Industrial Heat Pumps

U.S.A. Perspective

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EPRI’s Vision

To be a world leader in advancing science and technology solutions for a clean energy future

EPRI’s Mission

Advancing safe, reliable, affordable, and clean energy for society through global collaboration, science and technology innovation, and applied research.

Together…Shaping the Future of Energy®

Three Key Aspects of EPRI

Collaborative

Bring together scientists, engineers, academic researchers, and industry experts

Independent

Objective, scientifically based results address reliability, efficiency, affordability, health, safety, and the environment

Nonprofit

Chartered to serve the public benefit

EPRI's History in Industrial Heat Pumps

EPRI | ELECTRIC POWER RESEARCH INSTITUTE

Topics:
End use
Electrotechnology
Heat pumps
Technology utilization
Electrification
Industry

EPRI EM-6057
Project 2783-11
Final Report
October 1988

Industrial Heat Pump Manual

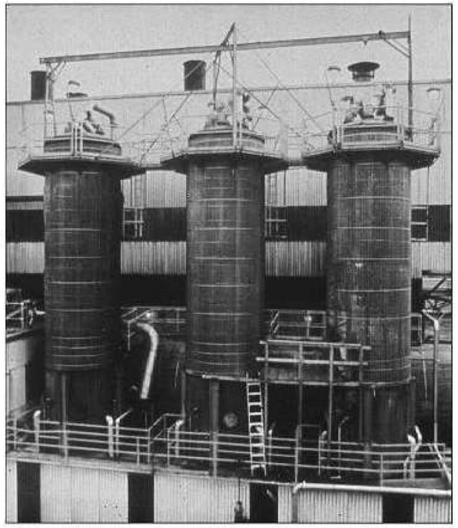
Technical and Applications Resource Guide for Electric Utilities

Prepared by
Linnhoff March, Inc.
Leesburg, Virginia

TECHCOMMENTARY

INDUSTRIAL HEAT PUMPS

Published by the EPRI Process Industry Coordination Office — Vol. 1, No. 4, 1988



An MVR heat pump conserves heat in this six-stage falling-film evaporator at a paper mill.

CAPTURING WASTED HEAT

There are often better ways to supply heat to industrial processes than burning fuel in steam boilers or process heaters. For many evaporation, distillation, and drying processes, industrial heat pumps represent a lower total energy cost alternative to fuel-consuming options.

For many industrial processes, energy costs represent over 25% of total manufacturing costs. Where applicable, industrial heat pumps can capture relatively low temperature waste heat and use a modest amount of mechanical energy to elevate the waste heat to a temperature that supplies process energy needs.

The unique heat recovery feature of heat pumps reduces energy costs for businesses such as

- Food processing
- Lumber drying
- Papermaking
- Chemical processing
- Petroleum refining.

Besides reducing costs, industrial heat pumps avoid gas discharge issues associated with direct fuel consumption.

ADVANTAGES

When properly applied and designed, heat pumps yield many benefits:

Lower energy costs — Heat pumps can substantially reduce energy costs, sometimes by 50% or more. Corresponding cooling requirements are also reduced, an important consideration when cooling water supply and treatment costs are high.

Reduced emissions— Unlike boilers and furnaces, electric-driven heat pumps do not produce pollutants. Installing heat pumps can help plants maintain or increase production capacity without violating ever-tightening restrictions on air and water emissions.

Increased capacity— Using a heat pump can overcome limitations in a plant's heating and cooling system. For example, using a heat pump may avoid the purchase of a steam boiler and cooling tower, which might have been required to evaporate and condense water in a product concentrator.

Improved product quality— Heat pumps generally provide heat at lower temperatures than other alternatives. As a result, heat-sensitive products avoid contact with localized hot spots, which degrade product properties and performance.

Less floor space— Heat pumps often require less space than competing energy supply systems. Heat pumps may be the solution to a tight layout design

TechCommentary / Vol. 1 / No. 41

Started in the 1980s!

EPRI's History in Industrial Heat Pumps (Continued)

TECHAPPLICATION

Heat Pumps in Petroleum Refining

An EPRI Process Industry Publication Vol. 4, No. 2, 1992

The Challenge: Simplifying Operations to Reduce Cost

In 1988, Diamond Shamrock, an independent petroleum refining and marketing company, determined that there was an opportunity to expand into new markets by upgrading refinery propylene, a by-product of the fluid catalytic cracking process. The company planned to construct a propane/propylene splitter to produce 500 million pounds per year of 99.5% purity propylene to be supplied as feedstock to polypropylene manufacturers.

