Liquid Air Combined Cycle Hybrid Energy Storage

TMCES Workshop
10-11 Aug 2021
San Antonio, TX

PINTAIL POWER

NATIONAL ENERGY TECHNOLOGY LABORATORY

CHALLENGE:
Bridge renewable and conventional generation

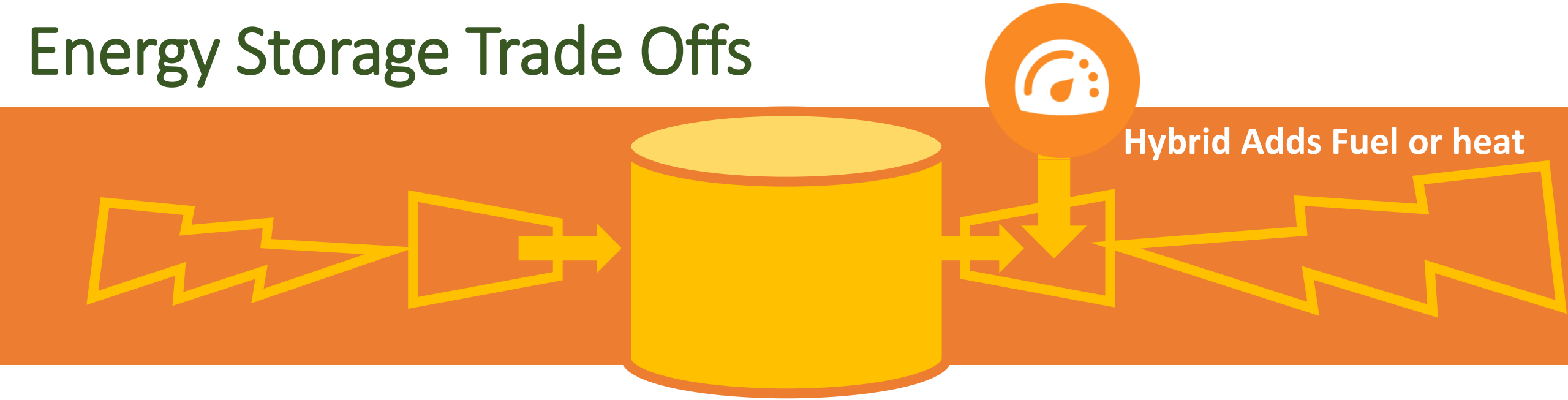
Low-cost, long-duration, large scale, low-carbon HYBRID ENERGY STORAGE

Why Hybrid Generation + Storage?

SYNERGY

- Capital cost
- Siting
- Technical
- Scalability
- Operating cost
- Operating flexibility
- Resilience
- Risk reduction
- Efficient use of clean fuels

Energy Storage Trade Offs



Charging Process

- Charging duration (power& efficiency)
- Cost per unit of power in
- Efficiency per unit of energy in

Storage Medium

- Safety
- Duration (quantity of energy)
- Density (Volume, acreage)
- Cost and availability of container
- Media cost per ton/gallon
- Mass/energy/exergy leakage rate
- Standby energy needs

Discharging Process

- Power output
- Cost per unit of power output
- Efficiency (electricity per unit of stored energy and fuel energy)

