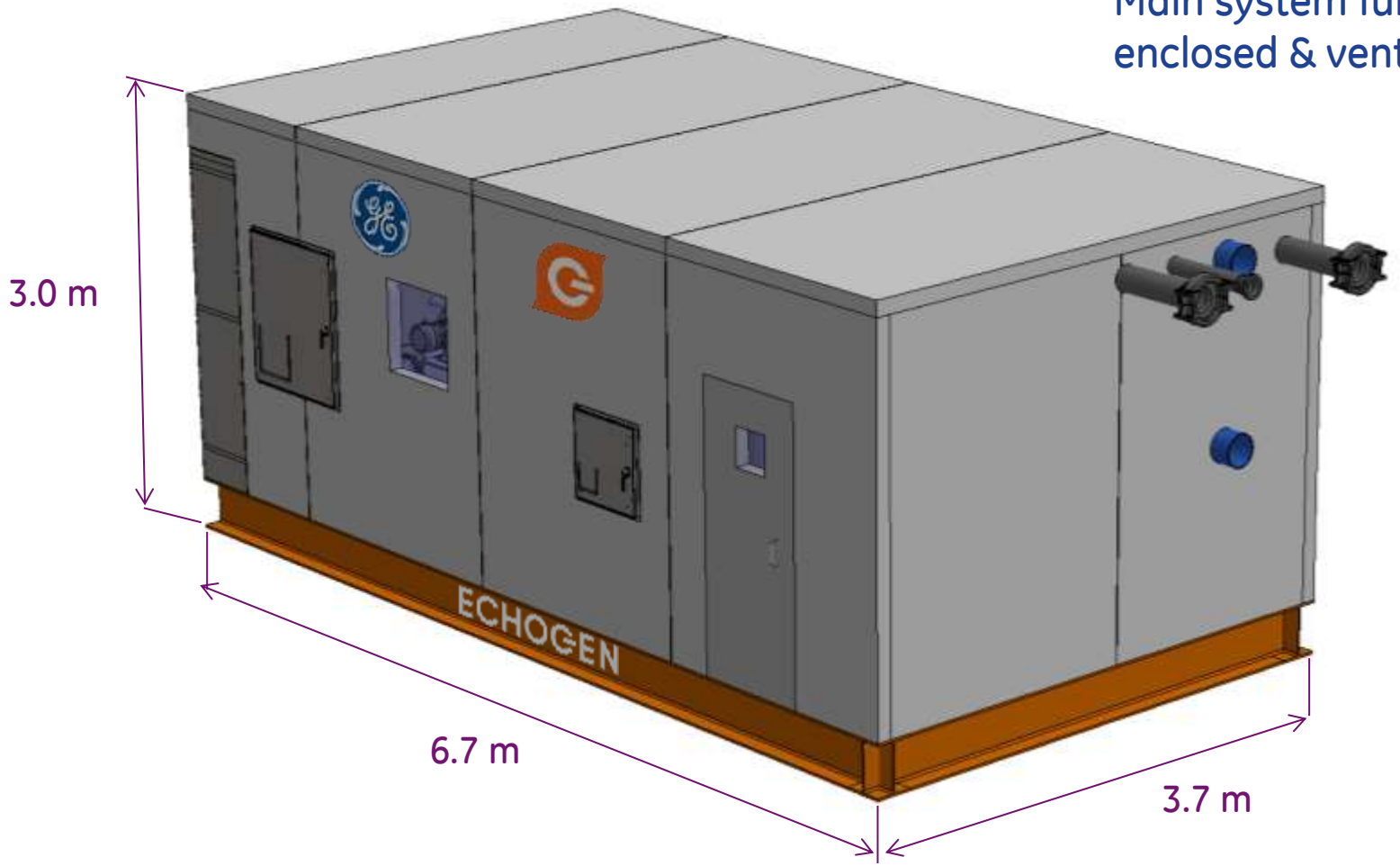
- Commercial marine installations

Commercial availability expected late 2016

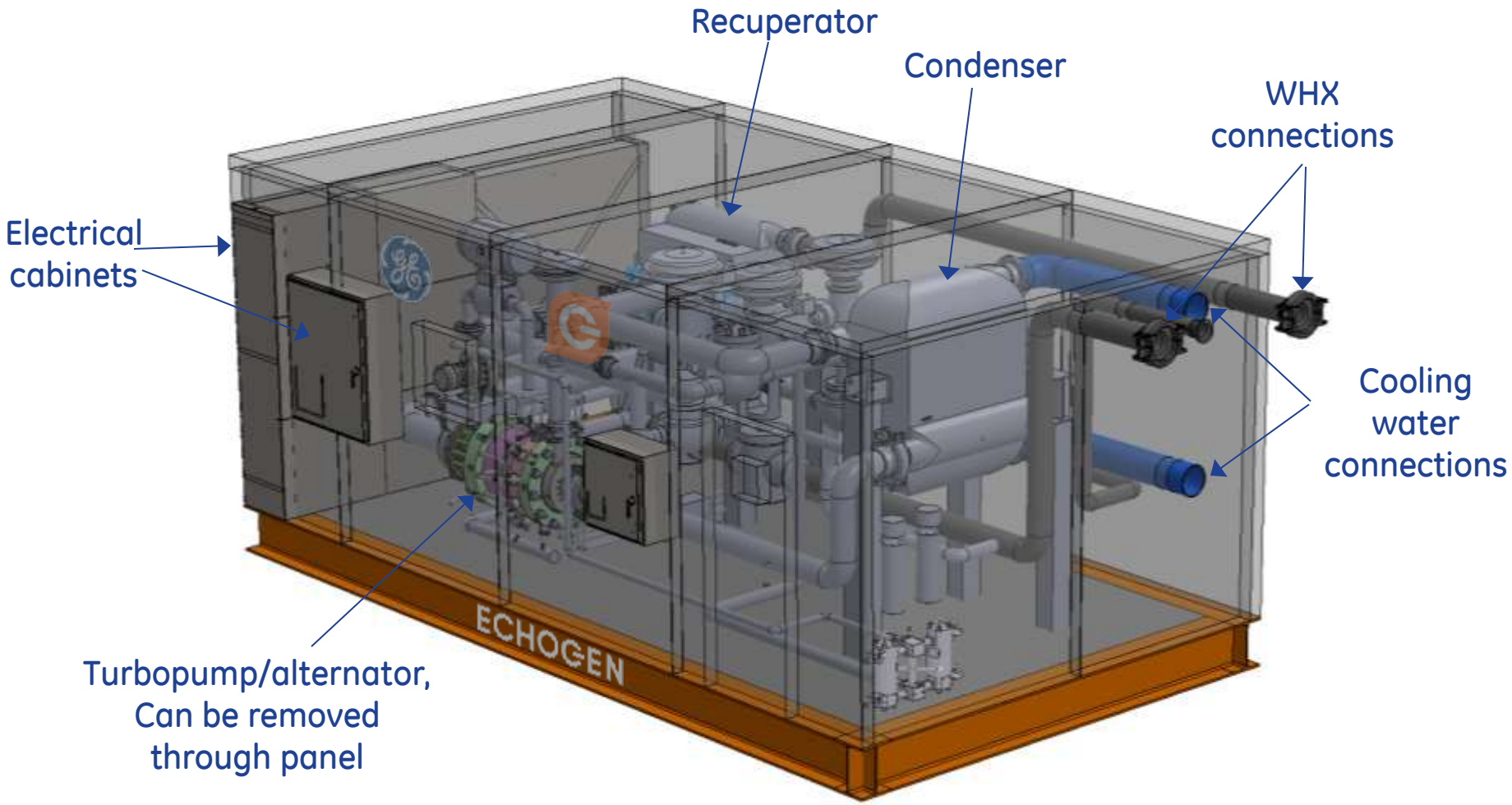
- Completed Preliminary Design
- Construction to be complete spring 2016
- Validation testing (land-based) 2nd half of 2016