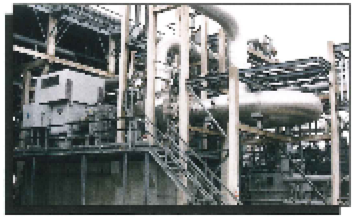
The selected site at Mont Belvieu, Texas offered underground salt-dome storage with a capacity to hold several million barrels of PP mix feedstock, propane product, and propylene product, but lacked the conventional cooling water and boiler steam needed to operate the splitter. To avoid the construction and maintenance expense of cooling and heating systems, Diamond installed an electric heat pump and saved more than $2 million dollars in construction costs.

The Conventional Way

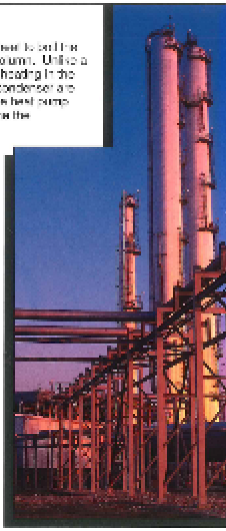
A conventional PP splitter uses steam from a boiler to vaporize liquid from the bottom of the column in a reboiler. The more volatile propylene vapors flow up the column and are cooled and condensed in a condenser, typically using cooling water. In a conventional splitter, the column's minimum operating pressure is limited by the temperature of the coolant available to condense the overhead vapors. By compressing the overhead vapors, the column can operate at a lower pressure and take advantage of the increased relative volatility between propylene and propane that occurs at lower pressures.

Compressing the overhead vapors with a heat pump increases the condensation temperatures so the vapors condense as they transfer heat to boil the liquid in the bottom of the column. Unlike a conventional splitter where heating in the reboiler and cooling in the condenser are two separate operations, the heat pump makes it possible to combine the condenser and reboiler operations by transferring heat directly from the overhead vapors to the bottom liquid, eliminating the need for a cooling tower, a steam boiler, and several other major equipment purchases. Without the compressor, heat transfer from the overhead vapor to the bottom liquid cannot occur because the liquid is warmer than the vapor.

The company considered using a gas turbine driver, but that possibility proved to be uneconomical since the company had no way of using the turbine's hot exhaust gasses. After careful evaluation, Diamond decided that for this site, an electric heat pump offered the most advantages.



The 6500 hp electric motor, speed increaser, and compressor saved Diamond Shamrock $2 million.



Twin towers of the heat-pumped propane/propylene splitter and smaller deethanizer column glisten in the Texas evening.

The New Way

Diamond's new PP splitter consists of two 16-foot diameter columns, each 275 feet tall. The heat pump consists of a single-stage, centrifugal compressor driven by a 6500 hp, 1800 rpm induction motor with a speed-increasing gear that turns the machine at 5900 rpm. Because the motor turns at a fixed speed, adjustable guide vanes were installed in the compressor suction to control pressure with a minimum loss of efficiency.

To meet tight product specifications, a heat pumped deethanizer column was added ahead of the PP splitter to separate ethylene and lighter materials from the feedstock. The deethanizer compressor is driven by a 1300 hp, 1800 rpm motor through a speed-increasing gear that turns the compressor at 5900 rpm.

TECHAPPLICATION

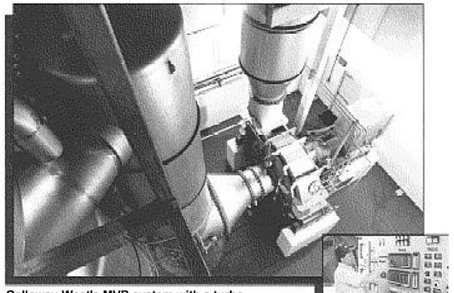
Heat Pumps in Food Processing

An EPRI Process Industry Publication Vol. 3, No. 4, 1991

The Challenge: Evaporating Energy Costs and Milk

Galloway-West Co., Inc. of Fond du Lac, Wisconsin required an energy efficient and flexible method to condense whole milk, skim milk, and whey products for use in sweetened condensed milk, dry milk powders, and milk solids sold to other segments of the food industry. The company's two steam-powered evaporators were expensive to operate due to high fuel costs for the gas-fired boilers supplying the steam. The limited range of evaporating temperatures of the older units also strained Galloway-West's ability to produce dairy products requiring low or high processing temperatures.