ASME PTC-53 Metrics: Both Hybrid and Pure-play

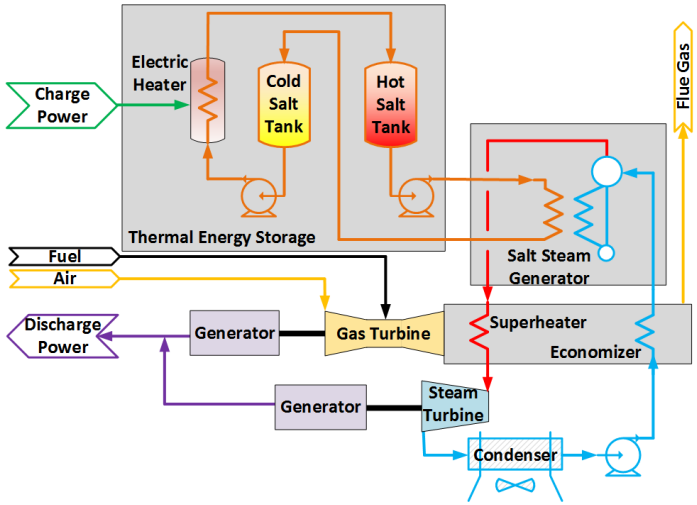
Symbol	Technical Factor	Economic Impact
P_D	Discharge power (MW)	CAPEX of discharge process ($/kW)
t_D	Discharge duration (h)	
P_C	Charge electric power (MW)	CAPEX of charge process ($/kW)
t_C	Charge duration (h)	
$E_C=P_Ct_C$	Charge electric energy (MWh)	CAPEX of storage reservoir ($/kWh)
$E_D=P_Dt_D$	Discharge electric energy (MWh)	
$FHR = Q_D/E_D$	Fuel Heat Rate $(MMBtu/MWh)_D$	Marginal Cost of Energy ($/MWh) $= FHR * Fuel\ Cost + PER * Power\ Cost$
$PER = E_C/E_D$	Primary Energy Rate $(MWh/MWh)_D$ (inverse Round Trip Efficiency)	PER impacts CAPEX of charge process and storage reservoir
$TR = t_C/t_D = PER\ P_D/P_C$	Time Rate (h/h)	Low TR increases Capacity Factor ≤ (1-TR) Low TR increases *Park Spread* (lowers Power Cost)

