Ingersoll-Rand Building Cooling, Heating and Power (BCHP) Integrated Energy System

Presented to
2003 Distributed Energy Resources Peer Review
by
Joseph Gerstmann
Advanced Mechanical Technology, Inc.

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BCHP Integrated Energy System Program Objective

Integrated system that generates steady grid independent power with concurrent production of cooling capacity and hot water year round.

- Secure electric power - 30 to 100 kWe
- Exhaust-driven, air-cooled, cooling system
- Factory integrated, turnkey product
- Custom package for supermarket applications
- Single-skid, roof-top installation

Ingersoll-Rand BCHP Team

- IR Energy Systems (Prime)
  - Microturbine manufacturing, sales, installation, financing, service, energy systems management programs.

    Project Manager. Work on packaging, integration, and cost reduction.
- IR Hussmann
  - Worlds largest manufacturer of equipment for supermarkets, convenience stores, food service industries, and commercial/industrial refrigeration, including cold storage warehouses and processing plants.

    Support development of the package that is attractive to supermarkets. Assist in commercialization.

Ingersoll-Rand BCHP Team

- Energy Concepts Company (ECC)
  - Developer of ammonia water absorption systems.

    Optimize and design absorption system to fit Powerworks
- Advanced Mechanical Technology Inc. (AMTI)
  - Developer of advanced heat transfer products.

    System modeling and analysis; design and development of interface heat exchangers.

PowerWorks BCHP Concept

- Packaged CHP system for supermarkets
- 70 kW gas-fired PowerWorks microturbine
- 15 RT (@ 95°F) exhaust-heated absorption chiller
- Chiller output used for Turbine Inlet Air Cooling (TIAC)
  - Increases power output and efficiency of turbine
  - Solves problem of reduced power output at high ambient temperatures
- Balance of chiller output is used for supplemental cooling (e.g., low-temperature refrigerant subcooling)
- Chiller heat rejection (condenser, absorber) may be used for water and space heating

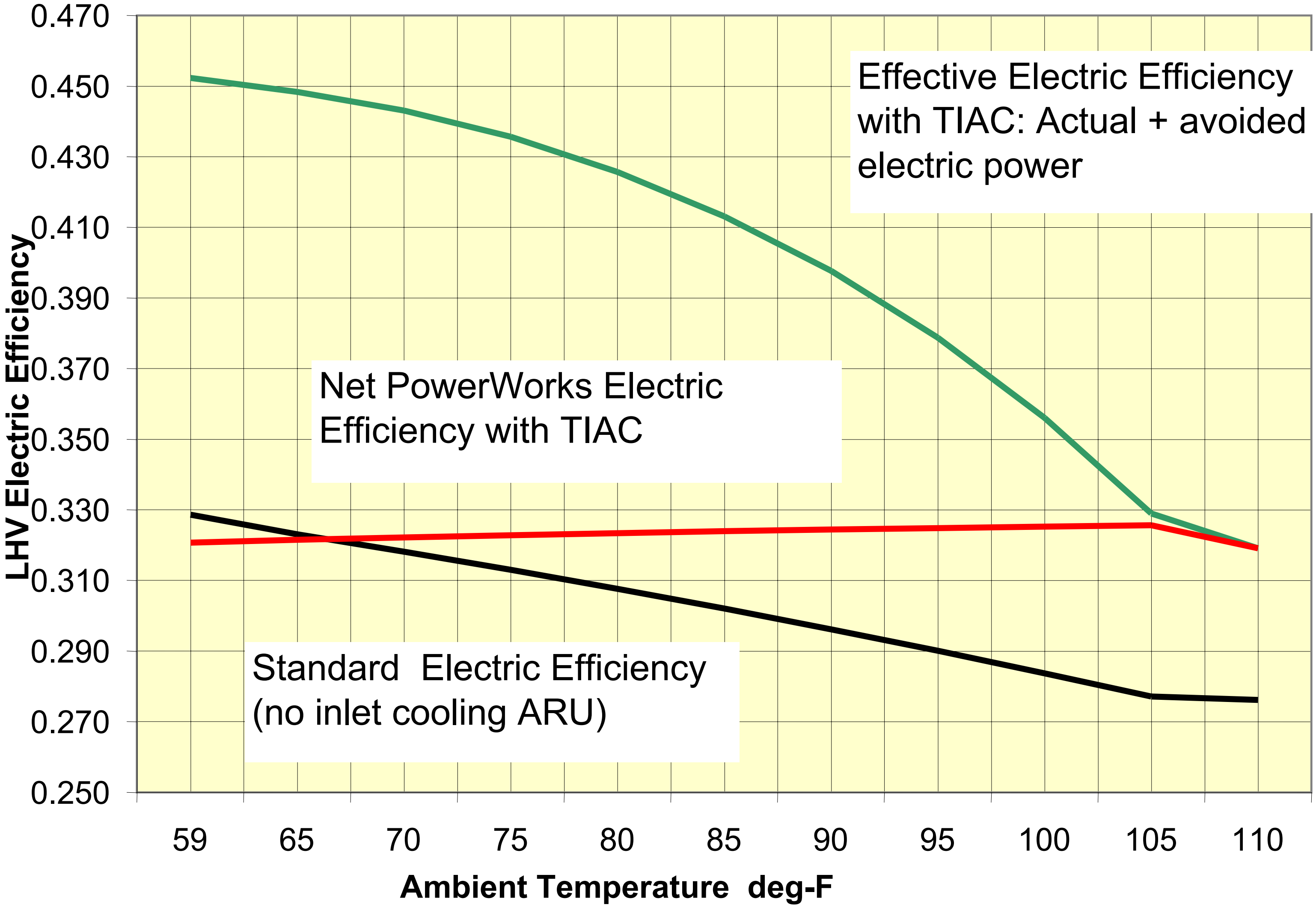
Why Refrigerant Subcooling?