Galloway-West overcame its production limitations by installing an energy-efficient mechanical vapor recompression (MVR) heat pump that increased production capacity and enabled the company to produce a wider range of products.



Galloway-West's MVR system with a turbofan reduced energy costs by 70%.

The Old Way

Galloway-West used a thermal vapor recompressor (TVR) system and a straight steam-driven evaporator with a combined throughput of 40,000 lbs/hr. The company considered upgrading its existing evaporators, but the older technology would not be as successful in the production of specialty milk products and a gas-based system would still be expensive to operate and vulnerable to fluctuating fuel prices. However, the operating cost of an electric-based system promised to be more predictable and less expensive.

The New Way

In mid-December 1990, Galloway-West started up its new MVR falling-film evaporator and began saving energy right away.

The new evaporator is a two-effect, multi-pass, semi-open heat pump driven by a 600 hp motor with a variable speed drive coupled to a turbofan. Since most of the energy used by the unit is electrical, the company reduces production costs by running the unit "off-peak" much of the time.

The MVR heat pump compresses the low-pressure water vapor removed from the evaporating milk products to a higher pressure, increasing the vapor's temperature. The hot compressed steam is then used to further evaporate the milk. The product makes multiple passes through the unit, becoming more and more concentrated. A new TVR finisher is used to boost concentrate levels on some products. As part of the MVR's heat-exchange design, cold incoming milk is pre-warmed as it cools the condensed product and condenses the steam.

The MVR heat pump in conjunction with a heat treatment system ahead of the MVR provides a greater range of heat treatments, so Galloway-West can more easily produce the products its customers want.

The new system lets operators adjust the turbofan's speed and use a variety of heat treatments.

The Results: Much More For Much Less

By switching to the MVR evaporator, Galloway-West saves energy and labor while increasing revenues.

Energy Savings: Using the MVR, Galloway-West saves 70% of its previous energy expense. The unit operates at a rate of $0.46 for every 1000 lbs of water removed, compared to the old system's rate of $1.56. An annual energy savings of $263,000 is projected from having replaced gas with electric power and utilizing its economical off-peak rates.

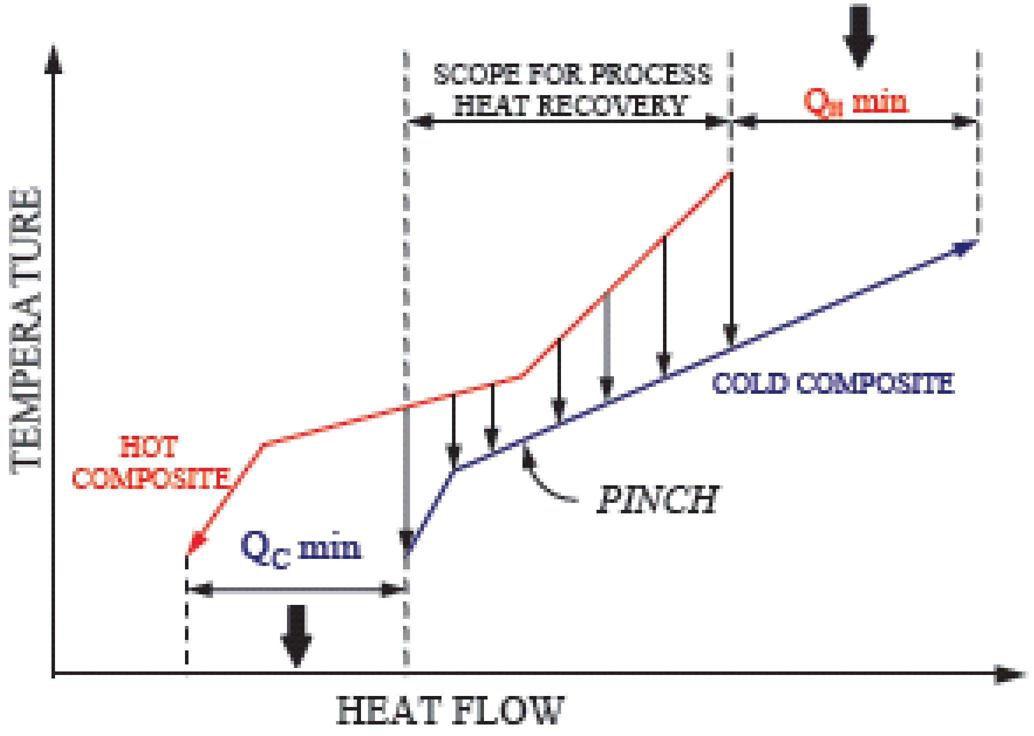
The evaporation process itself accounts for 92% of the savings, while 4% is due to the system's design for preheating and cooling product and for condensing steam. The rest of the savings results from the MVR's 50% turndown that allows the product to run directly to the dryers, avoiding cooling costs during storage and subsequent reheating.