DOE and Industry Support for Hybrids

DE-FE0032016

Liquid Salt Combined Cycle

Pilot Plant Design



Electric Power Research Institute

Pintail Power LLC

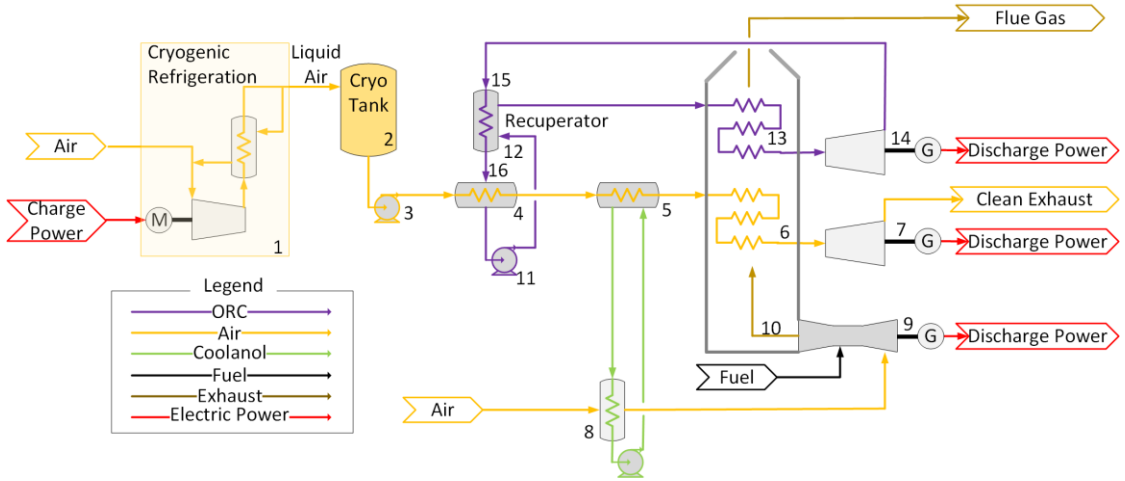
Southern Company

NexantECA

DE-FE0032002

Liquid Air Combined Cycle

Design Optimization

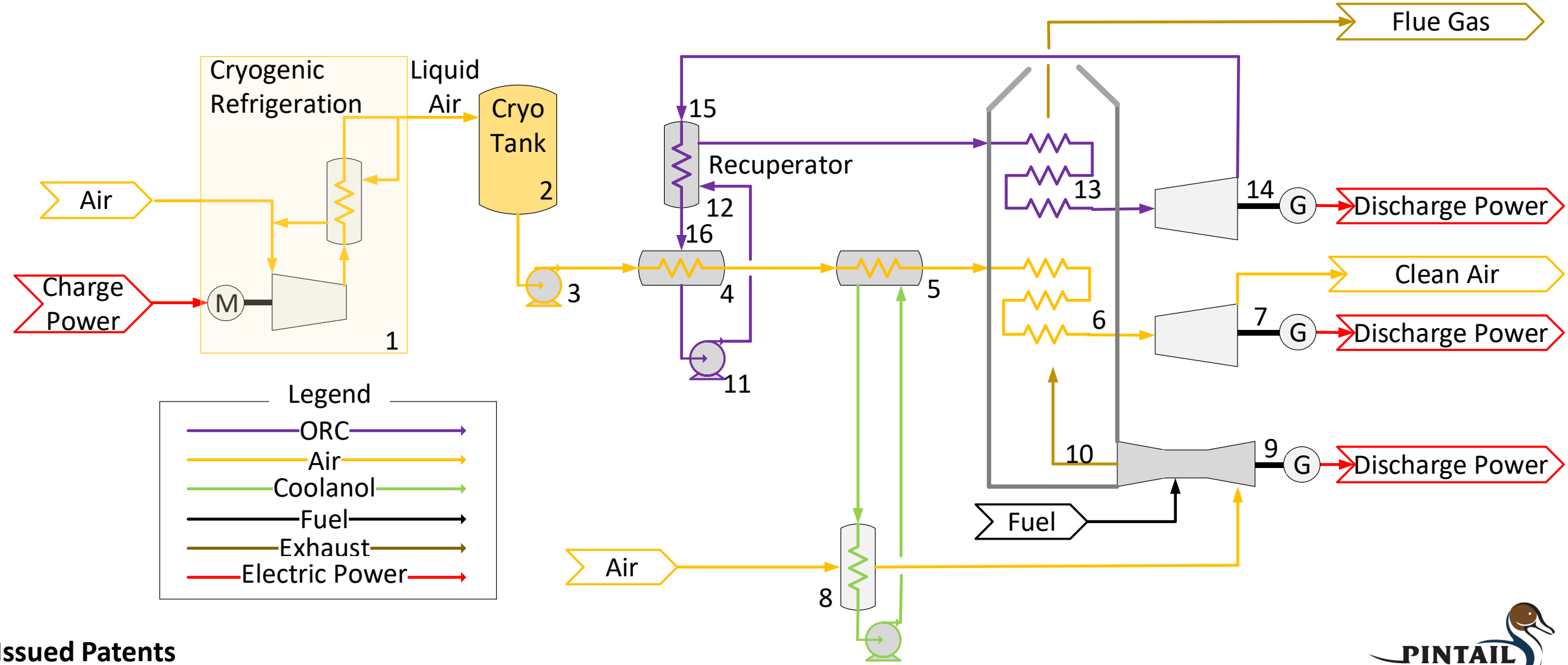


Southwest Research Institute

Pintail Power LLC

Wood

Hybrid: Liquid Air Combined Cycle ™ (LACC)



Issued Patents

US: 10,473,029; 10,738,696; 11,053,818;11,073,080; Europe: 3090198; 3365536

Liquid Air Combined Cycle (LACC ™) Hybrid

30,000 MWh/acre

- Safe high-density storage
- Daily/weekly/monthly/seasonal
- Standard cryogenic refrigeration plant
- Bullet or above/in-ground storage tanks
- Couples to any gas turbine or high-grade heat source
- Condensate recovery
  - Uses Higher Heating Value
  - Potential closed-loop electrolysis