- Refrigeration accounts for 50% of supermarket electrical load
- Low-temperature (-20°F) refrigeration requires ~2.5 kWe/ton
- Subcooling refrigerant at +50°F increases cooling capacity at -20°F at 1:1 ratio with no increase in compressor power
- Thermally activated refrigerant subcooling @ 50°F:
  - Achieves ~0.7 COP
  - Displaces up to 0.5 kWe/kWth; i.e., 50% efficiency
  - Fixed instead of variable evaporator temperature
  - Glycol loop provides simple interface

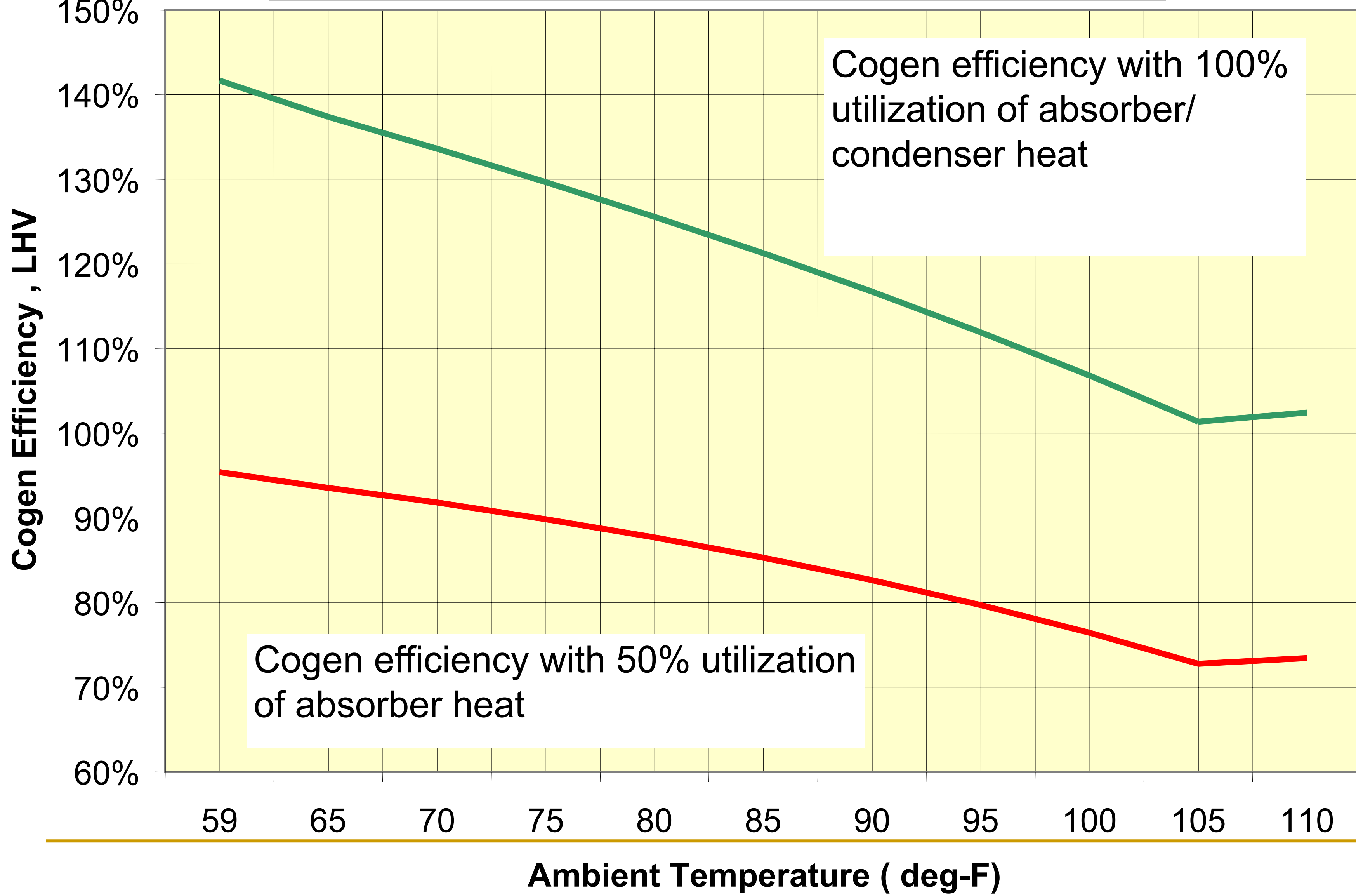
BCHP Package Summary

- Small well integrated package
- Steady grid independent power
- Minimal maintenance, annual service visit
- BCHP package at 95°F
  - 75 kWe
  - 100 kW or more of 140°F hot water
- BCHP Package at 59°F
  - Up to 100 kWe
  - Or 70 kWe plus 20 tons of subcooling displacing up to 50 kWe of compressor power
  - In excess of 100 kW of 140°F hot water

Integrated System Performance



$$\eta = \frac{\text{Electric power + Cooling "tonnage" + thermal heating}}{\text{Fuel input}}$$



BCHP Operating Cost Savings

City	PowerWorks Only		PowerWorks with TIAC, Subcooling, & Cogen	
