



# Vanderweil Engineers

## *Ammonia Refrigeration and Risk Mitigation for District Cooling Applications*

Presented by: Christopher W. Hastings, PE

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- How suitable is Ammonia for use in District Cooling Applications?
  - Risk
  - First Cost
  - Efficiency
- Feasible Applications
- Ammonia Safety
  - Code required components
  - Regulatory requirements
  - Best practices for leak mitigation



# Why Consider Ammonia?

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- High Cycle Efficiency
- Continuous use since the 1800's
  - Mature technology, large equipment manufacturer and contractor base worldwide
- Zero ODP, Zero GWP
- Self-alarming: pungent odor at less than 10 PPM
  - Readily absorbed in water
  - Lighter than air; leaks rise
- Ammonia refrigeration is widely used in urban and suburban locations throughout the U.S.
- Ammonia is being utilized in a number of District Cooling applications in the U.S. and overseas

# Application of Ammonia for Large Scale District Cooling

- **Low Temperature Thermal Storage**
  - Dual-temperature NH<sub>3</sub> chillers for ice generation/chilled water production
- **Evaporative Condensers**
  - High cycle efficiency/low first cost
  - Increased NH<sub>3</sub> charge
- **Air-Cooled Condensers**
  - High cycle efficiency/low first cost
  - No water use
  - Increased NH<sub>3</sub> charge
- **Water Chilling/Cooling Towers**
  - Low charge NH<sub>3</sub> PHE screw chillers with ammonia mitigation

# Ammonia Chillers

- Custom Fabricated Chillers
- Heat Exchanger Skid
  - Plate Frame Evaporator
    - Flooded – 1.5 lb/TR
    - Direct Expansion DX – under 1 lb/TR
  - Plate Frame Condenser
- Compressor Skid
  - Screw Compressors
    - 2,000 TR
    - Horizontal or Vertical Separators
- Multiple Vendors



# Low Temp Thermal Storage Applications

- Screw compressors capable of operating at multiple suction levels +15 deg F, +35 deg F
- Dual evaporator chiller: glycol (ice)/chilled water
- Single compressor serves two (2) chiller evaporators
- Positive displacement; stable operation
- Refrigerant economizer cycle increases efficiency
- Variable VI compressors
- Energy and first cost competitive with Freon centrifugal or screw units



# Heat Rejection Options

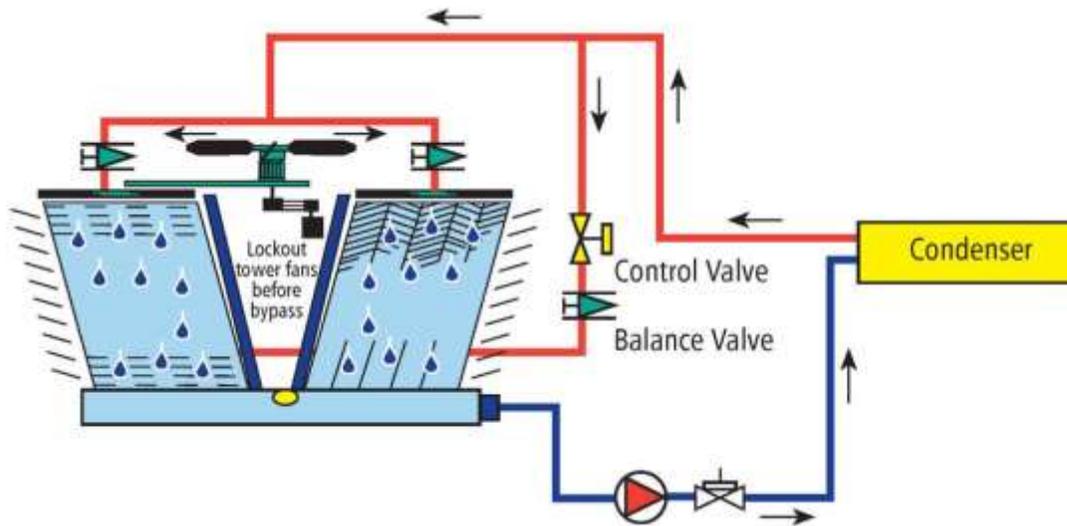
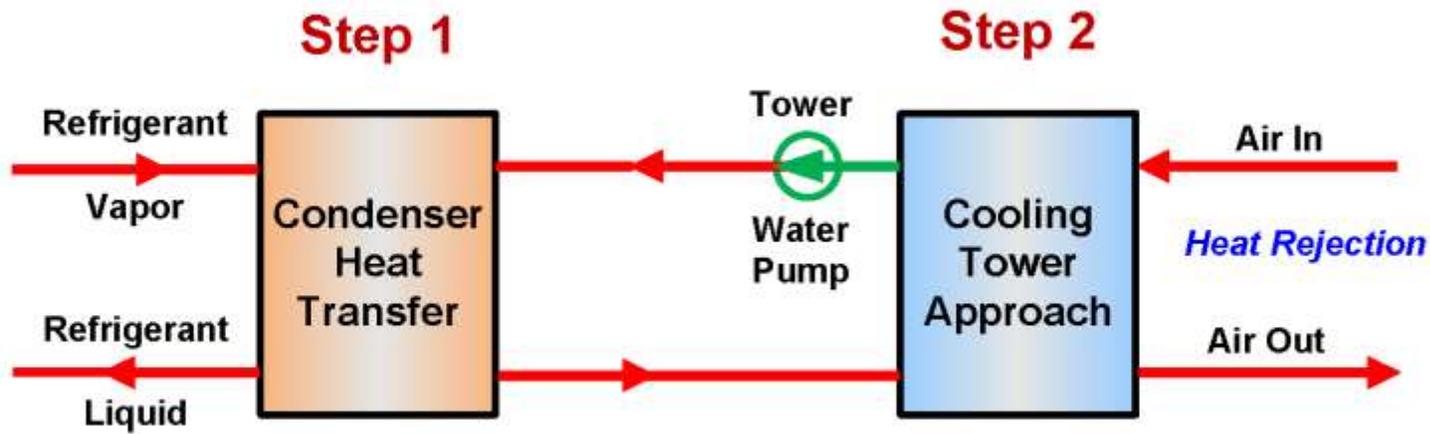
Example: 10,000 TR Cooling Tower System vs. Evaporative Condensers