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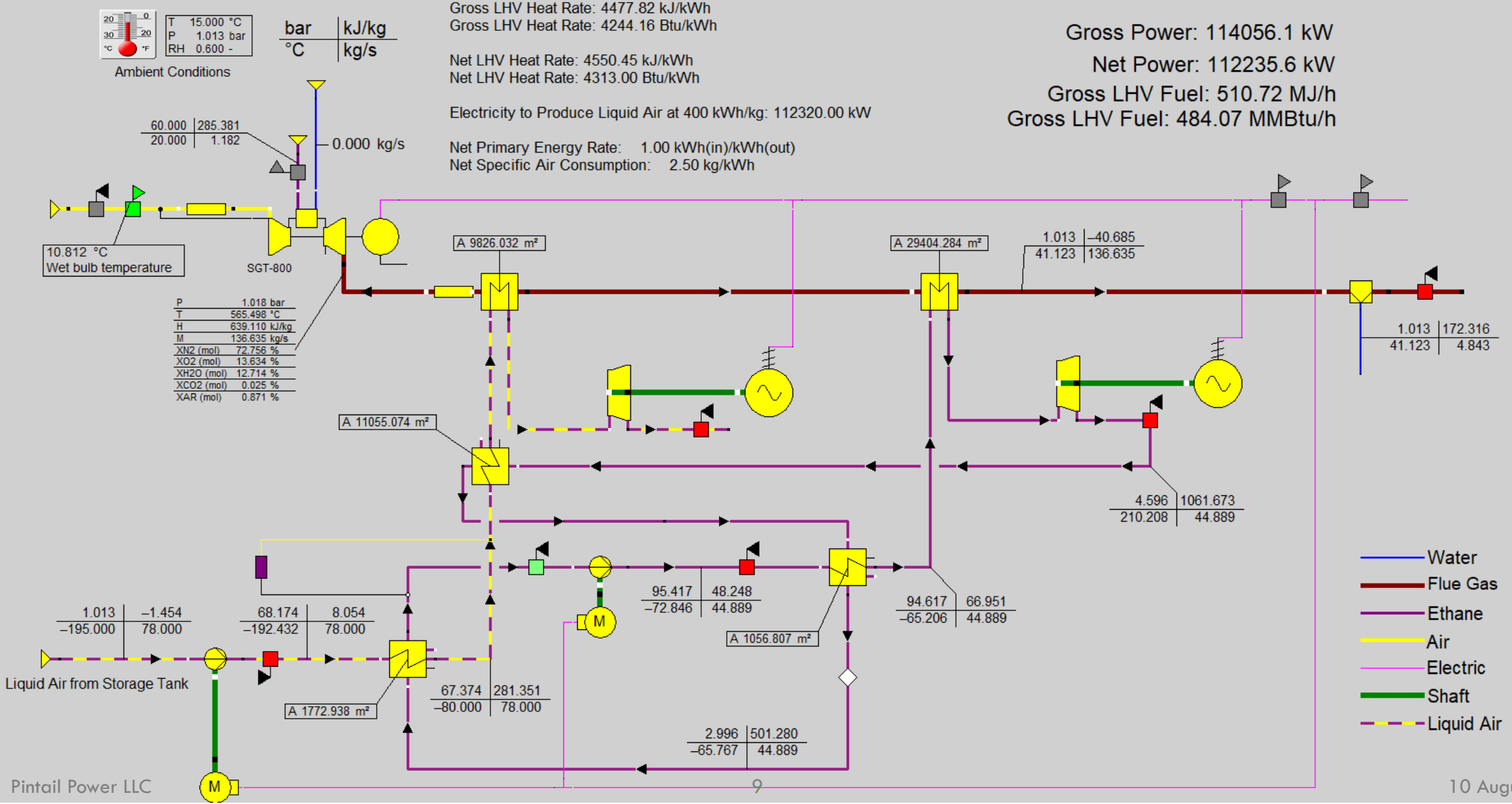
