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Supermarket Refrigeration System Design Process: A Consultant's View

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CTA Architects Engineers

Refrigeration System Selection

- Question that was asked.
  - *We would like to get a consultants perspective on the entire refrigeration system and design process. If you as the Refrigeration Engineer had no criteria, constraints, direction, etc. from the manufacturers or the client, what would your system design process be, what system(s) would you design, install, operate and maintain?*

Refrigeration Design Process

- Choices for doing a Refrigeration Design
  - In House Engineering Team
  - Equipment Manufacturer
  - Consulting Engineer
  - Any Others? (I can think of one more)

Refrigeration Design Process

- Refrigeration Engineering Program
  - Minor Program (Several Projects a Year)
    - Not large enough program to justify cost of Prototype Development
    - Utilize one source of design for consistent product or a couple of sources that communicate well
    - Use last project done as Criteria. Have some written standards

Refrigeration Design Process

- Refrigeration Engineering Program
  - Major Program (30+ Projects a Year)
    - Develop a Prototype and Criteria Update Process
      - Helps with coordination
      - Helps owner get what they want from multiple consultants
      - Cuts down on design costs
      - Reduces engineering time

Refrigeration Design Process

- Refrigeration Engineering Program
  - Advanced Refrigeration Design
    - Build time into schedule for full development
    - Bring all stake holders together
    - Utilize Refrigeration Consultant as hub that receives, distributes and coordinates with all stake holders.
      - Owner
      - Architect/Engineers
      - Equipment Manufacturer
      - Controls Manufacturer
      - Contractor

Refrigeration Design Process

- Refrigeration Engineering Program
  - Equipment Selection
    - Best to know whose equipment you will be designing around from the beginning.
      - Space Planning
      - Electrical Loads
      - BTU Loads
      - Component Selection
    - Have Refrigerated Case specifications figured out
    - If equipment is bid after design expect some re-design

Refrigeration Design Process

- Refrigeration Engineering Program
  - As Built Drawings
    - Require Consultant to provide final copy of latest design
      - Place Refrigeration Floor plan and Schedule on compressor room wall
      - Store Hard Copy of complete set of drawings in Compressor room in drawing tube
      - Develop storage process of Electronic CAD, DWF and PDF files in a usable format

Refrigeration System Selection

- System with a Natural Refrigerant

Not an Environmentalist
(but I do support improving the environment)

I am an Engineer and Businessman

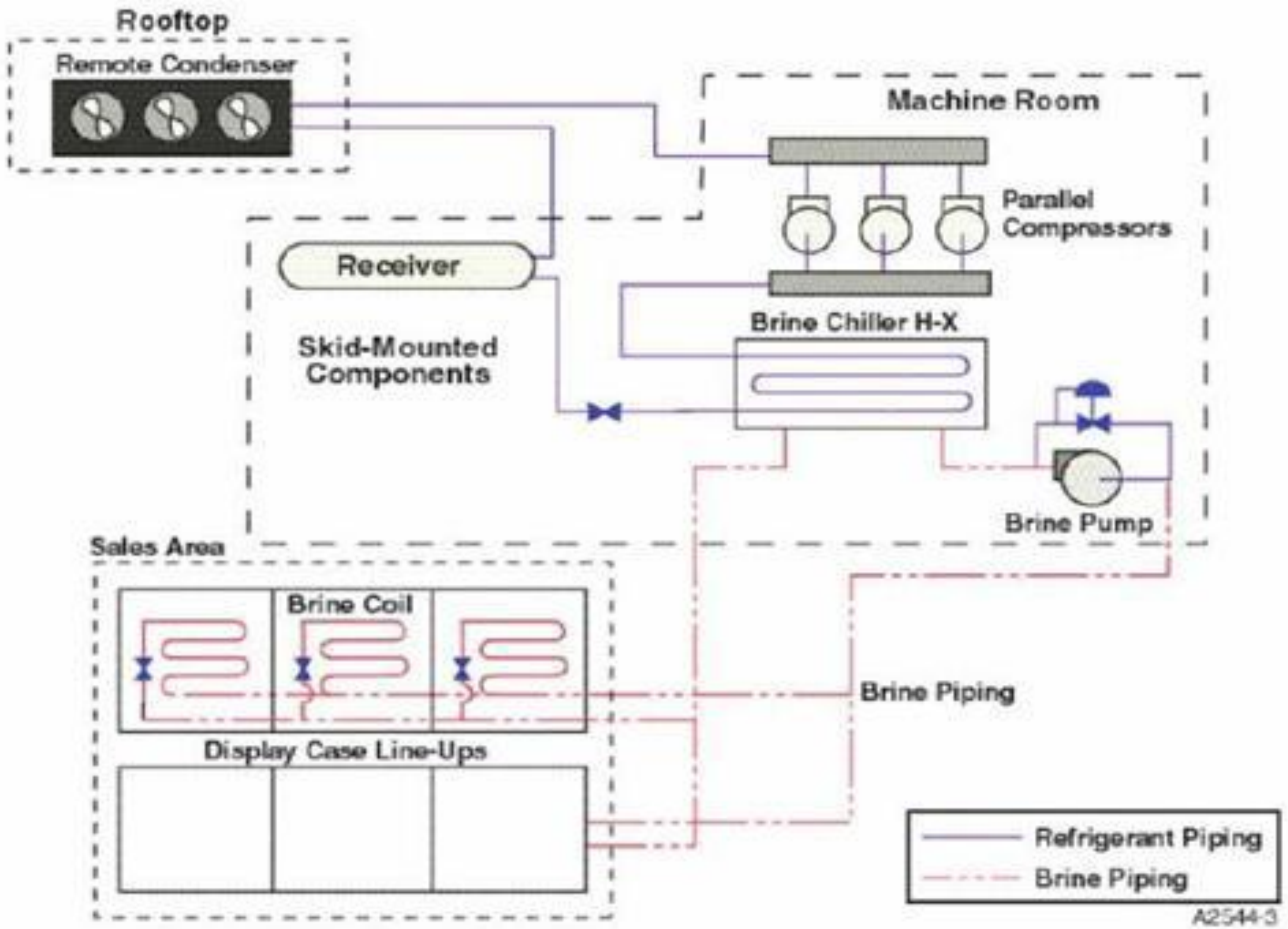
Refrigeration System Selection

- Why a Natural Refrigerant
  - Lowest Life Cycle Costs.
  - No more major Refrigerant Conversions every 10 to 15 years.
  - Energy Efficiency (in the right application)
  - Environmental Benefits
  - Future Proofing
    - Phase Outs, De-Listing, Taxes, Fines, Charge Limits