## Cooling Towers:

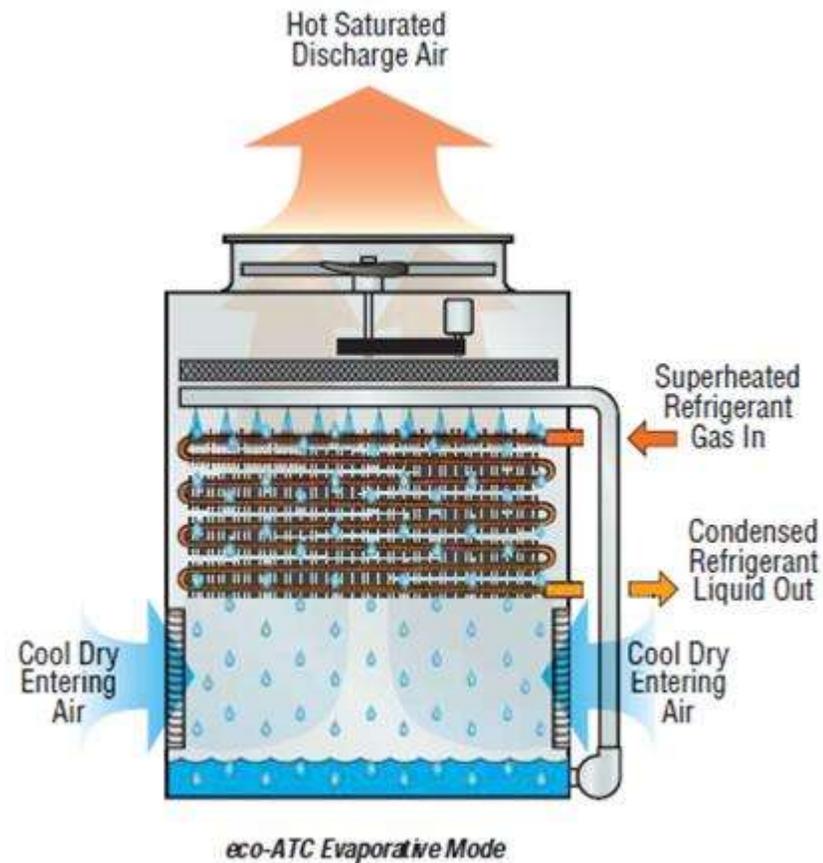
- 20,000 gpm, 85°-100°, 65°wb
  - (5) Tower Cells:  
75 HP, 375 HP
  - (5) Pumps:  
150 HP, 750 HP
  - Total System KW/TR: 0.85 KW/TR
  - 30" Mains
  - 12" Connections at chiller



# Cooling Tower



# Evaporative Condenser



Evaporative condenser achieves lower approach between refrigerant and ambient heat sink.