Documented in early 1990s

EPRI

Pinch Analysis – Appropriate Placement of Heat Pumps

- Minimize heat loss by thermal energy optimization technique
- Matching hot streams with cold streams via optimum heat recovery
- Minimize reliance on external energy inputs
- Pinch temperature (where heating and cooling curves come close together) defines an industrial site's unique heat distribution
- **Pinch Analysis also provides amount of waste heat that can be recovered by IHPs**



Source: EPRI Report CU-6775

EPRI and US DOE Championed "Pinch Technology" in 1990s

Some IHP Successes in the US

High End Cabernet Estate Winery Facility located in Alexander Valley California

First New Commercial Winery in the World to Achieve LEED Platinum Certification!

Water Source CO_2 Heat Pumps provide Hot Water for Winery DHW/Tank/Barrel Cleaning and Chilled Glycol for Barrel Room and Tank Cooling

(2) UNIMO ww units installed in Mechanical Room

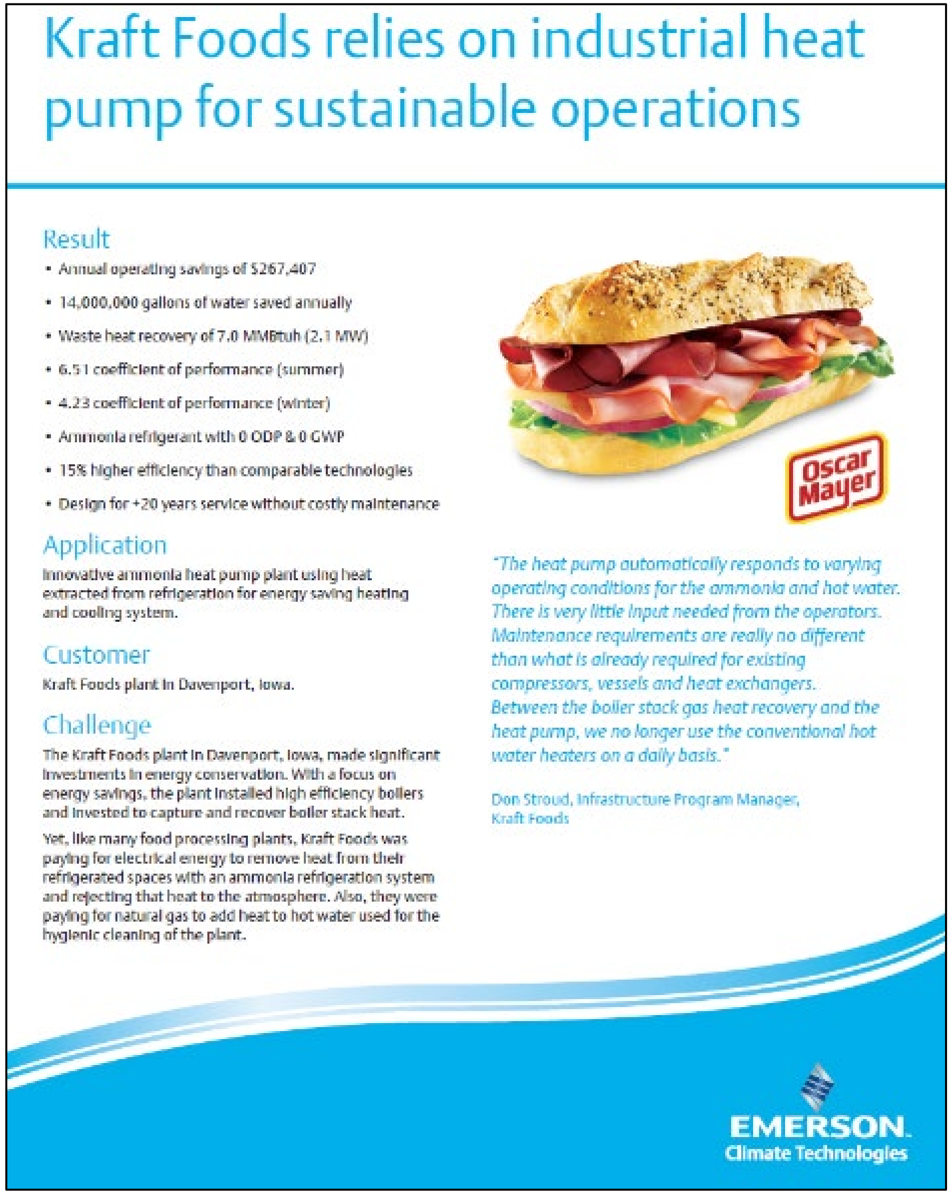
U.S. GREEN BUILDING COUNCIL
LEED PLATINUM
USGBC