	Savings	Run Time	Savings	Run Time
San Francisco, CA	$16,107	67%	$33,476	67%
Los Angeles, CA	$15,273	67%	$29,640	86%
New York, NY	$8,136	66%	$24,188	67%
Phoenix, AZ	$7,282	86%	$22,252	100%
Huntsville, AL	$889	67%	$10,956	88%
Boston, MA	-	-	$9,699	66%
Chicago, IL	-	-	$7,718	67%
Baltimore, MD	-	-	$3,451	50%
Minneapolis, MN	-	-	$2,857	66%
Miami, FL	-	-	$2,161	38%
Denver, CO	-	-	$1,295	51%
Houston, TX	-	-	$1,195	46%

<u>Assumptions:</u>

ARU capacity = 15 RT @ 95°F / 21 RT @ 59°F

Subcooling load = 24 RT @ 95°F / nil @ 40°F

Space heating design-point load = 476 kW @ 0°F

35°F TIAC

Max cogeneration = 100 kW

PowerWorks™ Microturbine

70kWe model

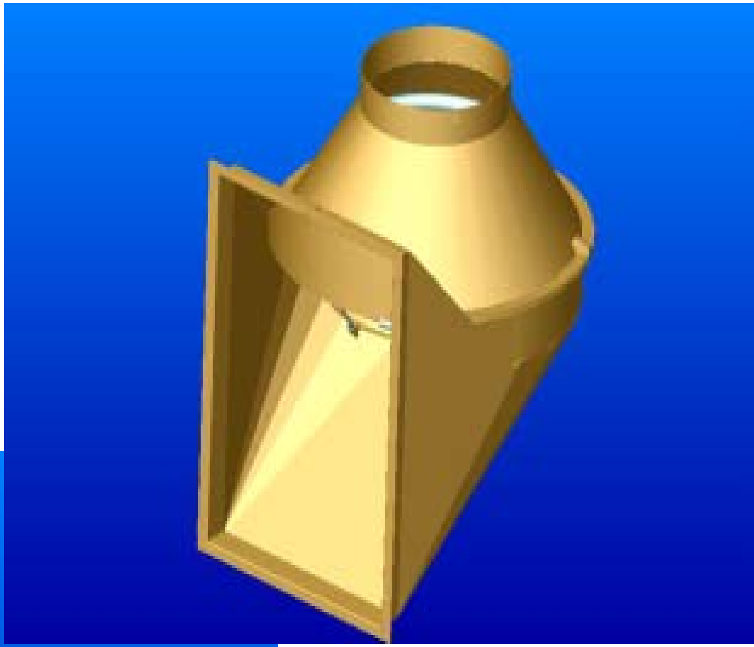
- Has 140% peaking power capacity on cold days (98 kWe)
- High efficiency
  - 30+% LHV electric
  - Up to 80% total with cogen
- Built-in gas booster
- Remote control and monitoring
- Low emissions
  - <9 ppmv NOx @ 15% O2 (natural gas)
- Dual fuel option (future)
- Compact, low noise enclosures
- 8,000 hour maintenance interval
- Up to 80,000 hour engine life