# Condenser Water System Options

- 2,000 TR Evaporative Condenser:
  - (2) cells per unit,  
Fans 150 HP,  
Pumps 15 HP
  - Total system: 0.73 KW/TR
- Piping:
  - 8" RD line (vapor)
  - 3" HPL line (liquid)
  - Close coupled to chiller



# Evaporative Condenser

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## Pros:

- Improved Efficiency:
  - Saves 15% Plant Power (1,400 HP)
- Piping Savings:
  - Condenser water system eliminated
  - Significant cost savings

## Cons:

- Increased NH<sub>3</sub> charge
- Water treatment at individual basins

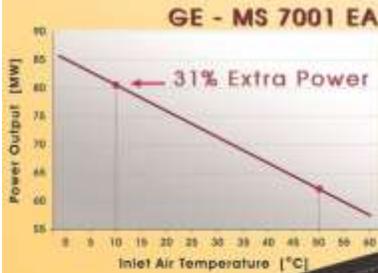
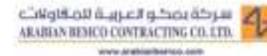
# Air Cooling

- High cycle efficiency when using direct air cooled condensers
- Middle East application: CHW production 0.95 kW/TR at 40 deg C design
- Lower first cost than many competing technologies



# Thermal Energy Storage System

## WORLD'S LARGEST THERMAL ENERGY STORAGE SYSTEM

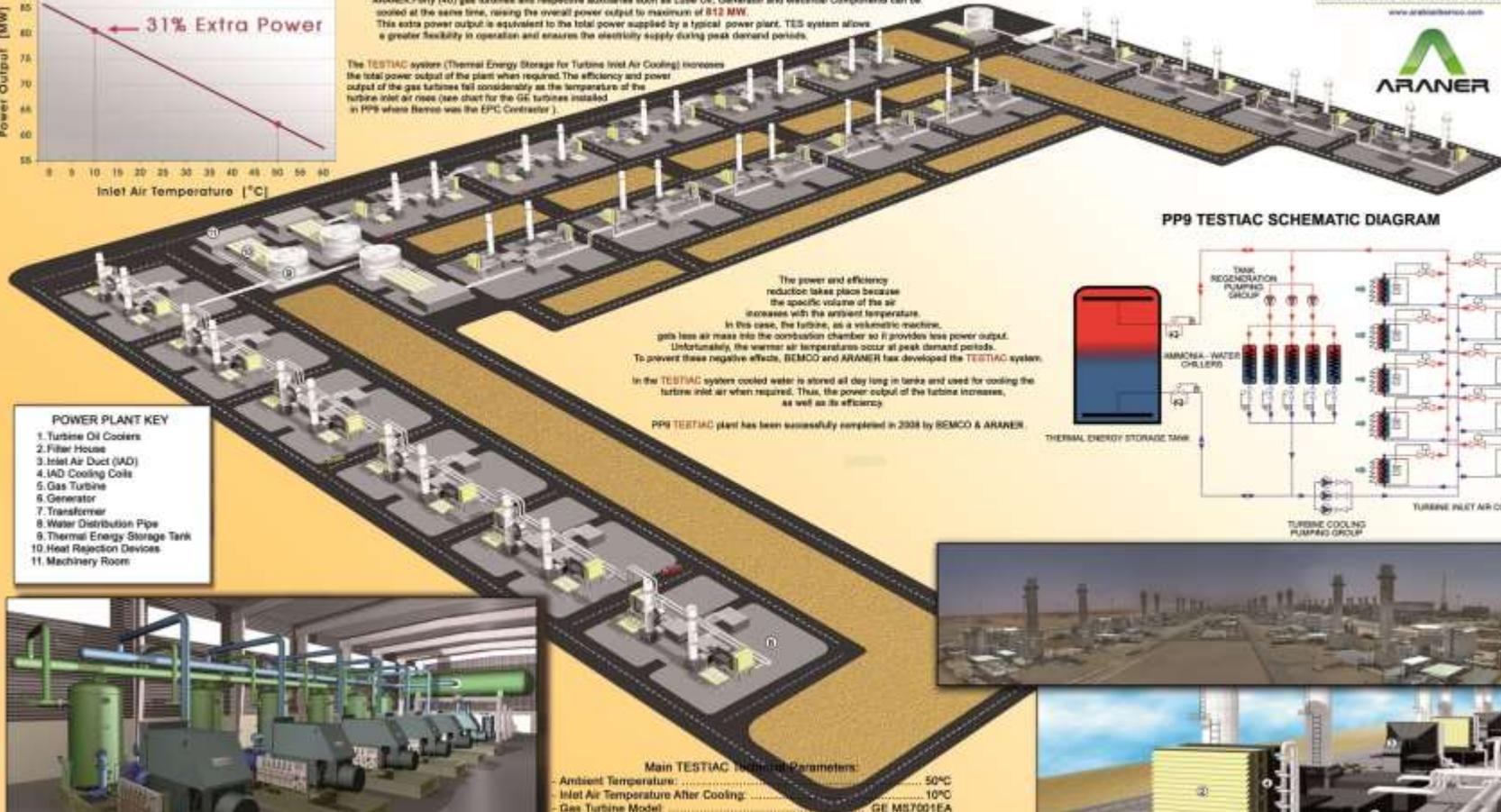


Riyadh Power Plant 9 - PP9 -, in the Kingdom of Saudi Arabia houses the largest Thermal Energy Storage (TES) system in the world.

The plant is owned by Saudi Electricity Company and is based on state-of-the-art technology developed by ARABIAN BEMCO and ARABER. Forty (40) gas turbines and respective auxiliaries such as Lube Oil, Generator and electrical Components can be cooled at the same time, raising the overall power output to maximum of 812 MW.