Unit piping

Courtesy of Mayekawa MYCOM

EPRI

Other Installations in the US



Kraft Foods relies on industrial heat pump for sustainable operations

Result
- Annual operating savings of $267,407
- 14,000,000 gallons of water saved annually
- Waste heat recovery of 7.0 MMBtuh (2.1 MW)
- 6.51 coefficient of performance (summer)
- 4.23 coefficient of performance (winter)
- Ammonia refrigerant with 0 ODP & 0 GWP
- 15% higher efficiency than comparable technologies
- Design for +20 years service without costly maintenance

Application
Innovative ammonia heat pump plant using heat extracted from refrigeration for energy saving heating and cooling system.

Customer
Kraft Foods plant in Davenport, Iowa.

Challenge
The Kraft Foods plant in Davenport, Iowa, made significant investments in energy conservation. With a focus on energy savings, the plant installed high efficiency boilers and invested to capture and recover boiler stack heat.

Yet, like many food processing plants, Kraft Foods was paying for electrical energy to remove heat from their refrigerated spaces with an ammonia refrigeration system and rejecting that heat to the atmosphere. Also, they were paying for natural gas to add heat to hot water used for the hygienic cleaning of the plant.

"The heat pump automatically responds to varying operating conditions for the ammonia and hot water. There is very little input needed from the operators. Maintenance requirements are really no different than what is already required for existing compressors, vessels and heat exchangers. Between the boiler stack gas heat recovery and the heat pump, we no longer use the conventional hot water heaters on a daily basis."