EPS30 Enclosure

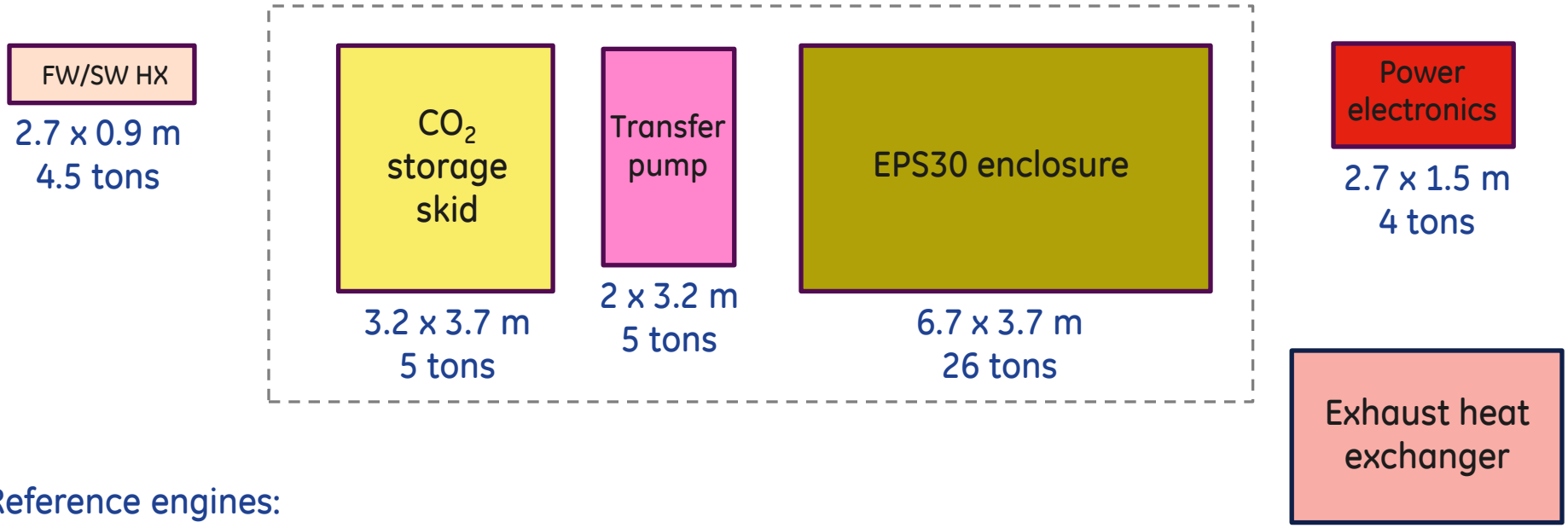
Main system fully enclosed & ventilated



EPS30 Enclosure



EPS30 System Layout



Reference engines:

LM500 GTG (4 MW)
7.0 x 2.4 m

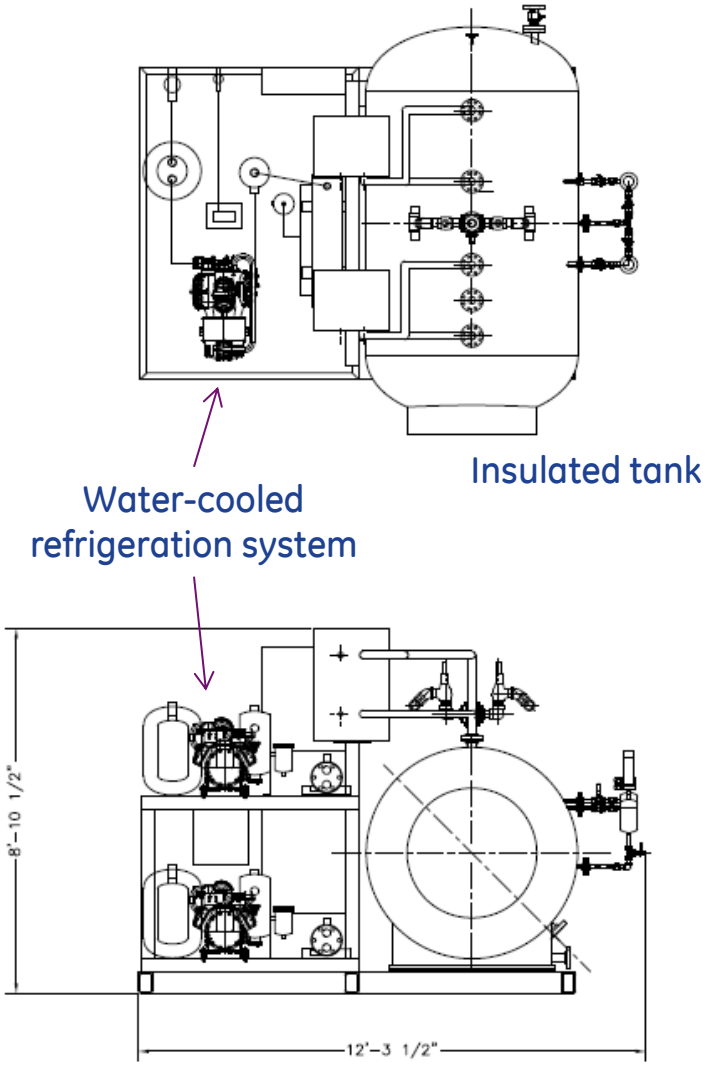
Cat C280-6G (1.6 MW)
7.1 x 1.8 m

Wartsila 16V46F (19.2 MW)
12.9 x 4.7 m
Engine only

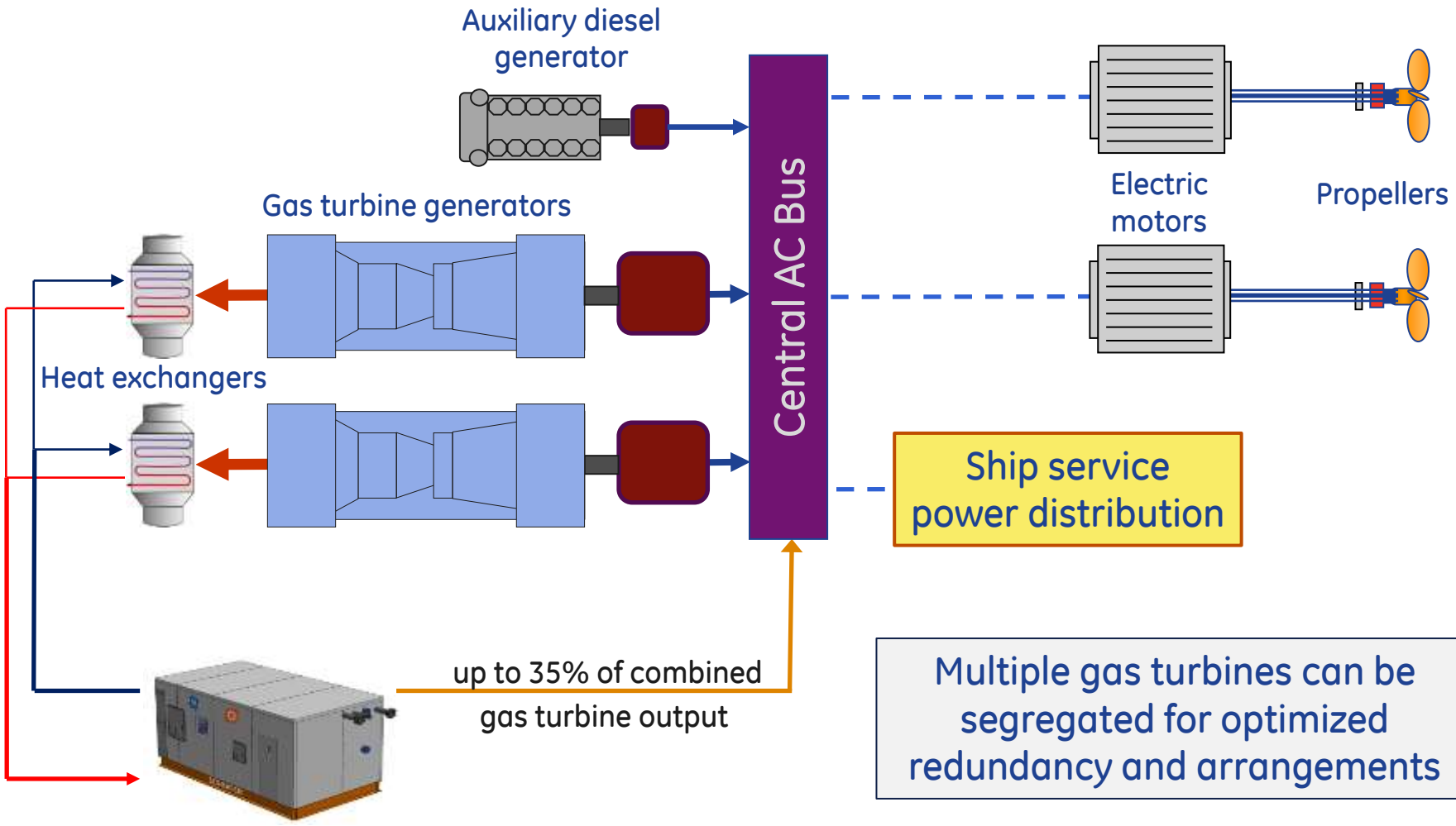
Scale: 1" = 8'

CO_2 Storage System

- Single-skid design incorporating tank and two refrigeration units
- ABS certified
- Internal tank baffle to prevent sloshing