This extra power output is equivalent to the total power supplied by a typical power plant. TES system allows a greater flexibility in operation and ensures the electricity supply during peak demand periods.

The TESTIAC system (Thermal Energy Storage for Turbine Inlet Air Cooling) increases the total power output of the plant when required. The efficiency and power output of the gas turbines fall considerably as the temperature of the turbine inlet air rises (see chart for the GE turbines installed in PP9 where BEMCO was the EPC Contractor).

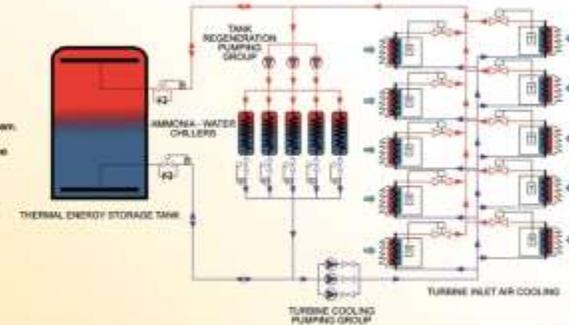


PP9 TESTIAC SCHEMATIC DIAGRAM

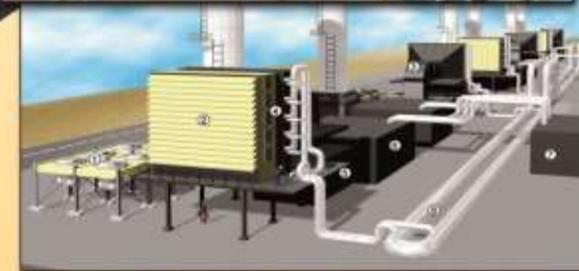
The power and efficiency reduction takes place because the specific volume of the air increases with the ambient temperature. In this case, the turbine, as a volumetric machine, gets less air mass into the combustion chamber so it provides less power output. Unfortunately, the warmer air temperatures occur at peak demand periods. To prevent these negative effects, BEMCO and ARABER has developed the TESTIAC system.

In the TESTIAC system cooled water is stored all day long in tanks and used for cooling the turbine inlet air when required. Thus, the power output of the turbine increases, as well as its efficiency.

PP9 TESTIAC plant has been successfully completed in 2008 by BEMCO & ARABER.