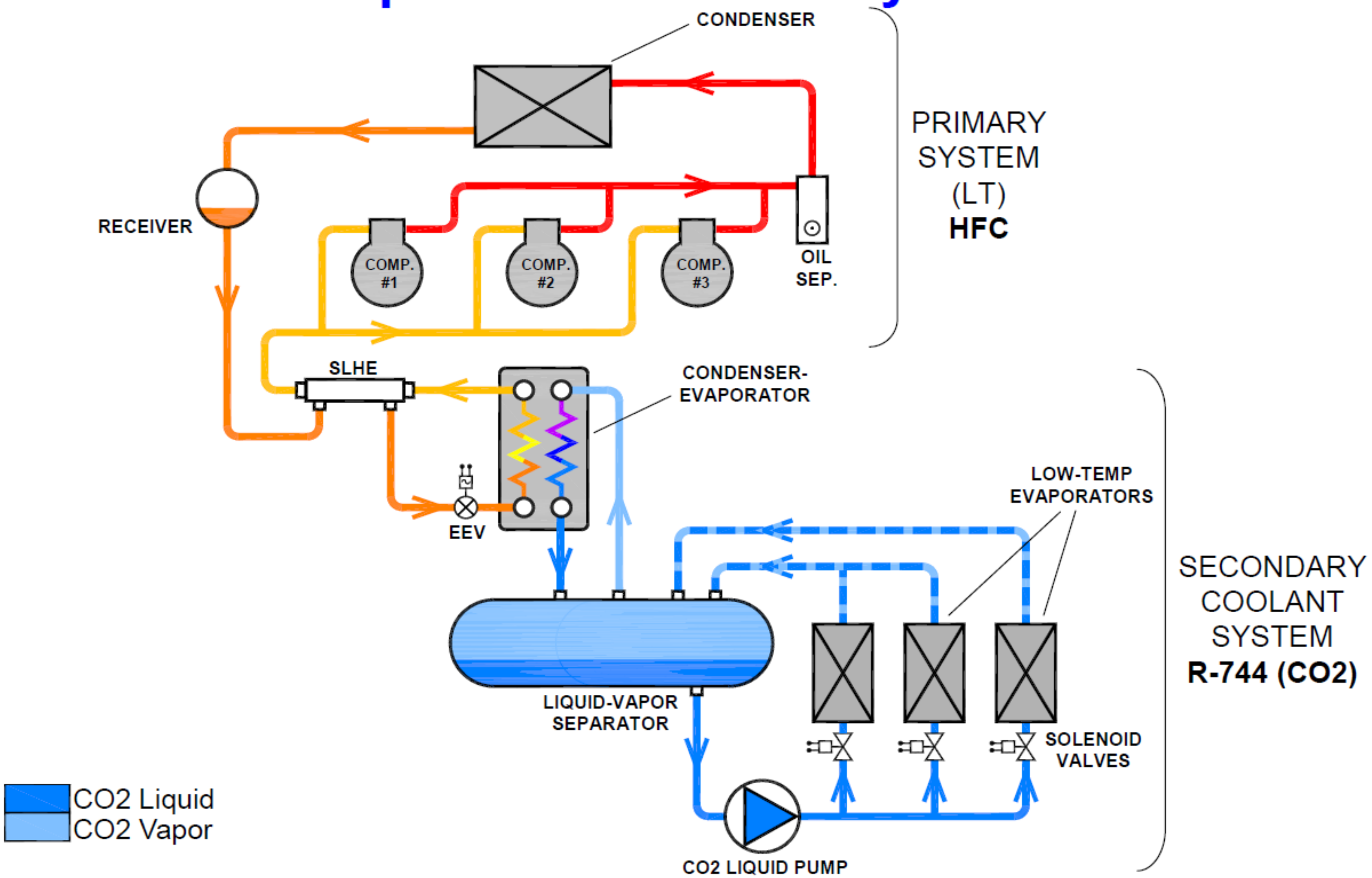
Refrigeration System Selection

- Natural Refrigerants are:
  - CO_2 (R-744)
  - Hydrocarbons (R-290, R-600, ect)
  - Ammonia (R-717)
  - Water (R-718)
  - Air (R-732)