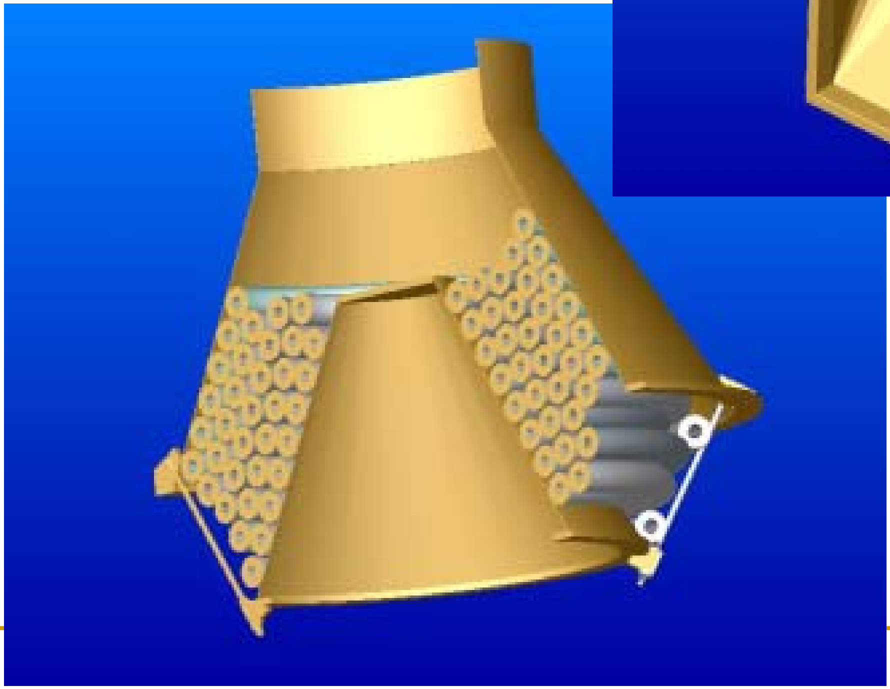
ECC Absorption System

- Small Size, 2.5’x5, 7 ft high
- 15 tons of cooling @ 95 F
- Higher capacities at lower ambient
- COP 0.6 - 1.0
- Up to 100 kW of hot water @ 140 F
- Air Cooled condenser & package
- Excellent Part Load Characteristics
- Low refrigeration temperatures
- Simple controls
- 8,000 hour maintenance interval
- 20 year life