- POWER PLANT KEY**
1. Turbine Oil Coolers
  2. Filter House
  3. Inlet Air Duct (IAD)
  4. IAD Cooling Coils
  5. Gas Turbine
  6. Generator
  7. Transformer
  8. Water Distribution Pipe
  9. Thermal Energy Storage Tank
  10. Heat Rejection Devices
  11. Machinery Room



**Main TESTIAC Technical Parameters:**

- Ambient Temperature:	50°C
- Inlet Air Temperature After Cooling:	10°C
- Gas Turbine Model:	GE MS7001EA
- Number of turbines cooled by TESTIAC:	40
- Number of Thermal Energy Storage Blocks:	4
- Number of Chillers:	20
- Total Cooling Load:	128,000 Ton (refrigeration)
- Total Refrigeration Capacity stored:	710,000 Ton-h (refrigeration)
- Electric Power Generation - EXTRA CAPACITY:	
* Design conditions cooling ( operating on Gas or Crude );	711 MW
* Emergency conditions cooling:	812 MW

# Ammonia Detection

- Ammonia is a toxic, *Highly Hazardous*, regulated chemical
- OSHA requirements for PSM: OSHA 29CFR 1910.119
- EPA requirements for RMP for systems with over 10,000 lbs: EPA 40CFR, Part 68
- Additional regional regulations: CaLARP, NJTCPA

Ammonia Concentration in Air (ppm)	Health Symptoms
25 <	Detectable by smell.
30	Uncomfortable; breathing support required.
50	OSHA PEL exposure limit.
100	Irritated eyes, throat, and mucous membranes. Mild eye, nose, and throat irritation; may develop tolerance in 1-2 weeks with no adverse effects.
140	Moderate eye irritation; no long-term effect in exposures of less than 2 hours.
300	Immediate danger to life limit (IDLH) .
400	Moderate throat irritation. Damage of mucous membranes with more than one hour exposure.
1,700	Fatal after short exposures - less than half an hour.
5,000	Immediate hazard to life.
15,000 >	Full body protection required.
160,000	Flammable in air (LEL).

# Typical Practices

- Safety systems required to meet unified national codes and local code requirements which vary regionally
  - Mechanical room construction
  - Ventilation
  - NH<sub>3</sub> detection with audible and visual alarms
  - Emergency shutdown stations
  - Diffusion systems, fireman control station, siamese dump connection
  - Code compliant construction largely not intended to mitigate releases