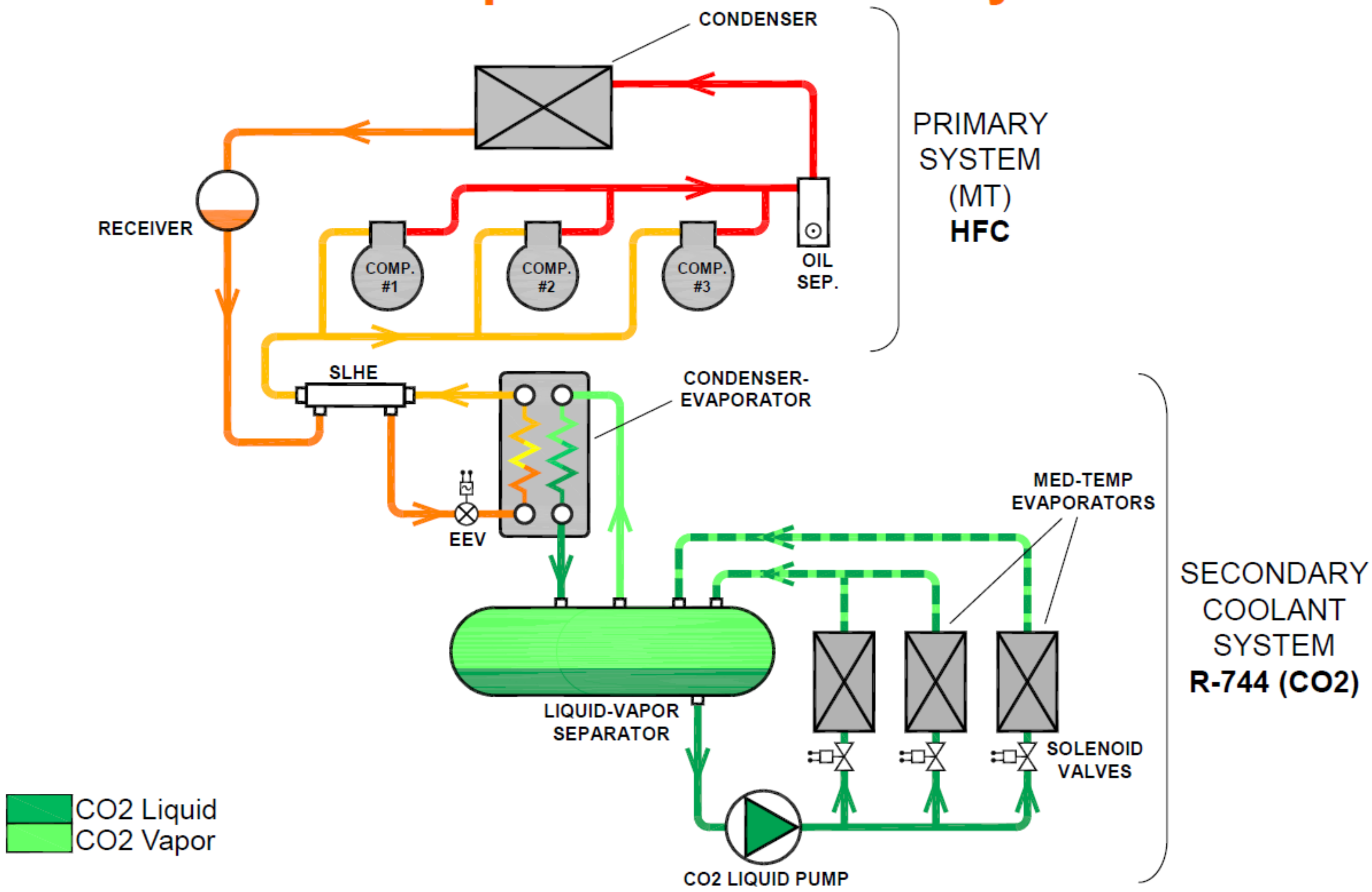
Refrigeration System Selection



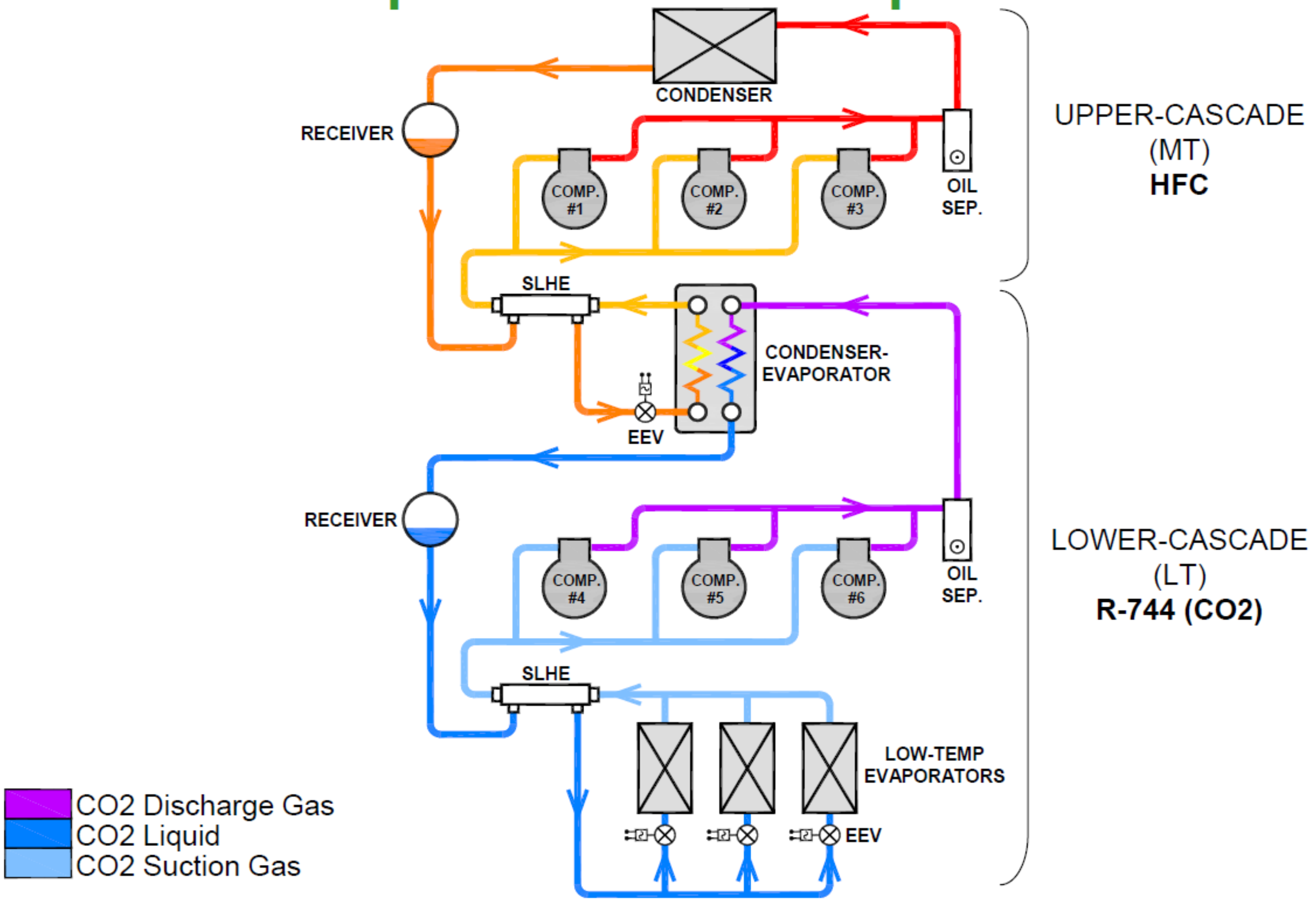
Low-Temperature Secondary Coolant

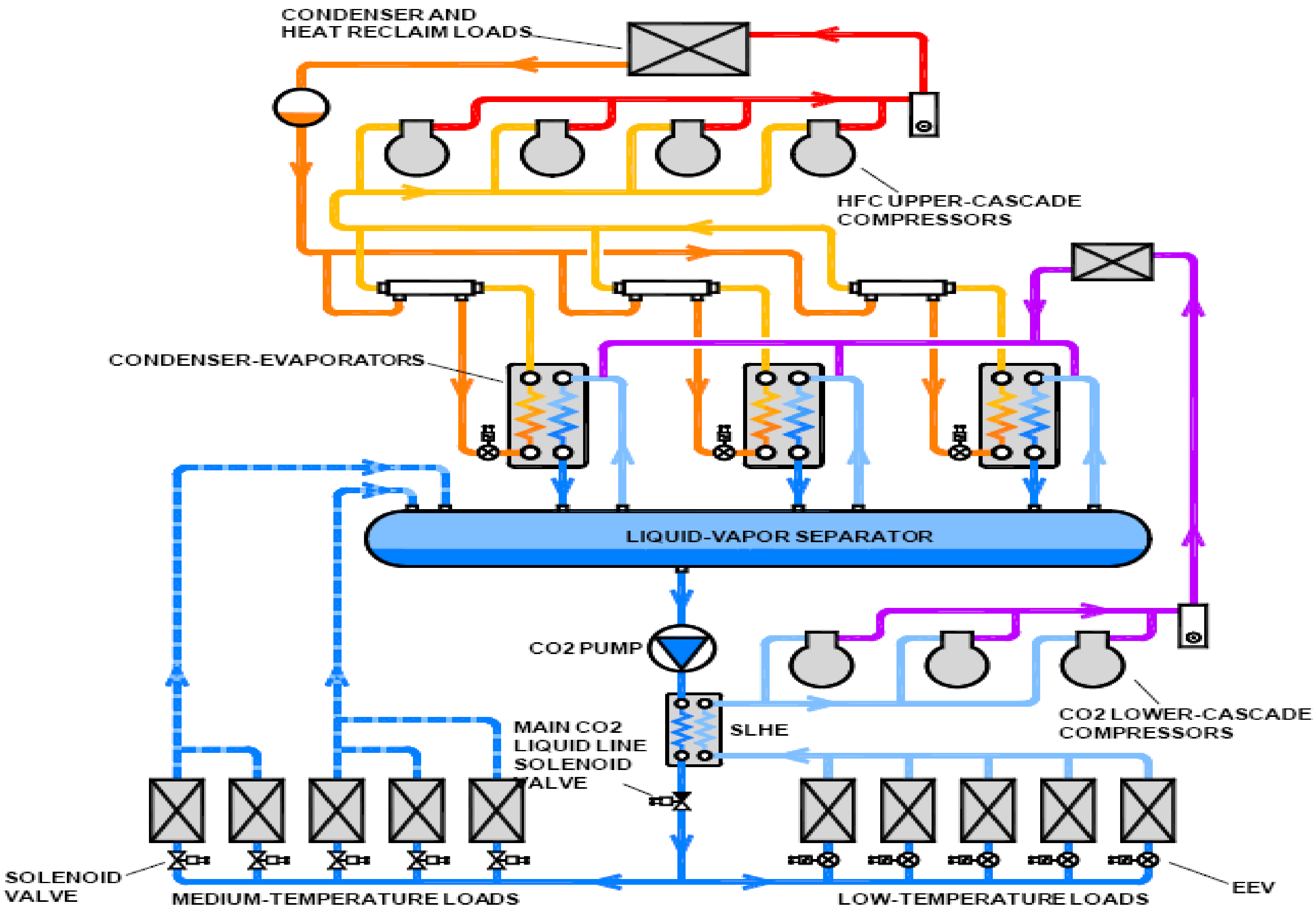


Medium-Temperature Secondary Coolant



Low-Temperature Direct Expansion Cascade




CONDENSER AND
HEAT RECLAIM LOADS
HFC UPPER-CASCADE
COMPRESSORS
CONDENSER-EVAPORATORS
LIQUID-VAPOR SEPARATOR
CO2 PUMP
MAIN CO2
LIQUID LINE
SOLENOID
VALVE
SLHE
CO2 LOWER-CASCADE
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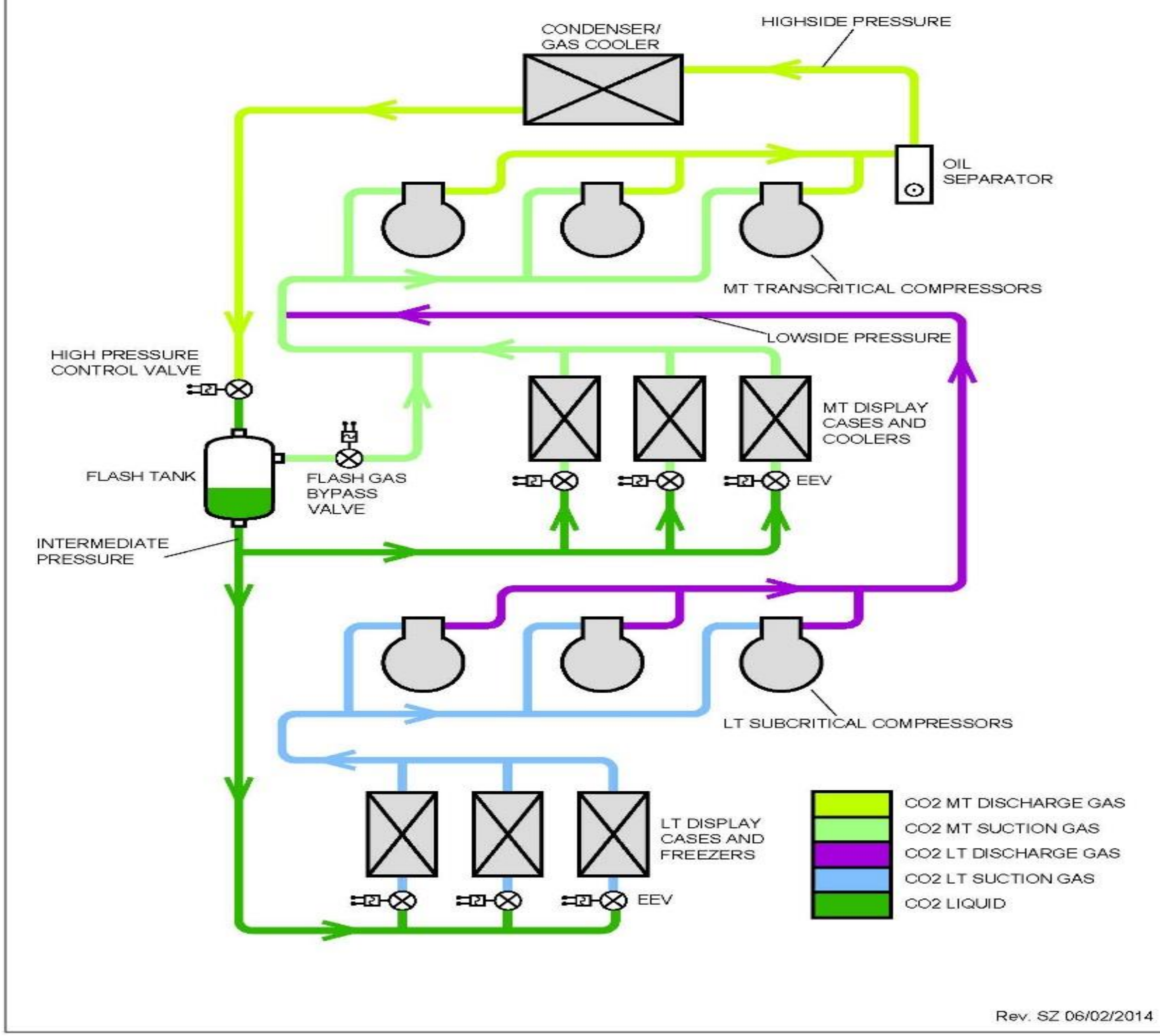
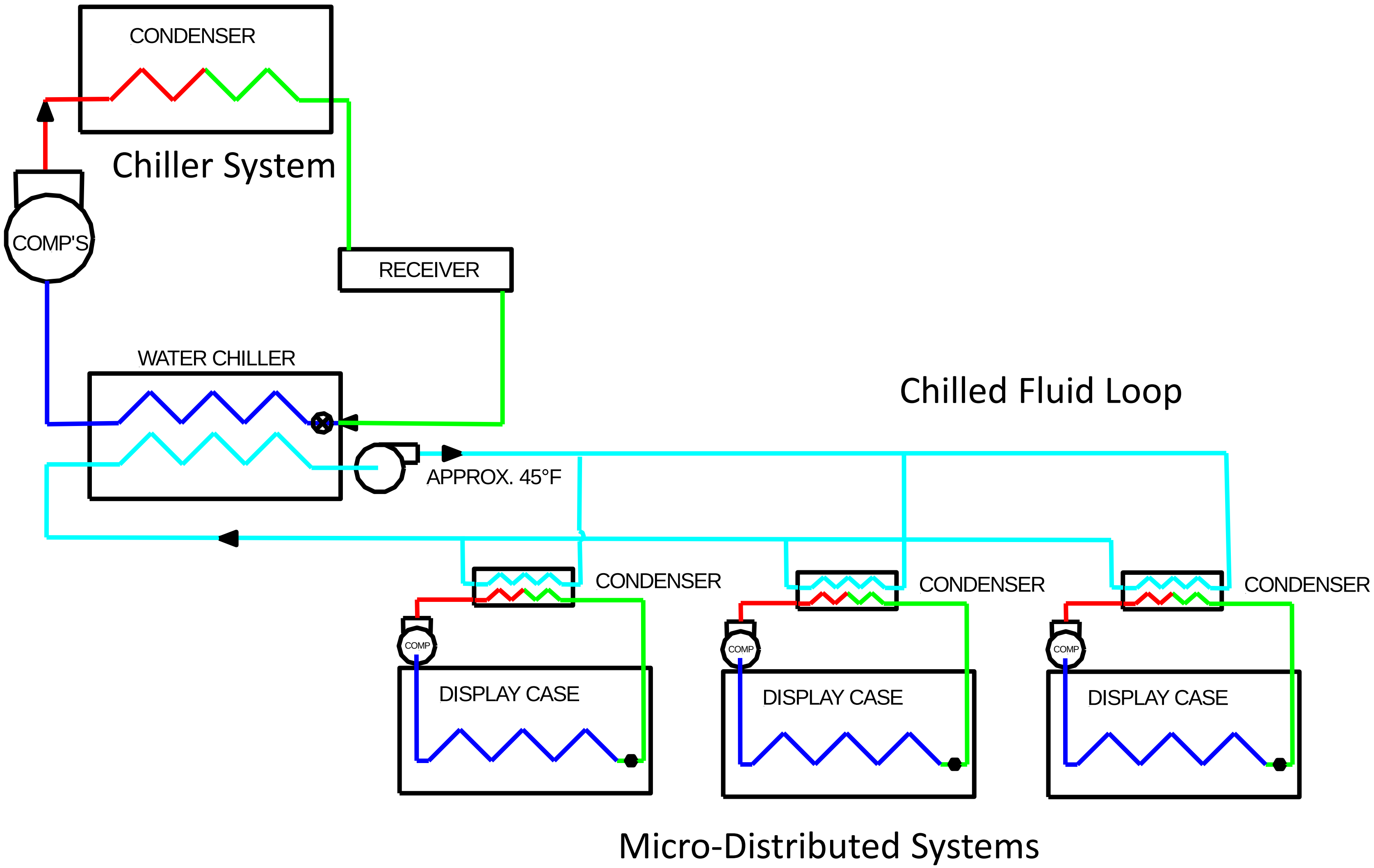
MEDIUM-TEMPERATURE LOADS
LOW-TEMPERATURE LOADS
EEV

BASIC CO2 TRANSCRITICAL BOOSTER SYSTEM DESIGN




CONDENSER
Chiller System
COMP'S
RECEIVER
WATER CHILLER
Chilled Fluid Loop
APPROX. 45°F
CONDENSER
CONDENSER
CONDENSER
COMP
COMP
COMP
DISPLAY CASE
DISPLAY CASE
DISPLAY CASE
Micro-Distributed Systems

Uniform Present Value Calculator