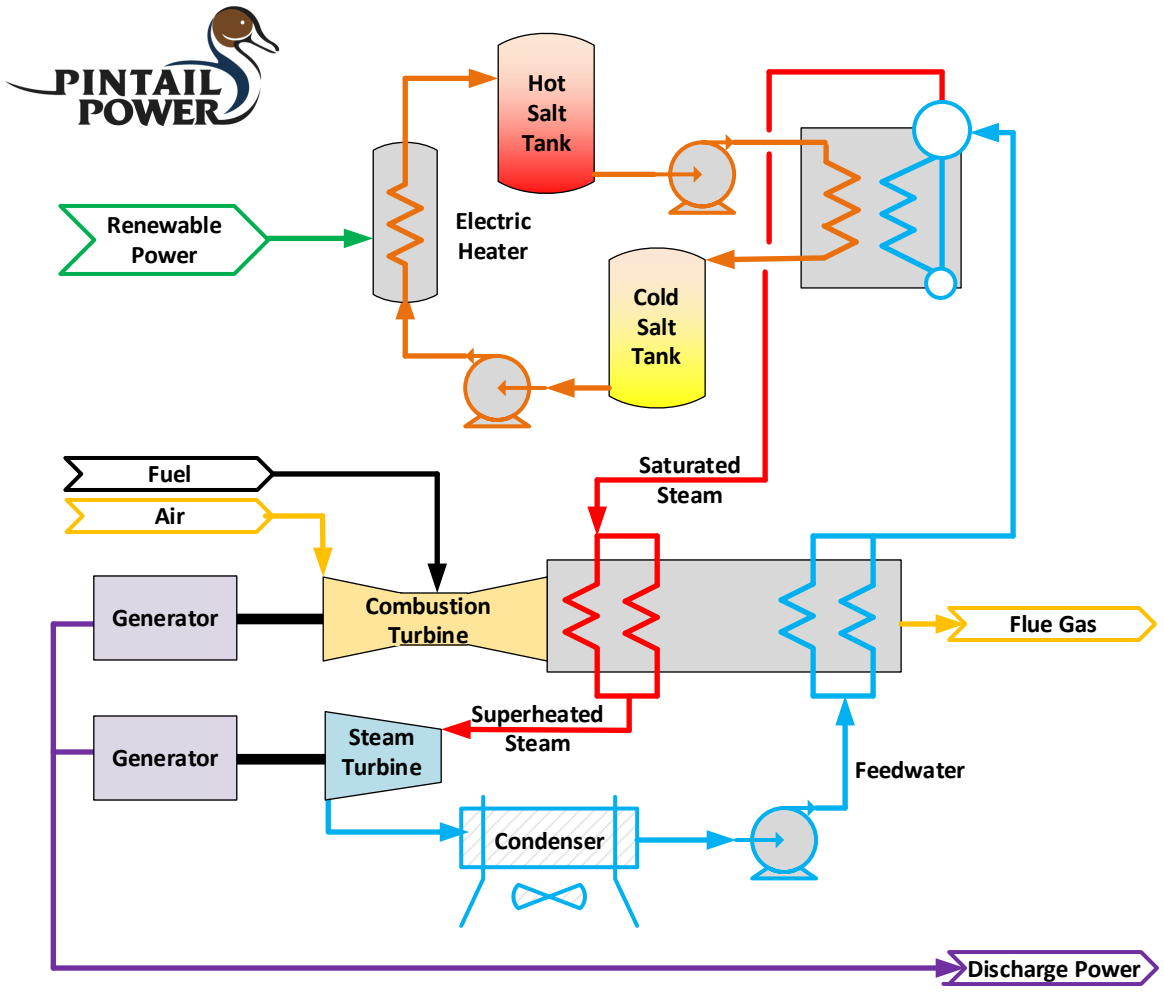
LACC Thermal Performance (Ebsilon)