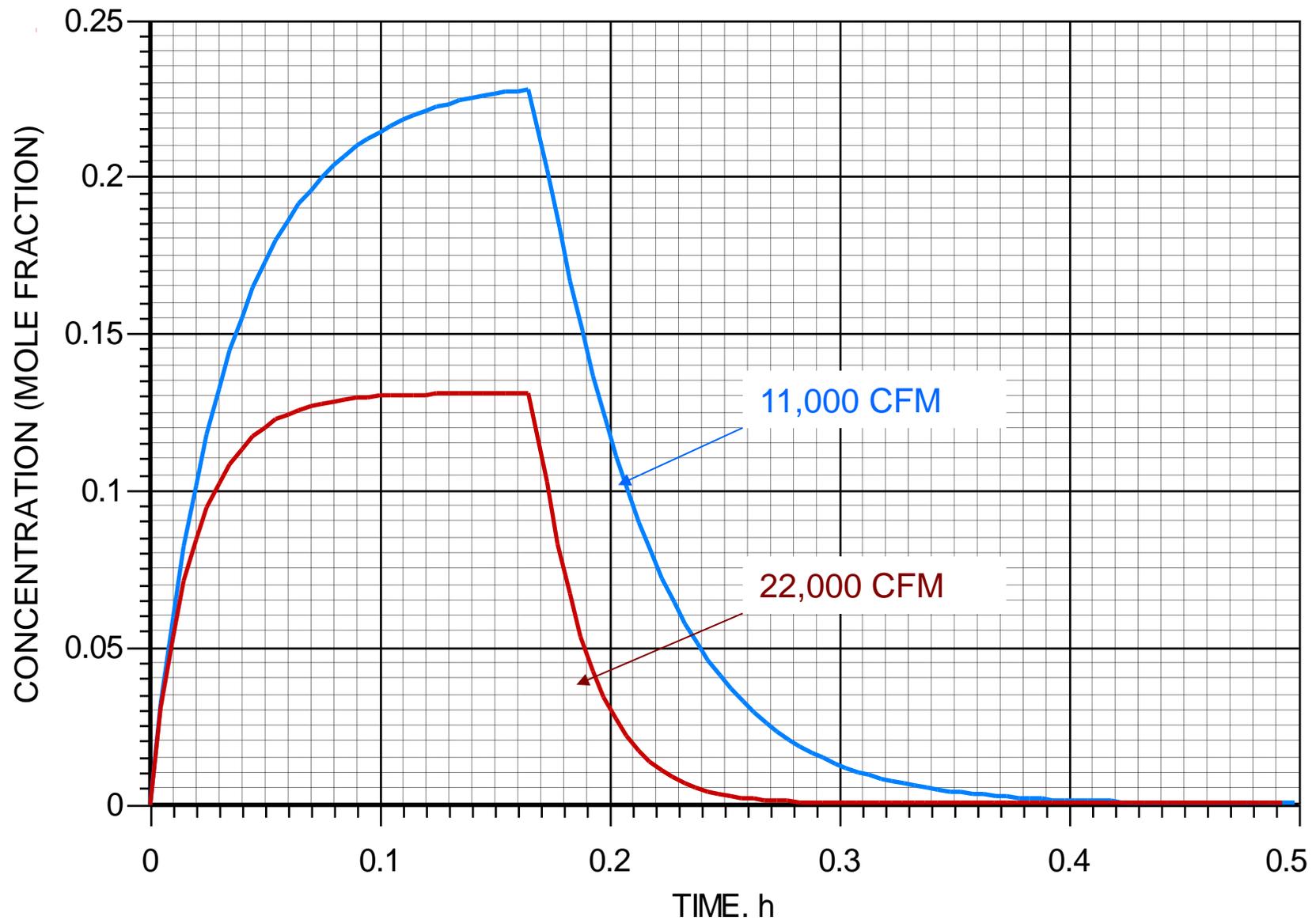


# Worst Case Leak Scenario

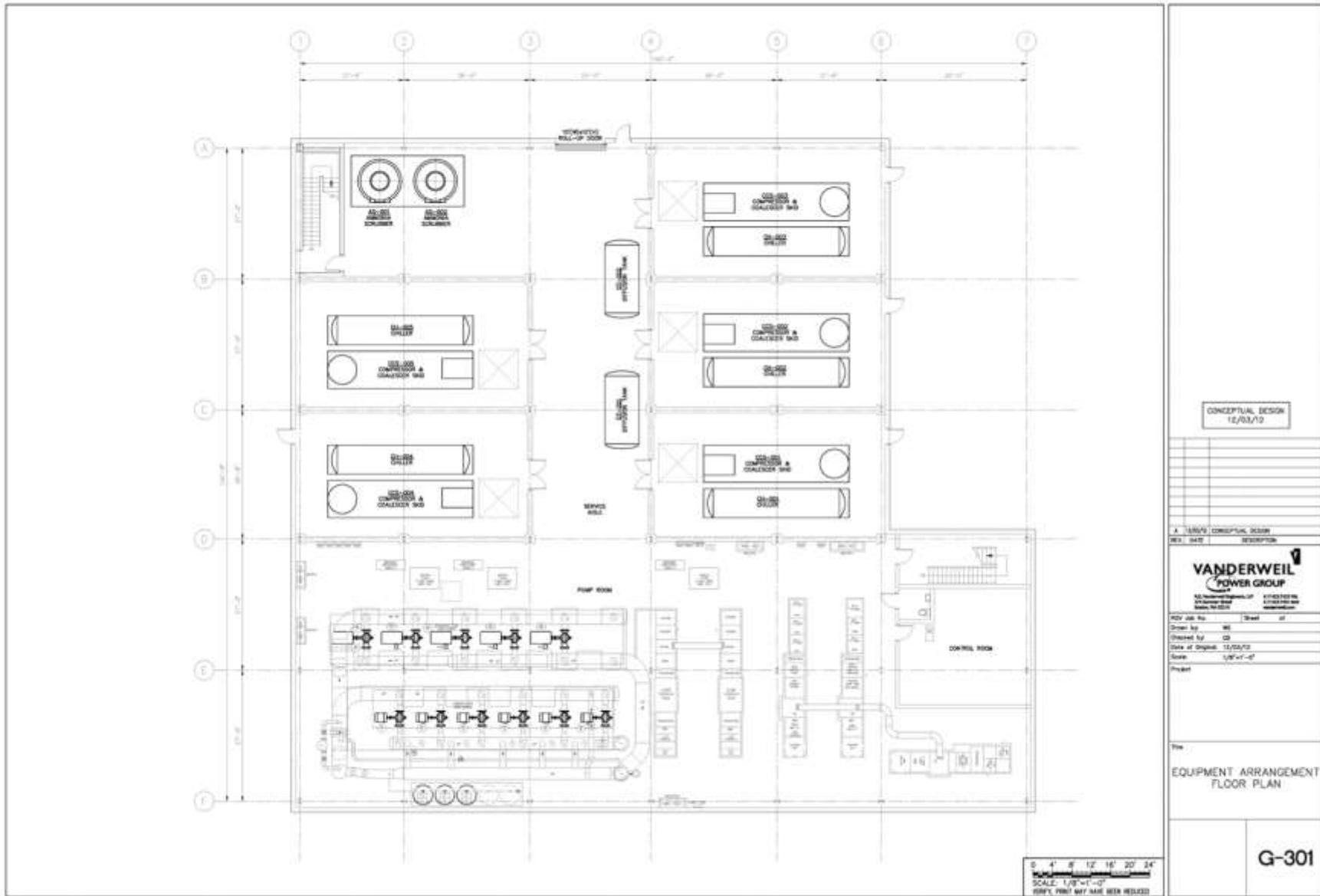
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- Example: Loss of system containing 3,500 lbs ammonia charge in 10 minutes
- Average ammonia vaporization rate of approximately 144 lb/min
- Expected maximum room concentration of 130,000 PPM
- How do you mitigate operation of exhaust system discharging large quantity of ammonia?
- Suggested mitigation criteria: Discharge exhaust concentration mitigated to below OSHA PEL (Permissible Exposure Limit)