	R-407a Central System		R-407a Distributive System		R-407a Med Secondary Glycol Low Secondary CO2		R-407a Med Secondary CO2 Low Secondary CO2	
Initial Compressor Condenser Equipment Costs		$ 250,000.00		$ 250,000.00		$ 312,500.00		$ 350,000.00
Initial Case/Evaporator Equipment Costs		$ 800,000.00		$ 800,000.00		$ 920,000.00		$ 920,000.00
Initial Installation Costs		$ 300,000.00		$ 270,000.00		$ 330,000.00		$ 330,000.00
Intial Refrigerant Costs		$ 32,000.00		$ 25,600.00		$ 30,940.00		$ 9,800.00
Annual Refrigerant Costs	$ 8,000.00	$ 77,697.99	$ 5,120.00	$ 49,726.71	$ 3,094.00	$ 30,049.70	$ 980.00	$ 9,518.00
Annual Energy Costs	$ 240,000.00	$ 2,330,939.76	$ 240,000.00	$ 2,330,939.76	$ 276,000.00	$ 2,680,580.72	$ 240,000.00	$ 2,330,939.76
Annual Maitenance Costs	$ 7,500.00	$ 72,841.87	$ 7,500.00	$ 72,841.87	$ 5,250.00	$ 50,989.31	$ 5,250.00	$ 50,989.31
Uniform Present Value (based on yrs) Percentage Higher then base line(100% equal)		$ 3,863,479.62 100%		$ 3,799,108.34 98%		$ 4,355,059.73 113%		$ 4,001,247.07 104%