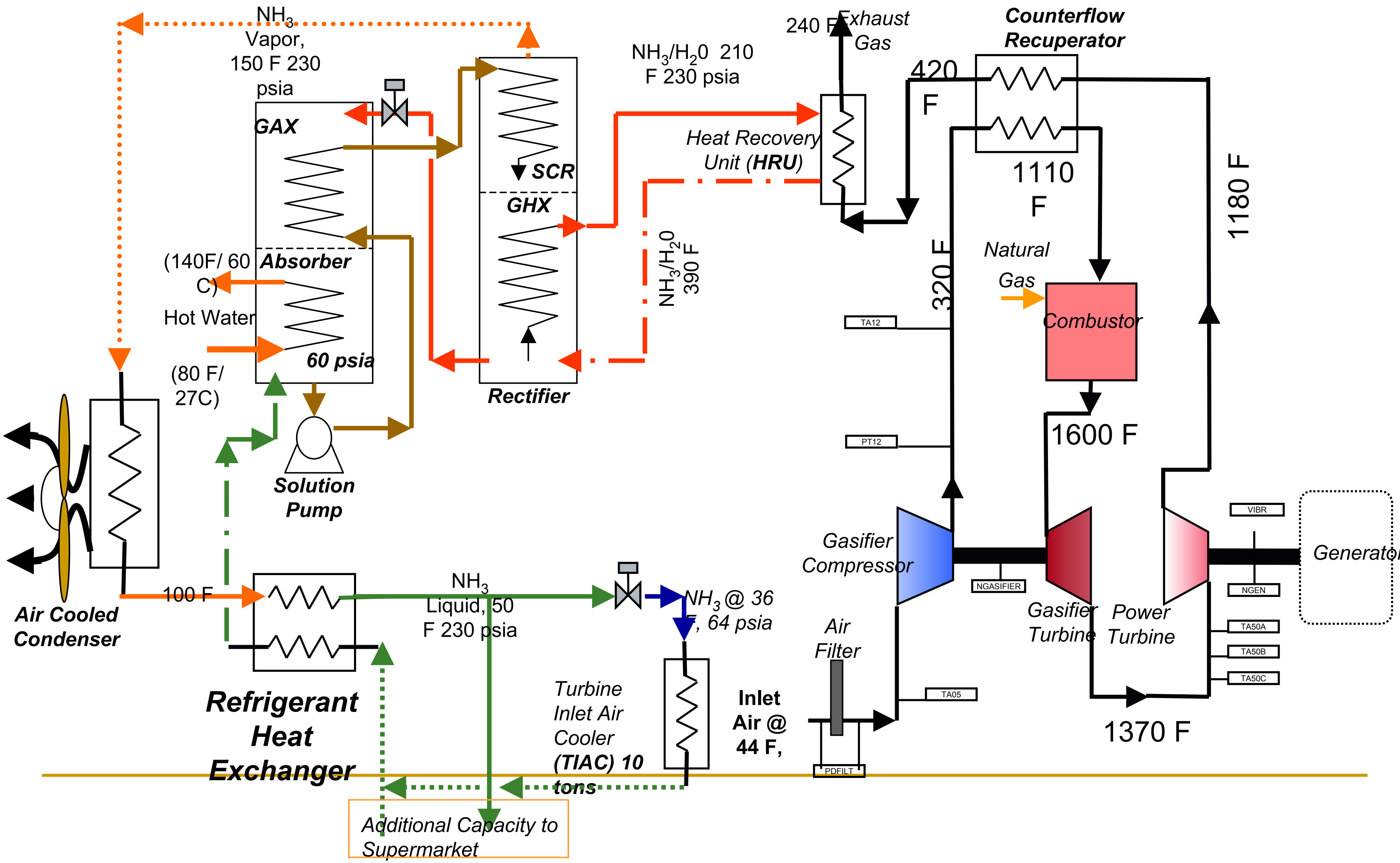
Heat Recovery Vapor Generator

- Compact coil mounts to turbine exhaust flange
- Lightweight stainless tubing with aluminum fins
- Low flow resistance minimizes back-pressure
- Can be dry-fired
- No need for bypass duct