Liquid Salt Combined Cycle ™ (LSCC) Hybrid

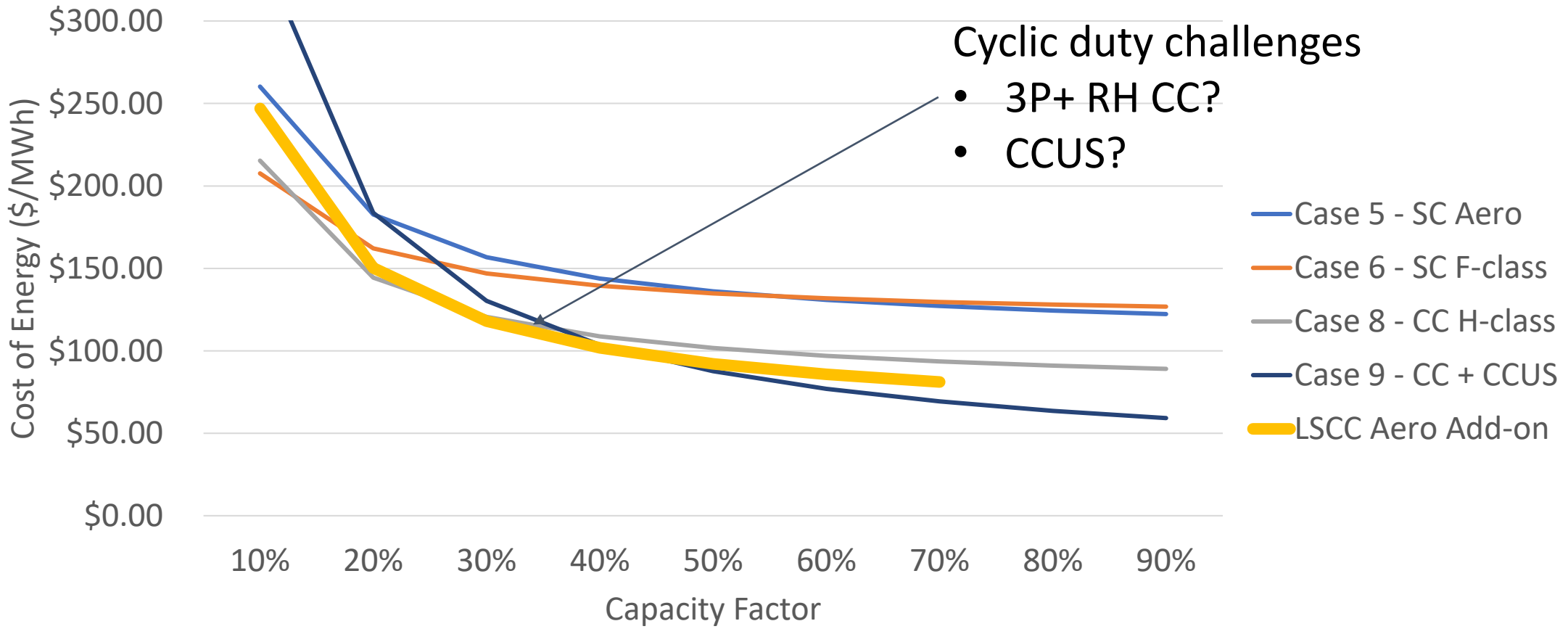


U.S. Patents 9,816,490; 10,113,535; 10,808,685, 10,982,570; others pending in US, Europe

- **Compact, Low-cost Storage**
  - $20-$30/kWh-AC marginal CAPEX
  - >700 MWh/acre
  - Intra/Inter-day (8 to 24 hours)
- **Superior Grid Coupling**
  - Fast charging + ancillary services
  - No rate/state of charge constraints
  - Fast discharge startup
- **Deployable now**
  - Add to existing gas turbines
  - Proven equipment, modest pressure & temperature conditions

Hybrids: Cheapest Way to Decarbonize

Hydrogen @ $1.5/kg ($11/MMBtu); N.G. @ $3/MMBtu; + CCUS



Sources: EIA 2020 S&L Cost and Performance Report, Pintail Power

- Low technical risk
- Equipment vendor and fuel neutral
- Deploy broadly with top EPCs
- Existing or new installations
- Retain good jobs and asset value
- **Ready today to meet tomorrow's needs**

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