Don Stroud, Infrastructure Program Manager, Kraft Foods

Oscar Mayer

EMERSON. Climate Technologies

Ref – AMI Foundation Conference 2012

Ref – Emerson Website

Next Frontier – Steam Generating Heat Pumps

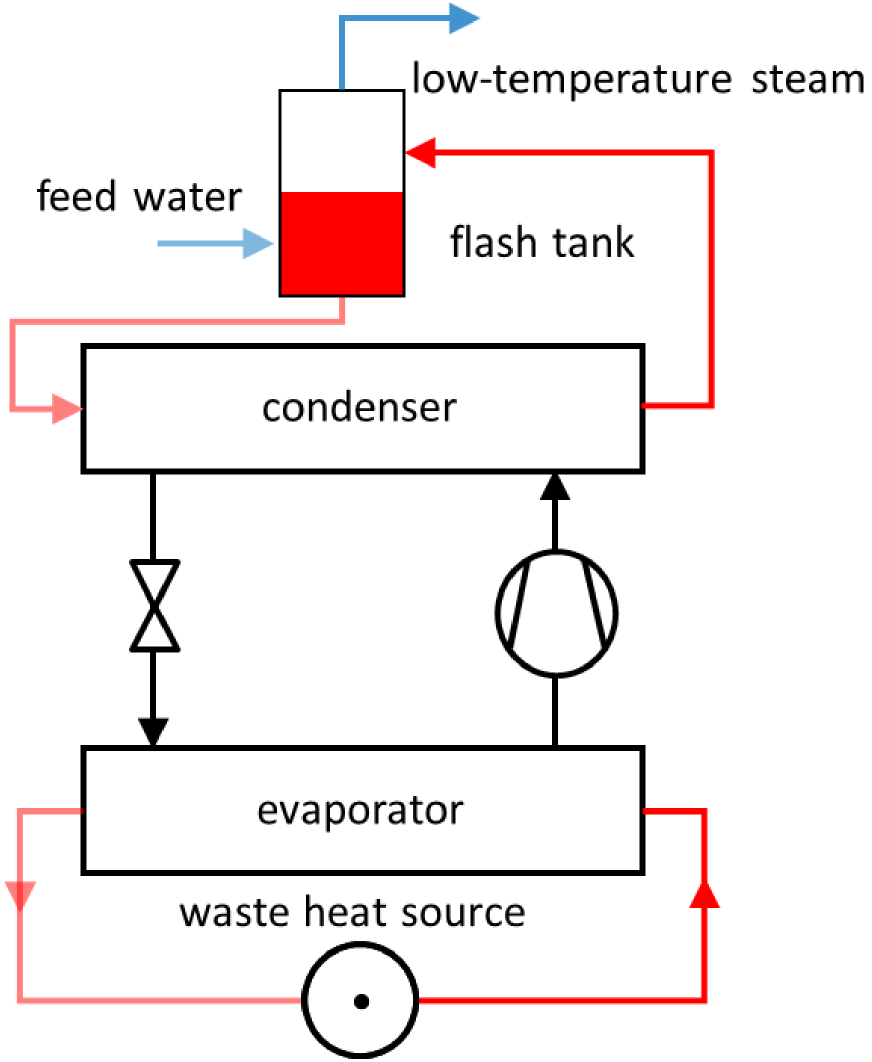
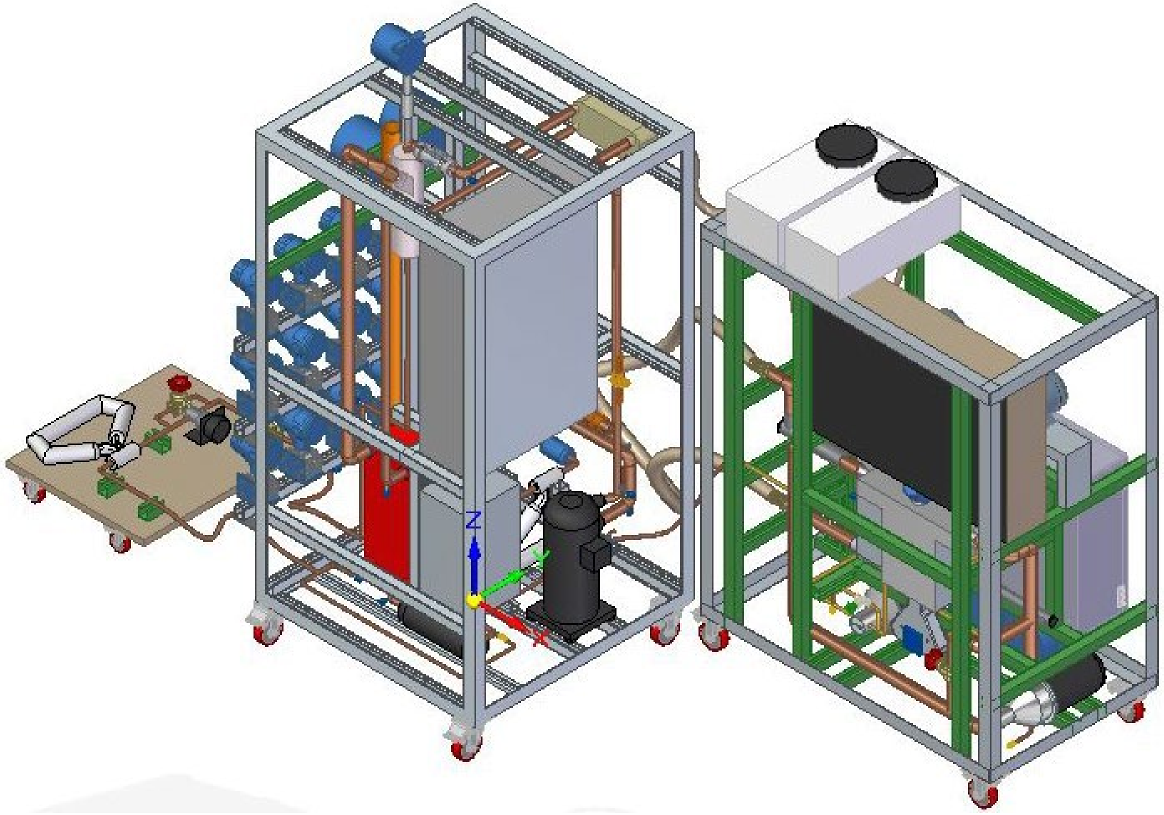