# Worst Case NH<sub>3</sub> Release with 40% Flashed (144 lb/min)



# 10,000 Ton Equipment Arrangement

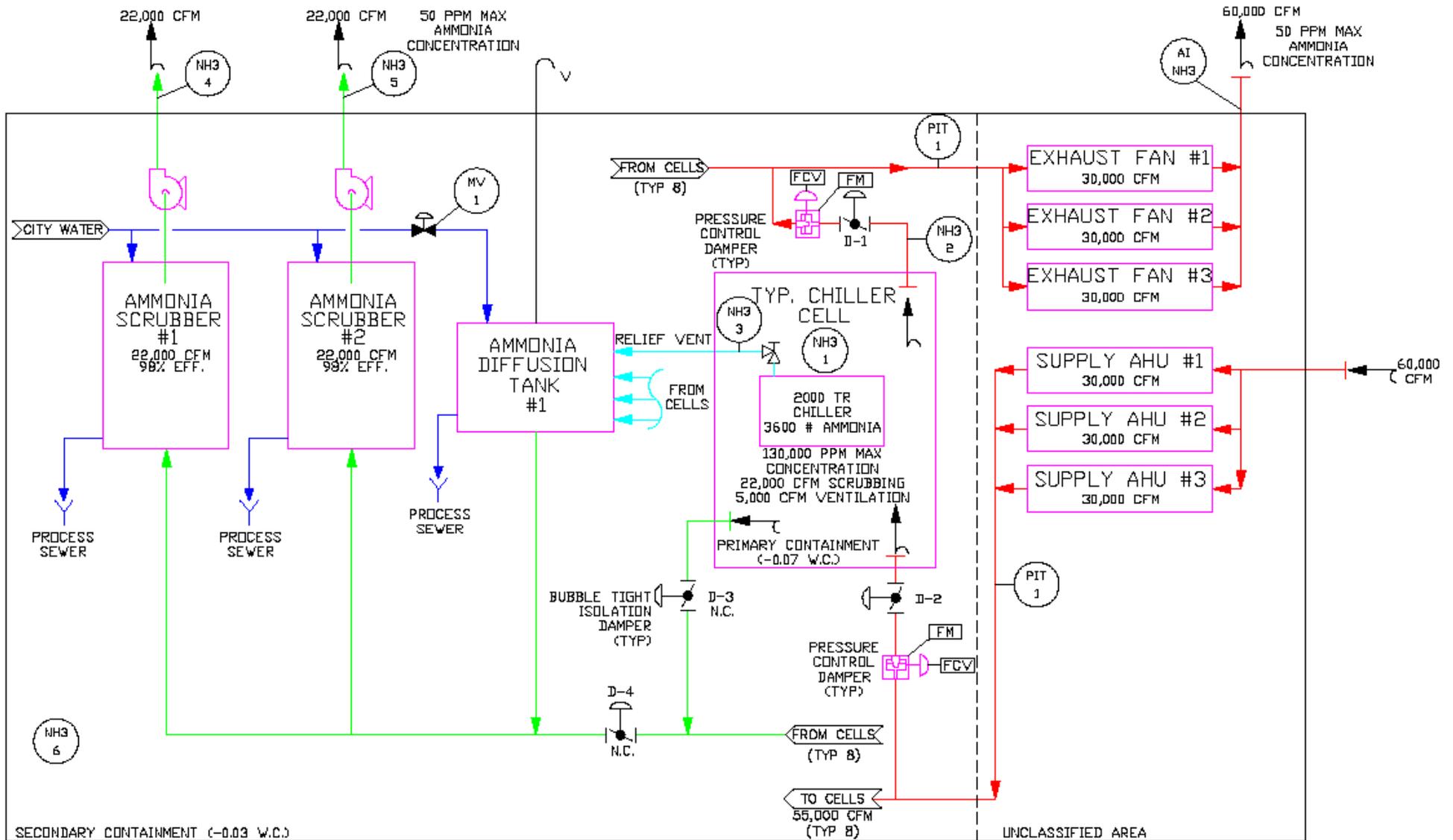


# New Ammonia Chiller Plant

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- **New Ammonia Chiller Plant:**
  - 10,000 TR
  - Five (5) 2,000 TR chiller modules
    - Low refrigerant charge technology
  - Ammonia Containment
    - Chiller cells provide primary containment boundary
    - Once-through scrubber system
    - Primary ammonia containment and ammonia transfer areas controlled to negative pressure
    - Secondary containment area: remainder of plant room

# Recommended Ammonia Containment System Overview



# Typical Chiller Cell

- Contains 2,000-ton chiller and ammonia leak collection sump
- Tight masonry construction
- Explosion blowout panels sized for max room pressure
- Chiller E-stop inside and outside each cell
- Scrubber: Removal of ammonia during leak event
- HVAC: Provides negative pressurization and space conditioning
- Diffusion Tank: Captures ammonia during PSV releases
- NH<sub>3</sub> Sensors: 0 - 20,000 ppm, multiple sensors
- Electrical Room Classification: Class I, Div 2
- Shunt-trip Unclassified Electrical Equipment: 20,000 PPM

# Ammonia Scrubber System

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- Ammonia scrubber system sized for 100% redundancy
- Packed tower type scrubber; FRP construction
- 22,000 CFM once-through air per chiller cell
- 22,000 CFM once-through air per scrubber (50 PPM outlet)
- Emergency back-up power supply
- Specialty bubble tight isolation dampers on each cells scrubber exhaust duct
- Explosion-proof motors and electrical devices

# HVAC System

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- Primary/secondary containment areas with active room pressure and flow control
- Headered make-up and exhaust air systems
- 100% fresh air supply to primary ammonia transfer control areas
- Specialty bubble tight isolation dampers at primary containment cells
- 22,000 CFM per chiller cell (air cooled motors)
- 5,700 CFM per chiller cell (TEWAC motors)

# Conclusions

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- Ammonia is *not* a mainstream technology for District Cooling
- Ammonia *is* efficient and cost competitive in applications that favor available technology
- Ammonia refrigeration is reliable and safe
- Mitigation systems can be employed to reduce risk
- Additional information on Natural Refrigerants can be found at:
  - [www.iiar.org](http://www.iiar.org) International Institute of Ammonia Refrigeration
  - [www.reta.com](http://www.reta.com) Refrigerating Engineers & Technicians Association
  - [www.eurammon.com](http://www.eurammon.com) Eurammon Initiative for Natural Refrigerants
  - [www.iifiir.org](http://www.iifiir.org) International Institute of Refrigeration

# Heat Recovery Technologies

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- Heat Pump Scavenging System
  - NH<sub>3</sub> heat pump compressor connect to 2,000 TR chiller
- Potential Technologies
  - Scavenging compressor utilizing refrigerant discharge gas
  - Heat recovery chiller utilizing cooling tower water
- Multiple Venders Offer “Standard” Products
  - Vilter
  - Frick/Sabroe
- COP of ~6.0

# Heat Recovery

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- Recover heat from process cooling to offset fossil fuels at distributed boilers
- Requires simultaneous heating and refrigeration loads
- Waste heat low grade 90 deg F with straight refrigeration cycle
- Increase quality of available heat with further compression and temperature increase to 120 - 140 deg F
- Scavenging heat pump  $\text{NH}_3$
- Transcritical  $\text{CO}_2$
- Evaluate additional power requirements for compression and fossil fuel burned