Discount Rate	6%
Period(yrs)	15
Refrigerant Leak Rate (Central System)	25%
Refrigerant Leak Rate (Distributive System)	20%
Refrigerant Leak Rate (Secondary System)	10%
Refrigerant Leak Rate (Cascade)	15%
Refrigerant Leak Rate (Transcritial CO2)	15%
$/kW-h	$ 0.12
Annual kW-h	2,000,000.00
lb of R-407a	4,000.00
lb of CO2	1,800.00
lb of NH3	100.00
lb of Glycol	1,600.00
$/lb of R-407a	$ 8.00
$/lb of CO2	$ 1.00
$/lb of NH3	$ 5.00
$/lb glycol	$ 12.00

R-407a High Side Med Seconday CO2 Low Cascade CO2		NH3 High Side Med Seconday CO2 Low Cascade CO2		Med/Low Transcritcal CO2 Booster	
	$ 350,000.00		$ 937,500.00		$ 350,000.00
	$ 920,000.00		$ 920,000.00		$ 920,000.00
	$ 345,000.00		$ 375,000.00		$ 360,000.00
	$ 9,800.00		$ 2,300.00		$ 2,400.00
$ 1,470.00	$ 14,277.01	$ 280.00	$ 2,719.43	$ 360.00	$ 3,496.41
$ 216,000.00	$ 2,097,845.78	$ 204,000.00	$ 1,981,298.79	$ 204,000.00	$ 1,981,298.79
$ 6,750.00	$ 65,557.68	$ 18,750.00	$ 182,104.67	$ 8,250.00	$ 80,126.05
	$ 3,802,480.47 98%		$ 4,400,922.89 114%		$ 3,697,321.26 96%

–Inputs

- Typical Refrigeration Equipment costs
- Typical Maintenance Costs
- General agreed upon Energy (kW-h) differences between system types
- Industry Average Refrigerant Costs
- Industry Average Leak Rates
- Typical Refrigerant Charge amounts

Discount Rate	6%
Period(yrs)	15
Refrigerant Leak Rate (Central System)	25%
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Refrigerant Leak Rate (Secondary System)	10%
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Refrigerant Leak Rate (Transcritial CO2)	15%
$/kW-h	$ 0.12
Annual kW-h	2,000,000.00
lb of R-407a	4,000.00
lb of CO2	1,800.00
lb of NH3	100.00
gal of Glycol	1,600.00
$/lb of R-407a	$ 8.00
$/lb of CO2	$ 1.00
$/lb of NH3	$ 5.00
$/gal glycol	$ 12.00

Uniform Present Value Calculator

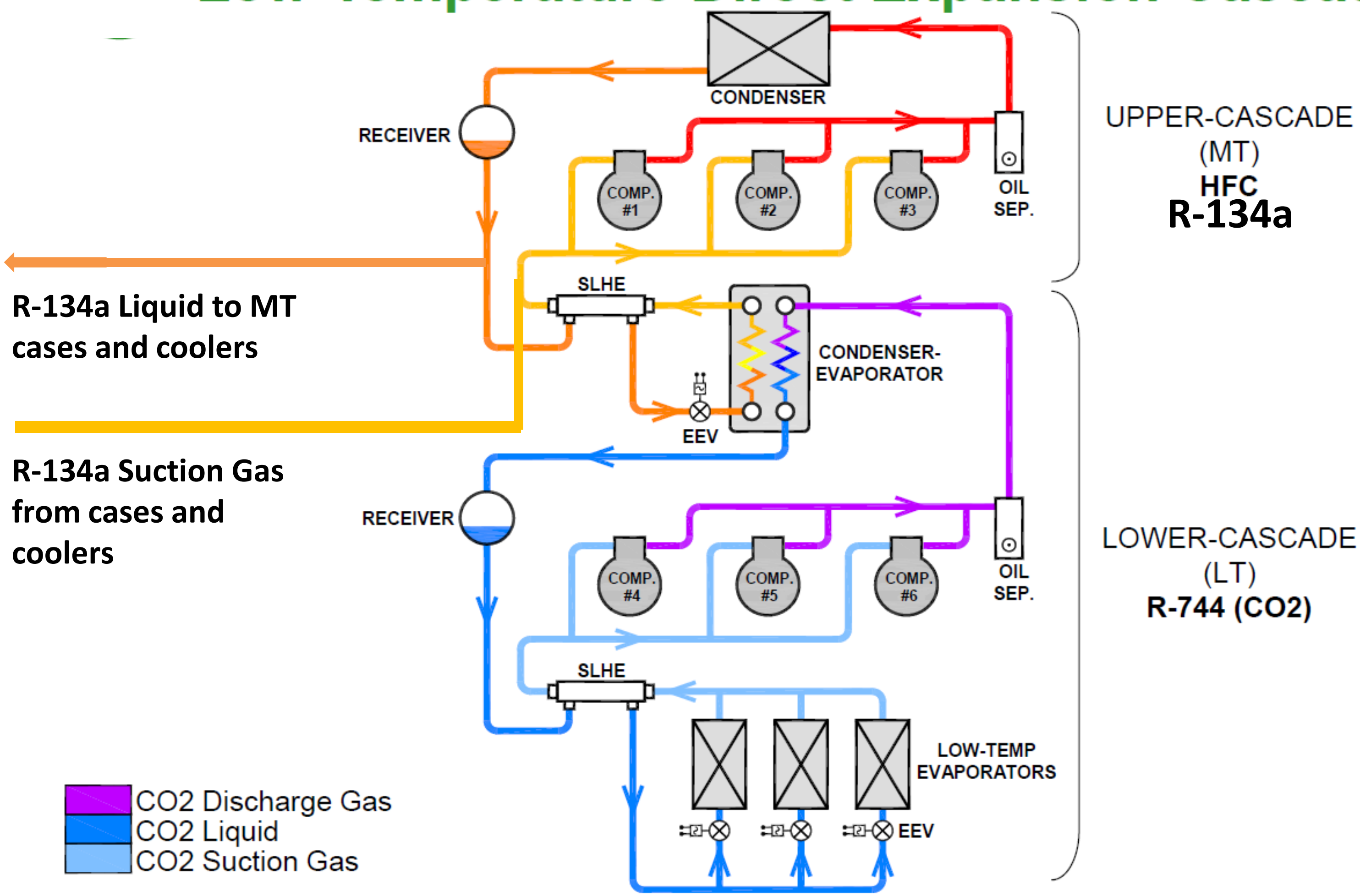
		R-407a Central System
Initial Compressor Condenser Equipment Costs		$ 250,000.00
Initial Case/Evaporator Equipment Costs		$ 800,000.00
Initial Installation Costs		$ 300,000.00
Intial Refrigerant Costs		$ 32,000.00
Annual Refrigerant Costs	$ 8,000.00	$ 77,697.99
Annual Energy Costs	$ 240,000.00	$ 2,330,939.76
Annual Maitenance Costs	$ 7,500.00	$ 72,841.87
Uniform Present Value (based on yrs) Percentage Higher then base line(100% equal)		$ 3,863,479.62 100%

15 Year Life Cycle Analysis	R-407a Central System	R-407a Distributed System	R-407a Med Secondary Glycol Low Secondary CO2	R-407a Med Secondary CO2 Low Secondary CO2
First Costs(Equip/Install)	100%	98%	116%	119%
Initial Refrig Costs	100%	80%	97%	31%
Annual Refrig Costs	100%	64%	39%	12%
Annual Energy Costs	100%	100%	115%	100%
Annual Maint. Costs	100%	100%	70%	70%
Life Cycle Cost	**100%**	**98%**	**113%**	**104%**

R-134a Med/ CO_2 DX Low **98%**

	R-407a High Side Med Seconday CO2 Low Cascade CO2	NH3 High Side Med Seconday CO2 Low Cascade CO2	Med/Low Transcritcal CO2 Booster
First Costs(Equip/Install)	120%	165%	120%
Initial Refrig Costs	31%	7%	8%
Annual Refrig Costs	18%	3%	5%
Annual Energy Costs	90%	85%	85%
Annual Maint. Costs	90%	250%	110%
Life Cycle Cost	**98%**	**114%**	**96%**