Photo – EDF Lab, France

EPRI Project: High temperature heat pump that can produce steam at low pressure

- Key characteristics of the heat pumps:
  - 30 kW prototype system
  - Low ODP, GWP refrigerant
  - Develop prototype system produce steam at 120°C from waste heat (80°C) @ COP of 3.4
  - Test in a lab in California; make it ready for field deployment
  - Offer solutions for industrial decarbonization in California and Nation



Project funded by California Energy Commission – Ongoing

Photos of the 30kW prototype system

HP Prototype System

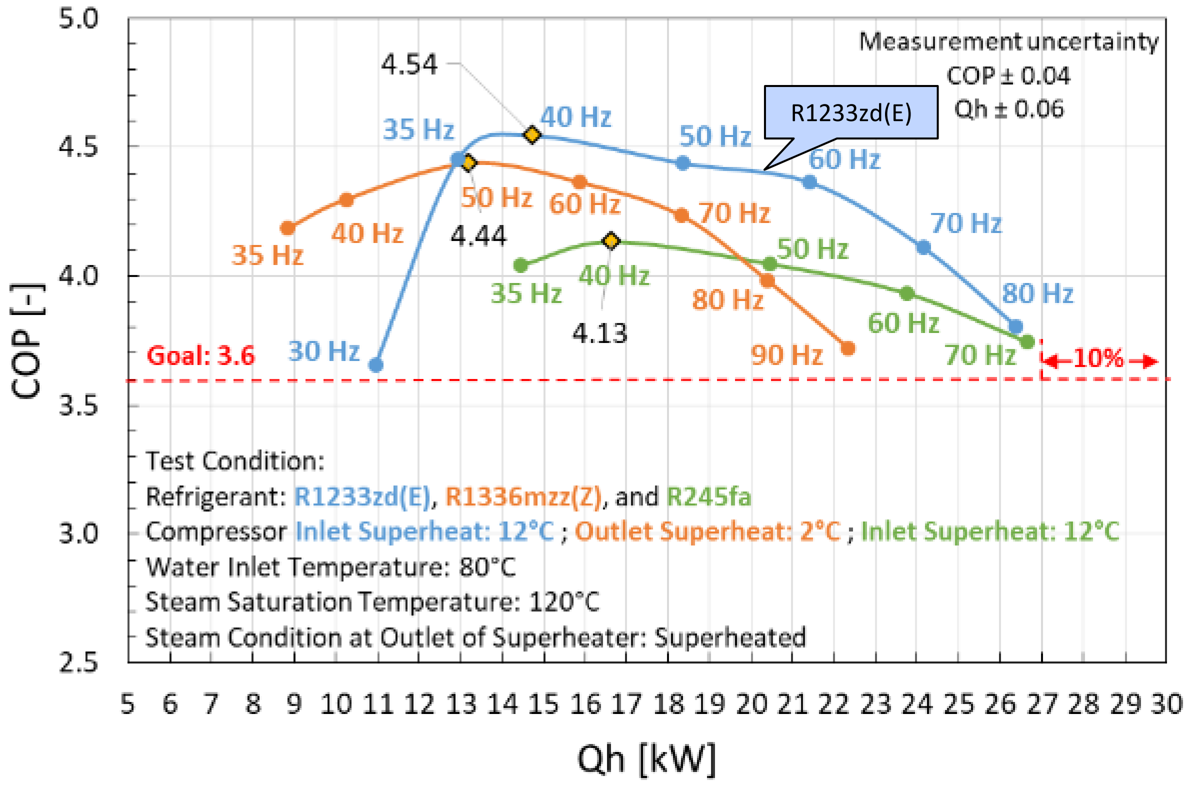
Prototype Showing Monitoring Instrumentation

Prototype Showing Controllers and ASDs

Prototype Testing Results

Key findings from the tests:

- Coefficient of Performance (COP) has an inverse relation with system speed, a direct indicator of system load
- Higher load (capacity) or compressor speed results in lower COP values
- Two refrigerants performed the best
  - R1233zd[E]: Higher COP, but has ODP
  - R1336mzz[Z]: Lower COP, no ODP
  - System should be optimized to obtain the target COP>3.4 or greater