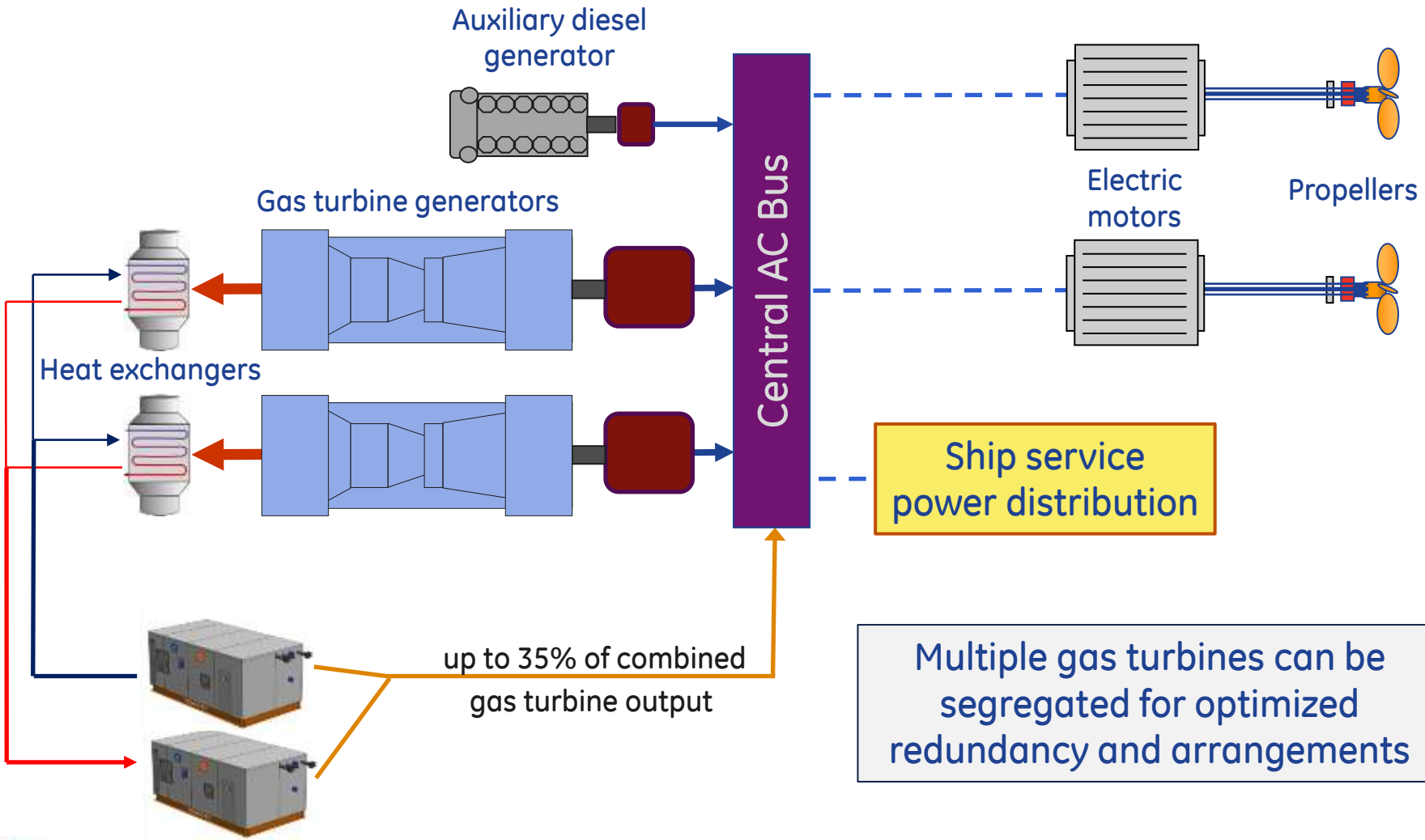
Electric drive installation



Multiple gas turbines can be segregated for optimized redundancy and arrangements

CO_2 heat recovery system(s)

Electric drive installation



Multiple gas turbines can be segregated for optimized redundancy and arrangements

CO_2 heat recovery system(s)

Summary

- Electric/hybrid ship architectures can take full advantage of exhaust heat recovery (EHR)
- EHR allows for up to 50% efficiency from a gas turbine power plant
- CO_2-based heat recovery has numerous advantages over steam including simplicity and reduced operating costs
- Echogen and GE are developing a class-approved marine solution to be available in 2016

Please visit us at the GE Marine Booth #3070