Low-Temperature Direct Expansion Cascade



	R-407a Central System	R-407a Distributed System	R-407a Med Secondary Glycol Low Secondary CO2	R-407a Med Secondary CO2 Low Secondary CO2
Life Cycle Cost	**100%**	**98%**	**113%**	**104%**
TEWI Direct (metric Ton CO2-e)	14,715	9,479	2,141	2,142
TEWI Indirect (metric Ton CO2-e)	18,053	18,053	20,761	18,053
TEWI Total (metric Ton CO2-e)	32,768	27,531	22,901	20,194
TEWI % of Baseline	**100%**	**84%**	**70%**	**62%**

R-134a Med/ CO2 DX Low
69%

		R-407a High Side Med Seconday CO2 Low Cascade CO2	NH3 High Side Med Seconday CO2 Low Cascade CO2	Med/Low Transcritcal CO2 Booster
Life Cycle Cost		**98%**	**114%**	**96%**
TEWI Direct (metric Ton CO2-e)		2,142	1	3
TEWI Indirect (metric Ton CO2-e)		16,247	15,345	15,345
TEWI Total (metric Ton CO2-e)		18,389	15,346	15,347
TEWI % of Baseline		**56%**	**47%**	**47%**

Summary

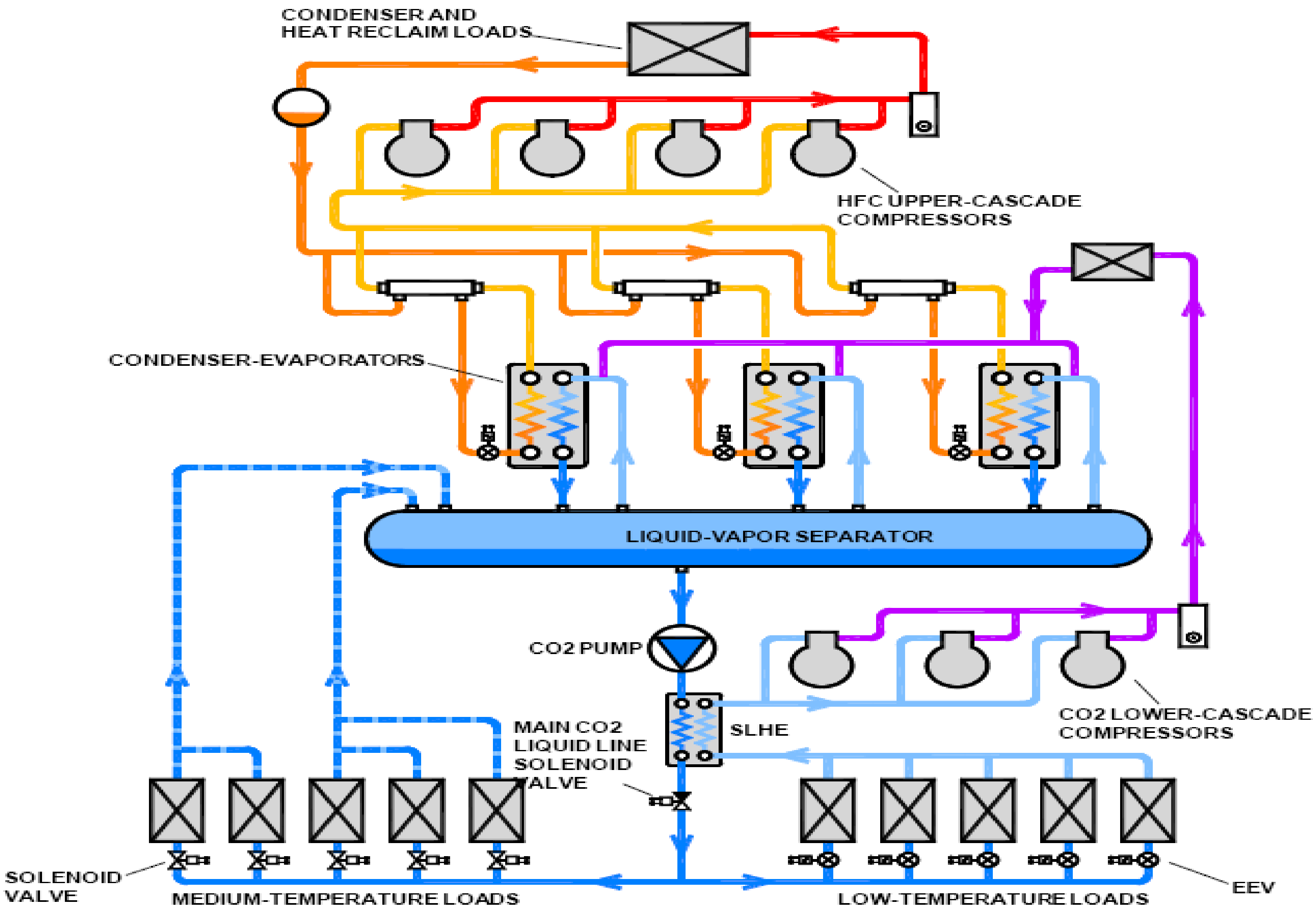
Don’t believe Advanced systems of the future will look like current advanced refrigeration systems of today.

- Standardized
- Assembly Line
- Modules
- Off the shelf package units

Summary

90% Natural Refrigerant Systems will use refrigerant with GWP near or below 500

- Low GWP won't be 1500 to 2000 (R-134a/R-407a)
- Possibly
  - A2L (R-32, L-40, DR-7, ARM-20, HDR-110 and others)
  - HFO (HFO-1234yf, HFO-1234ze)
  - New Refrigerants (R-448a, R-449a, ARM-32)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LIQUID LINE
SOLENOID
VALVE
SLHE
CO2 LOWER-CASCADE
COMPRESSORS
SOLENOID
VALVE
MEDIUM-TEMPERATURE LOADS
LOW-TEMPERATURE LOADS
EEV

Summary

CO_2 as a Refrigerant is inexpensive and has a Really Low GWP (GWP=1)

- Better Heat transfer than Glycol or Brine
- Lower pump energy requirements than Glycol or Brine
- CO_2 Systems have Smaller Pipe size requirements than Glycol, Brine or DX systems
- CO_2 Systems can be energy neutral or better then traditional DX systems

Summary

For End Users Having an Aggressive Energy and Sustainability Goals

- CO_2 Transcritical (where feasible)
- Ammonia/CO_2 Cascade
- Micro Distributed
- A2L/CO_2 Cascade (with SNAP and UL approvals)