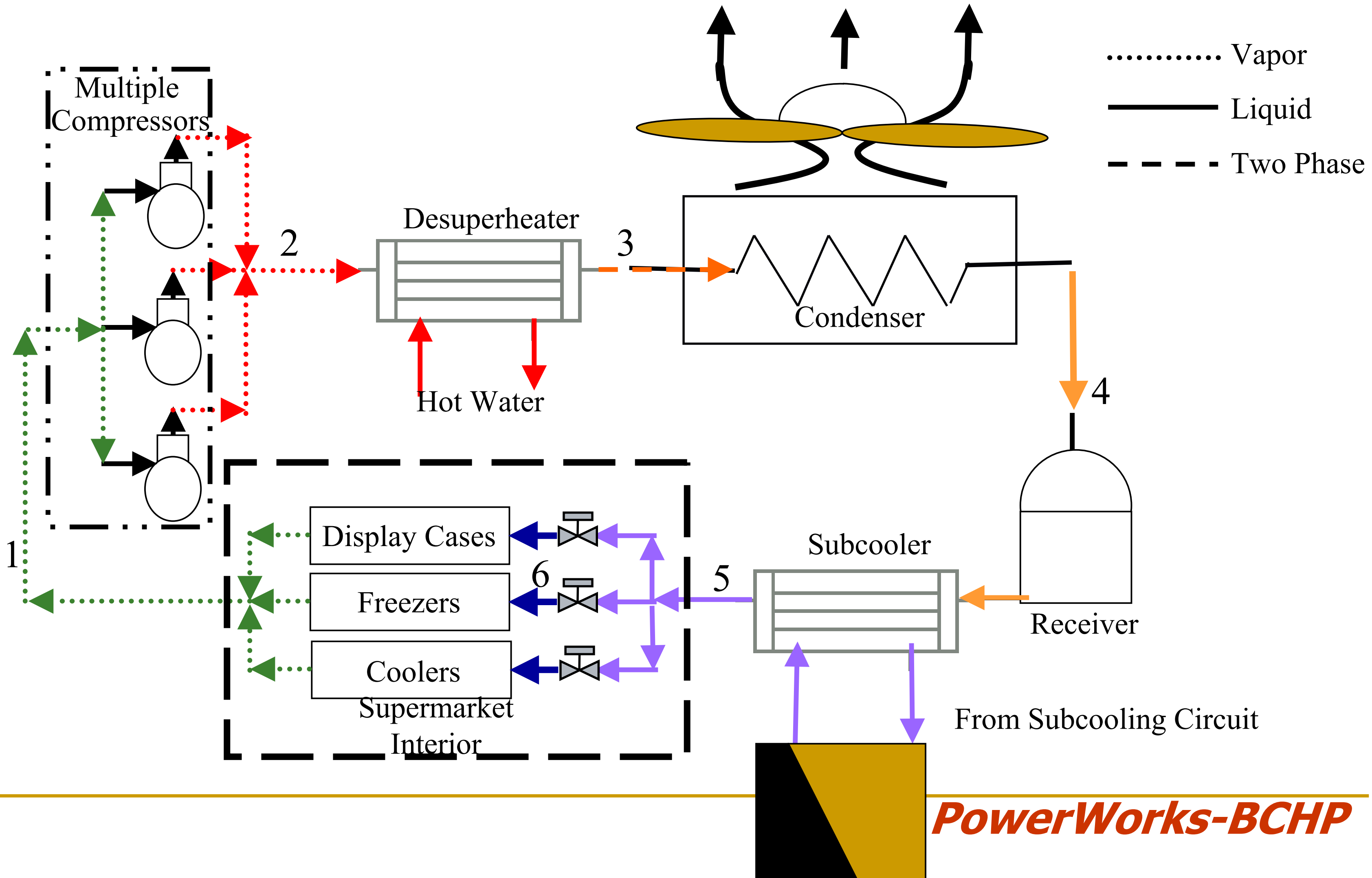




Turbine/Chiller Schematic



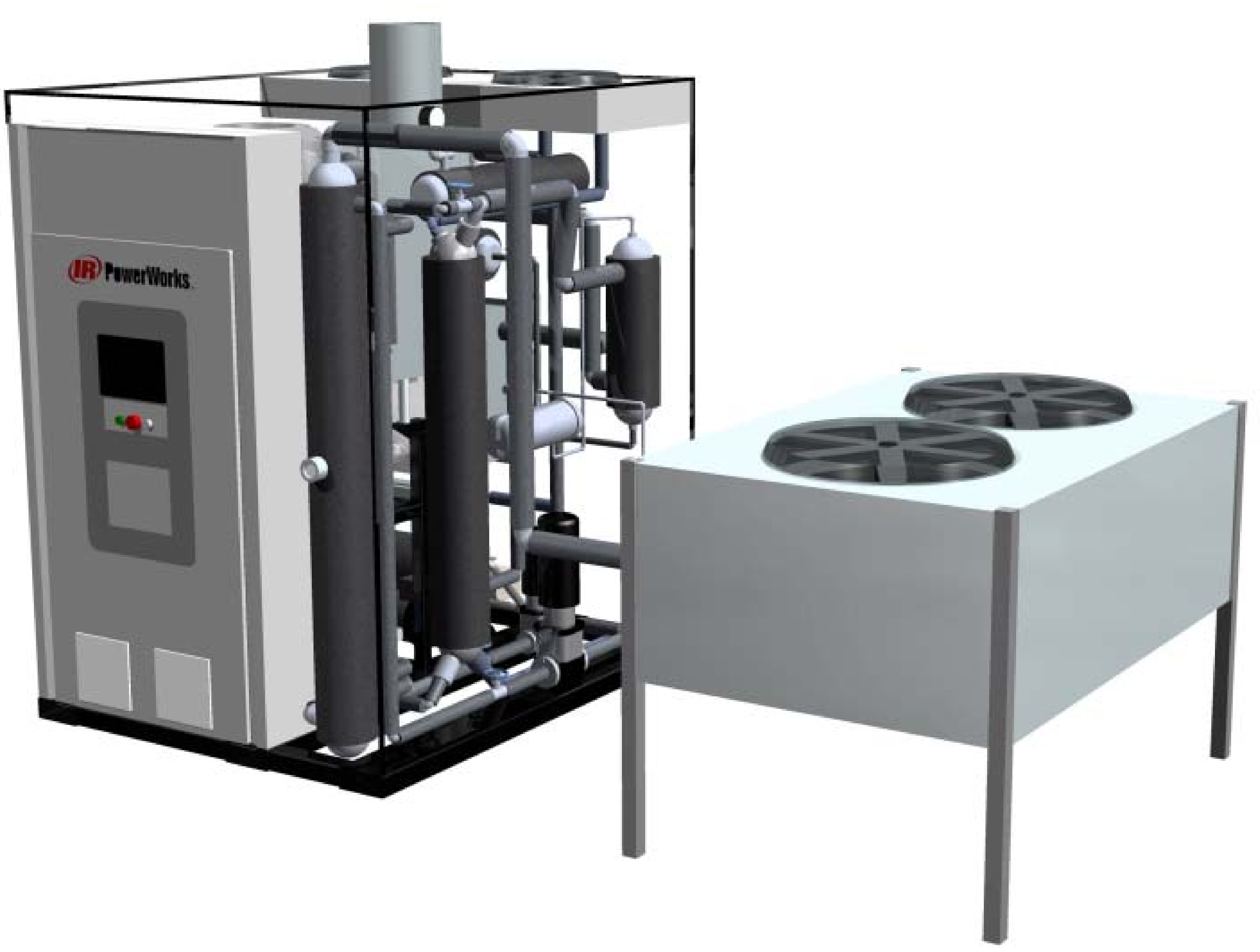
Standard Supermarket Refrigeration System - with **PowerWorks-Subcooler**