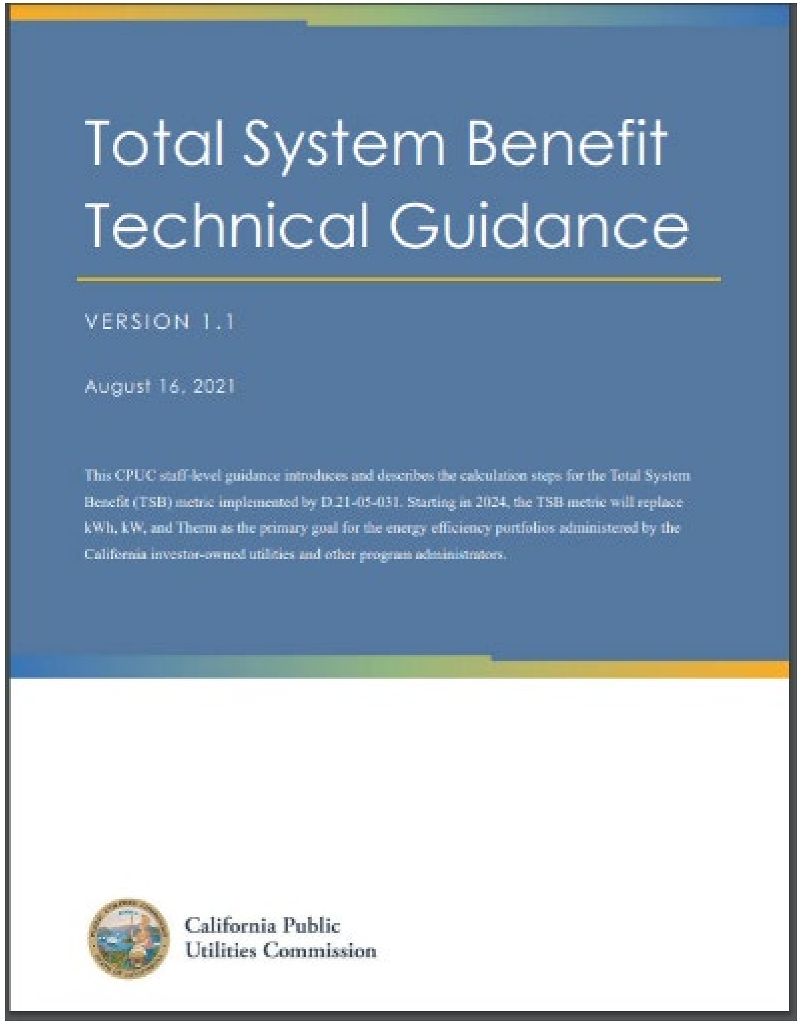


Next Steps – EPRI Lab Tests + Field Tests

Utility Incentive Programs – California Example of TSB

CPUC has initiated the application of a Total System Benefits (TSB) approach to address the following:

- ***Comprehensively capture fuel switching benefits and environmental benefits***
- Include other high value but non-monetized benefits
- Other system benefits


Total System Benefit Technical Guidance

VERSION 1.1

August 16, 2021

This CPUC staff-level guidance introduces and describes the calculation steps for the Total System Benefit (TSB) metric implemented by D.21-05-031. Starting in 2024, the TSB metric will replace kWh, kW, and Therm as the primary goal for the energy efficiency portfolios administered by the California investor-owned utilities and other program administrators.

California Public Utilities Commission

Starts in 2024 – Other States May Follow Soon

Heat Pumps and the Grid – A Consideration

Top barriers to Heat Pumps at scale that must be addressed:

- **Power availability**
- **Power reliability**
- **Grid interconnections**
- **Grid readiness**

Some Enabling Actions

Ensure utilities (and regulators) are in lock-step with technology developers, OEMs, and consumers

Optimize systems and processes that support the pace of activity/investment required

Develop needed tools and technologies that enable HP scale and (perhaps) capture the grid benefits of HPs

Customers and Utilities Need to Work Together!

Industrial Heat Pumps – Needs

- Document Status of Current Applications
- Focus on Technology Development
- Apply Technology to Several Applications
- Conduct Case Studies and Technology Transfer
- Utility and Government Incentives
- **Collaboration between all Stakeholders**

Thank You!

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Together...Shaping the Future of Energy®