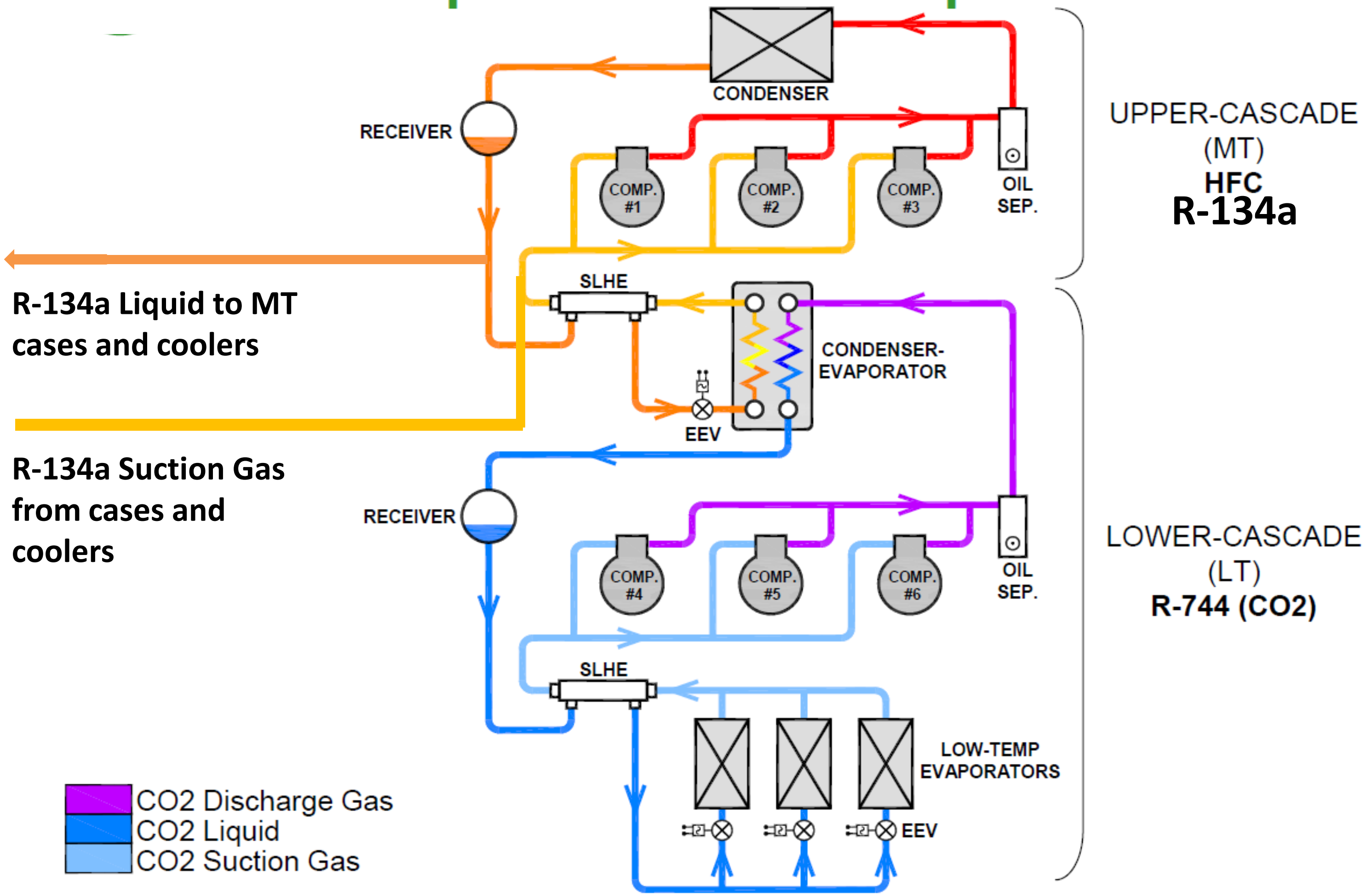
Summary

- System Types this Refrigeration Consultant would choose if the selection was solely up to me

Summary

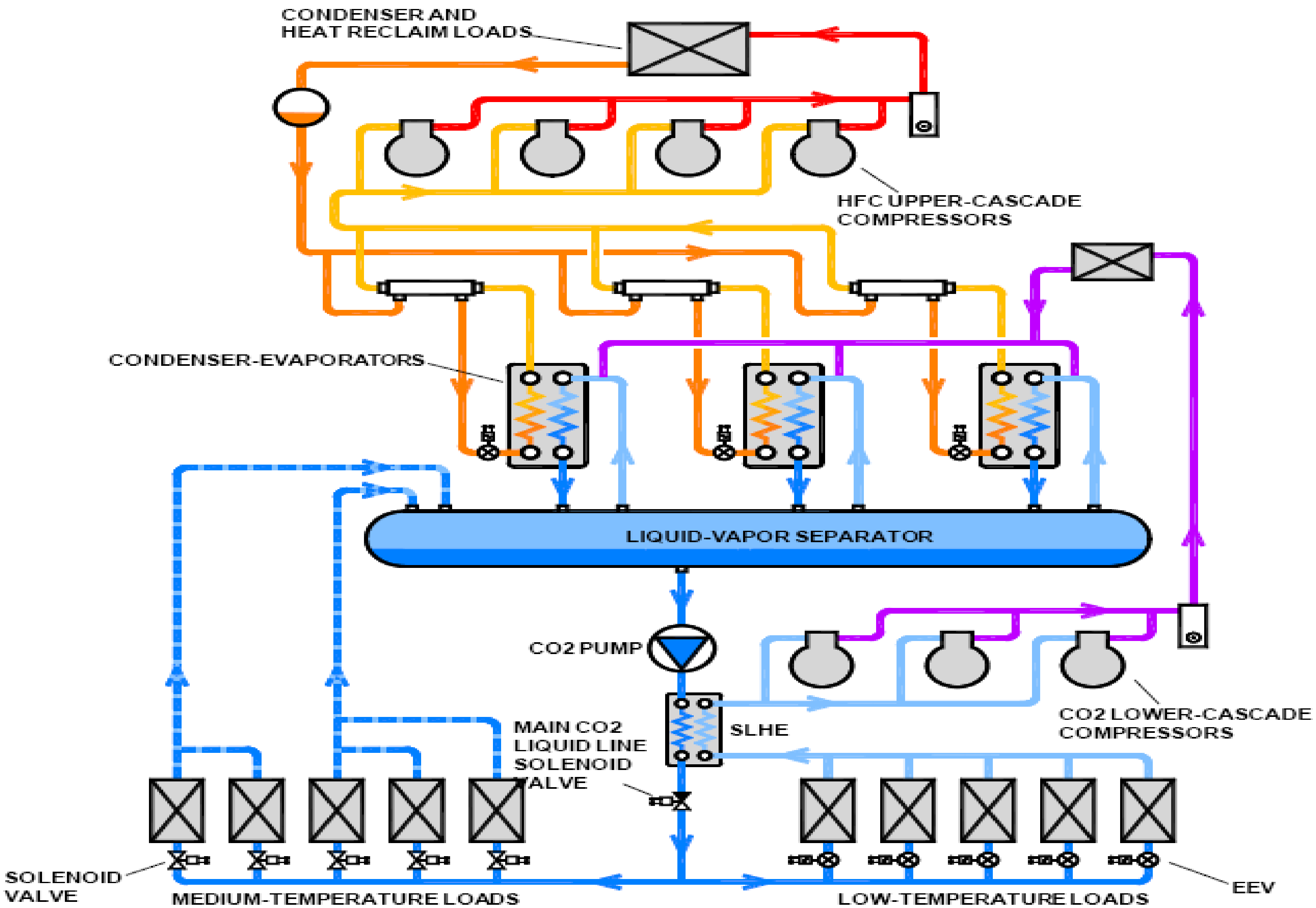
- 40% Natural Refrigerant Solution
  - R-134a Hybrid System
    - R-134a Medium Temp System
    - Low Temperature CO_2 Cascade DX
  - Benefits over Industry Standard R-407a system
    - Lower Energy Use
    - Lower Life Cycle Cost
    - Lower TEWI value