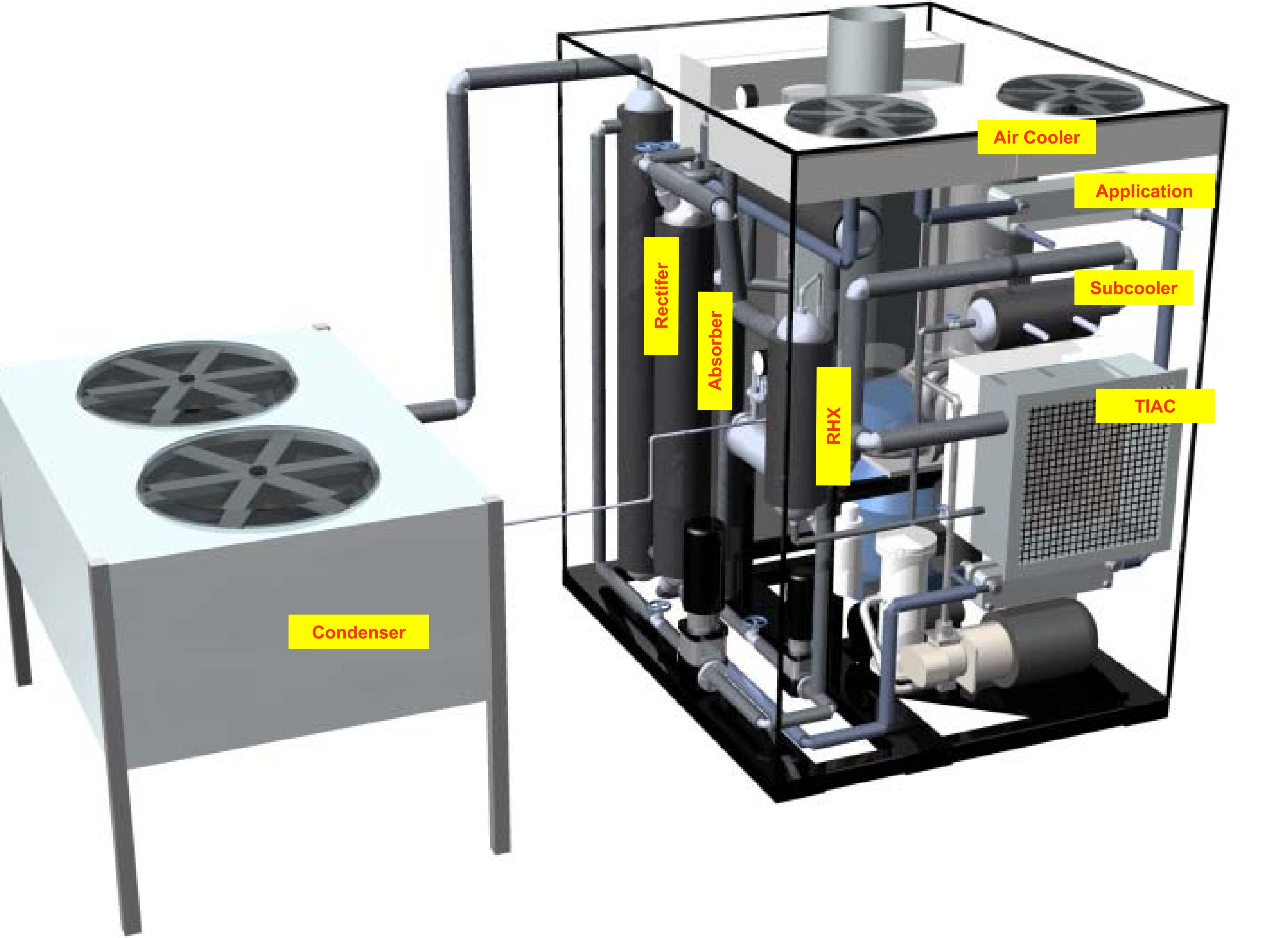


PowerWorks-BCHP

BCHP Package Layout/Specification

- **Single Skid 6x6 ft 7 ft high with detached condenser**
  - Factory assembled outdoor enclosure
  - Well packaged with minimum ammonia charge
  - Minimal installation cost
- **Common cooling loop**
  - Absorber cooling in series with PowerWorks lubrication system
  - Application heat exchanger and heat dump radiator
- **Year-round operation**
  - Base load operation
  - Cooling capacity utilized for engine inlet air cooling and supermarket subcooling
  - Heat available for space heating, desiccant regeneration, and hot water
- **Minimum maintenance**
  - No winterization
  - No cooling tower
  - Annual service visit: fans and pump


PowerWorks


Air Cooler
Application
Subcooler
Rectifer
Absorber
RHX
TIAC
Condenser

PowerWorks BCHP in Hussmann Enclosure

Test Results

- COP close to design
- Heat Recovery and cooling within 80% of design.
  - Low turbine exhaust temperature
  - Component heat losses
  - High parasitic power
  - Non-optimum flow rates
- First-generation test results indicate that there are no show stoppers.

Test Results

Parameter	Design	Actual	Design	Actual
Ambient Temperature – deg F	68	65	82	84
TIAC Outlet – deg F	40	43	48	46
Lift – deg F	69	57	66	74
COP	0.659	0.667	.675	.654
Heat Recovery – kW	75.3	69.6	76.4	60.7
Cooling - Tons	14.1	13.2	14.7	11.3

BCHP Program Plan

▪ Project Plan	Completed: Nov. 2001
▪ Commercialization Study	Completed: March 02
▪ Package System Concept Definition	Completed, May 02
▪ Optimization and Final Design	
❑ Thermo-economic optimization	Completed, July 02
❑ Preliminary hardware selection	Completed Sep 02
❑ Breadboard absorber unit build & test	July 02 - February 03
▪ Prototype Fabrication	
❑ Microturbine & Enclosure,	Completed Jan 03
❑ Absorber Prototype Addition	Completed Jun 03
❑ Commissioning at IR	Completed Aug 03
▪ Laboratory Testing	
❑ Testing	Completed Oct 03
❑ Reports	Ongoing

Future Development

- Controls
  - Improve stability
  - Hands-off startup and operation