Low-Temperature Direct Expansion Cascade



Summary

- 90% Natural Refrigerant Solution
  - Low Charge HFC System
    - R-134a chiller
    - Medium Temperature CO2 Secondary
    - Low Temperature CO2 Cascade DX
  - Benefits over Industry Standard R-407a system
    - Lower Energy Use
    - Lower Life Cycle Cost
    - Lower TEWI value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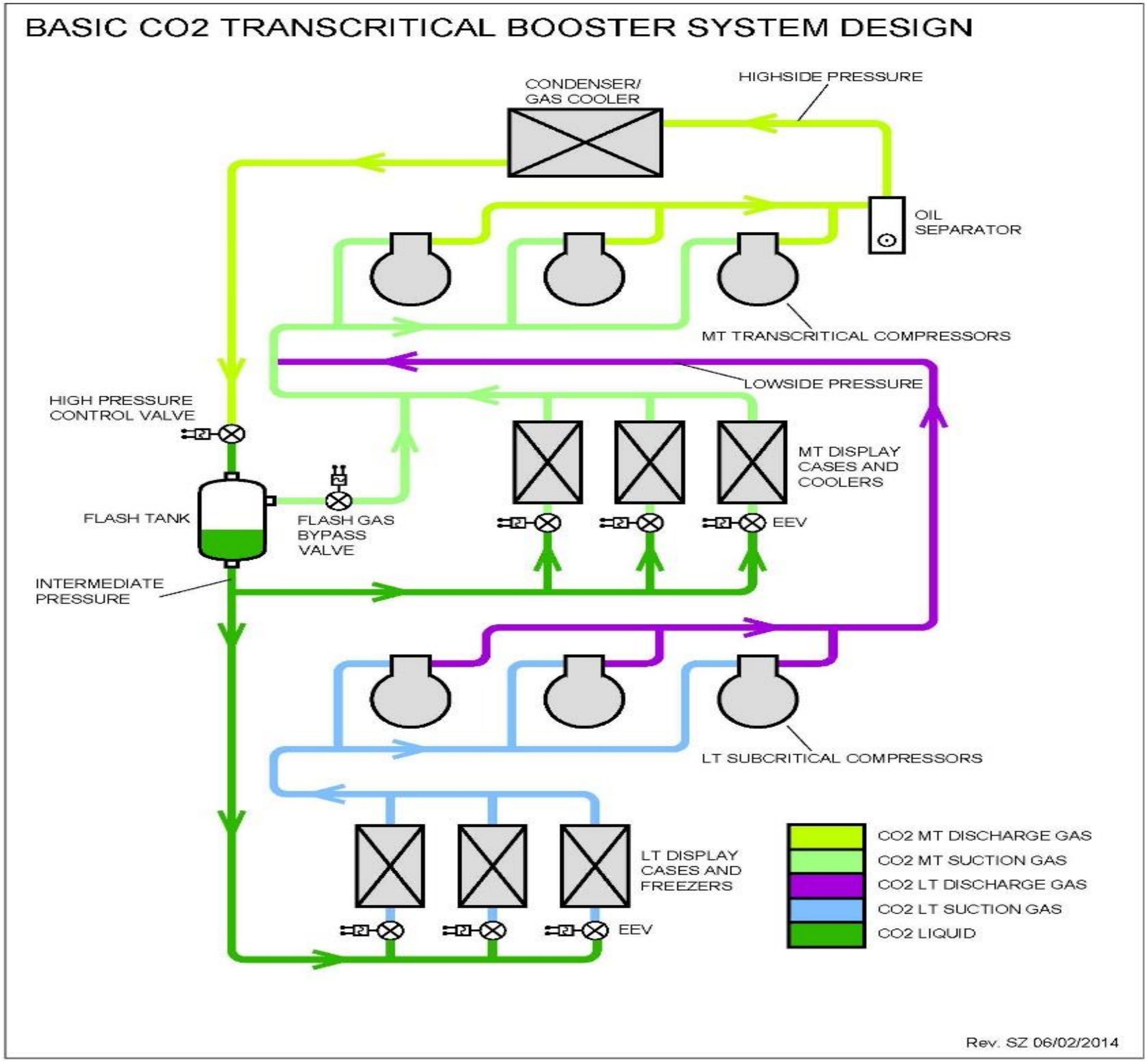
LOW-TEMPERATURE LOADS
EEV

Summary

- 100% Natural Refrigeration System
  - CO2 Transcritical or Enhanced Transcritical
    - Where annual ambient temperatures are such that there is an energy benefit
  - Benefits over Industry Standard R-407a system
    - Lower Energy Use (in the right application)
    - Lower Life Cycle Cost
    - Very low TEWI value


BASIC CO2 TRANSCRITICAL BOOSTER SYSTEM DESIGN
CONDENSER/ GAS COOLER
HIGHSIDE PRESSURE
OIL SEPARATOR
MT TRANSCRITICAL COMPRESSORS
LOWSIDE PRESSURE
HIGH PRESSURE CONTROL VALVE
MT DISPLAY CASES AND COOLERS
FLASH TANK
FLASH GAS BYPASS VALVE
EEV
INTERMEDIATE PRESSURE
LT SUBCRITICAL COMPRESSORS
LT DISPLAY CASES AND FREEZERS
EEV
CO2 MT DISCHARGE GAS
CO2 MT SUCTION GAS
CO2 LT DISCHARGE GAS
CO2 LT SUCTION GAS
CO2 LIQUID
Rev. SZ 06/02/2014

Summary

- 100% Natural Refrigeration System
  - Ammonia System
    - Ammonia Chiller
    - Medium Temperature CO2 Secondary
    - Low Temperature CO2 Cascade DX
  - Benefits over Industry Standard R-407a system
    - Lower Energy Use
    - ~~Lower Life Cycle Cost~~ (Changes when CO2 cost something)
    - Lowest possible TEWI value

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Life Cycle Cost	100%	98%	113%	104%
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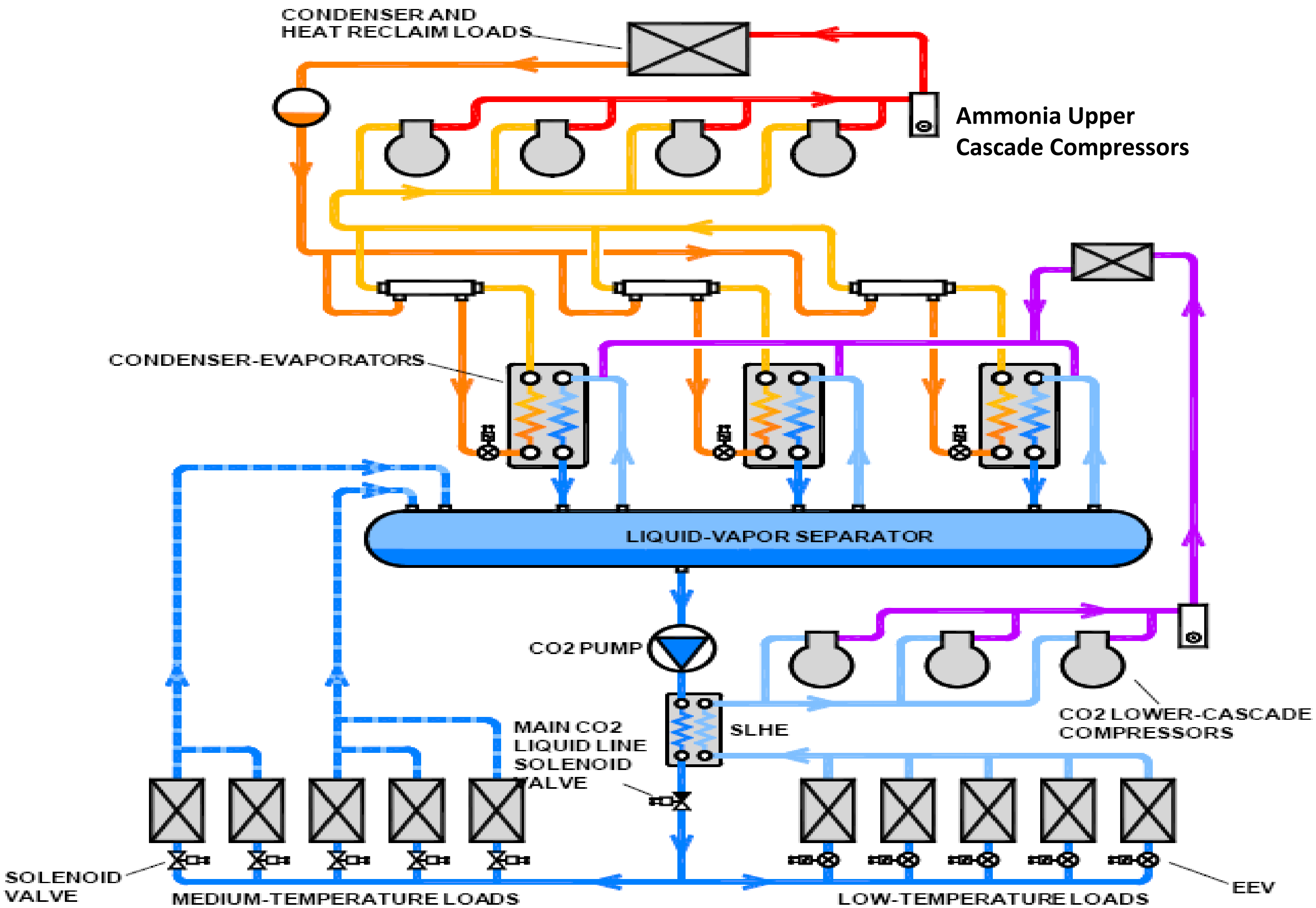
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MEDIUM-TEMPERATURE LOADS
LOW-TEMPERATURE LOADS
EEV

Thank You

Rob Arthur, P.E., P Eng, LEED AP

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