- Components
  - Upgrade to achieve design capacities
  - Reduce refrigerant and working fluid inventories
- Reduce parasitics
  - Component sizing and selection
  - Balance flows
- Packaging
  - Complete single-skid unitary outdoor package

Future Development - cont

- Develop and implement improved operational strategies
  - Energy pricing & demand scheduling
  - Allocation of cooling between TIAC and subcooling
- Reduce System Costs
  - Simplify system design
  - Refine component design
  - Sourcing of key components
- Field Evaluation
  - Reliability
  - Performance
  - Economics
- Additional Applications
  - Larger sizes
  - Other engines (e.g., IC)
  - Other markets

Market challenges: First Cost !

- Utilize IR-Retail Solutions/Hussmann sales, installation and service
  - The market leader in this business sector
- Ship turn-key - standard product
  - Hold down capital cost
  - Hold down installation cost
- Advancements in integrated microturbine / absorption technology
  - Commonalty of subsystems (heat rejection, controls, packaging
  - Innovative heat exchangers used in NH3 absorber
- Design for ultra-high reliability and long service interval
  - Proven and conservative gas turbine design

Summary of Results

- TIAC
  - Boosts microturbine power and efficiency
  - Reduces $/kW at high ambients
- Single-effect Aqua-Ammonia Absorber
  - Achieves high COP from low-temperature exhaust without cooling tower
  - Provides secondary heat recovery at useful (140°F) temperature
  - High-glide desorber increases recoverable heat at high average input temperature for good cycle efficiency
- Heat Recovery Vapor Generator
  - Lightweight low-pressure-drop coil mounts directly on turbine exhaust flange
  - Self-draining design permits dry-firing; avoids need for bypass duct
- Refrigerant Subcooling
  - Practical CHP interface for supermarket (and other) refrigeration with high displaced power impact
- Energy Savings
  - Over 40% generated-plus-displaced electrical efficiency
  - Over 80% thermal efficiency