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Sustainability Through Refrigeration Energy Efficiency & Technology Choice

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School of Engineering & Advanced Technology
Massey University

Winery Engineering Association Conference
21 July, 2016

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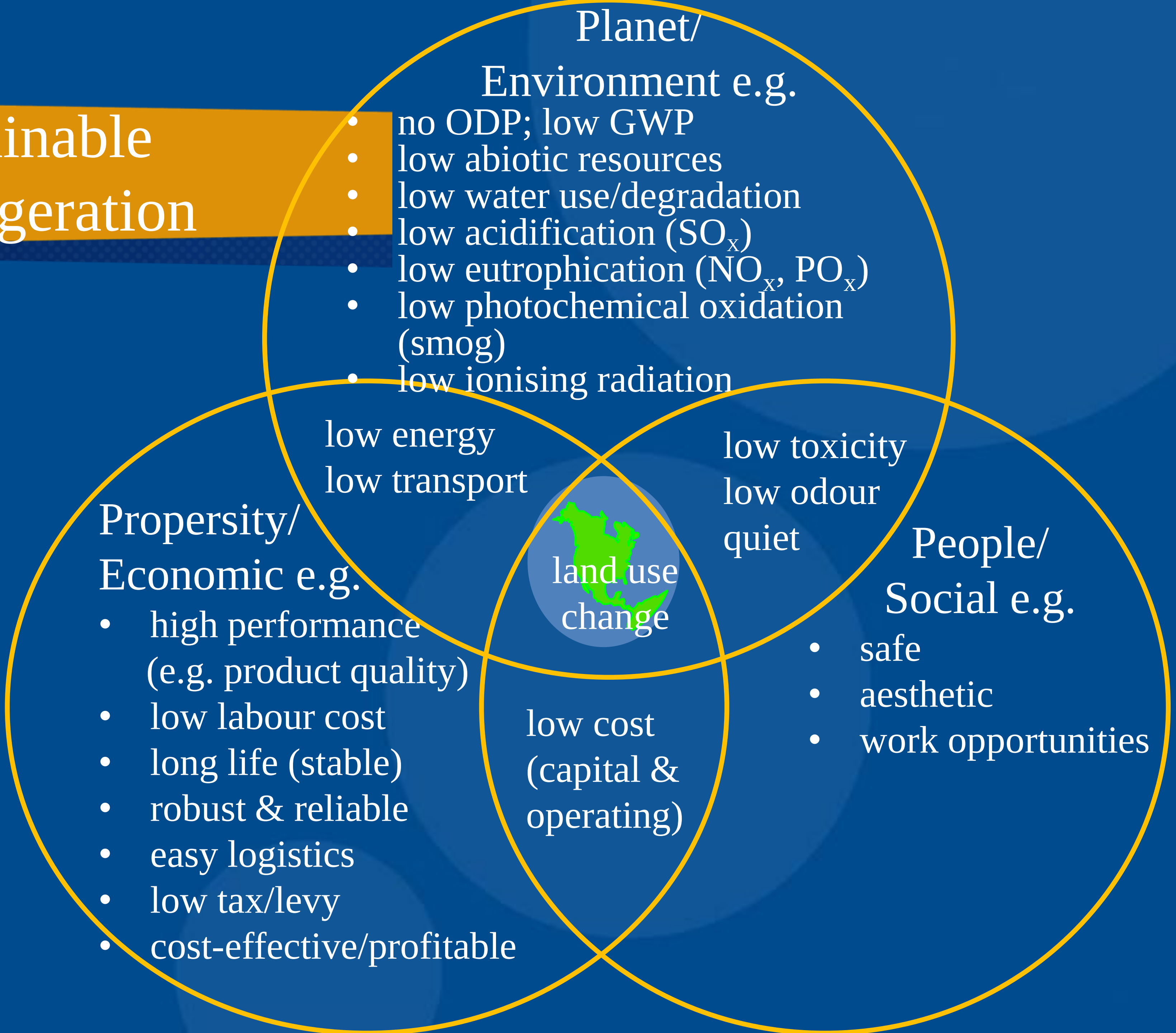
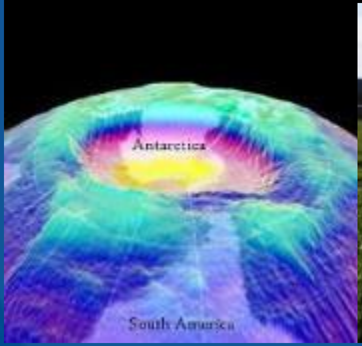
Agenda

- Refrigeration Sustainability
- Sustainability Strategies
- Refrigerant and Technology Options
- Energy Efficiency Opportunities

Sustainable Refrigeration

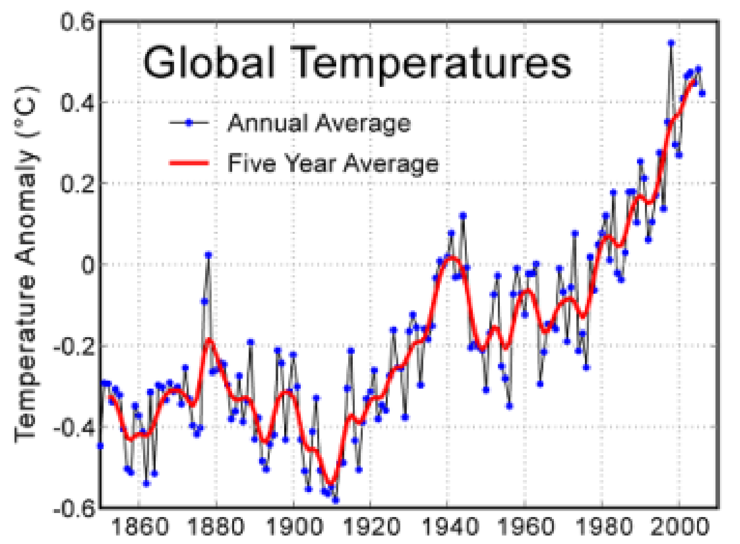


Environmental Sustainability



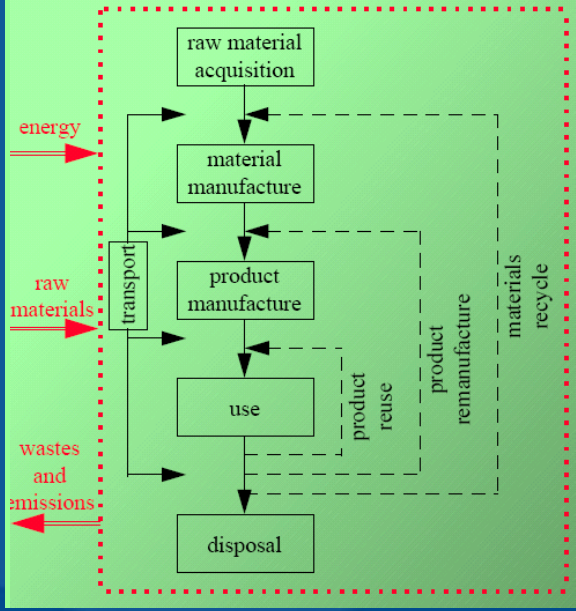
Providing the needs of the present without detracting from the ability to fulfil the needs of the future - ASHRAE (2006)

- **global warming**
- **ozone depletion**
- **water use**
- **abiotic resource depletion**
- land use change
- eutrophication
- acidification
- human toxicity
- photochemical oxidation
- dust
- ecotoxicity
- ionising radiation



Measuring Sustainability

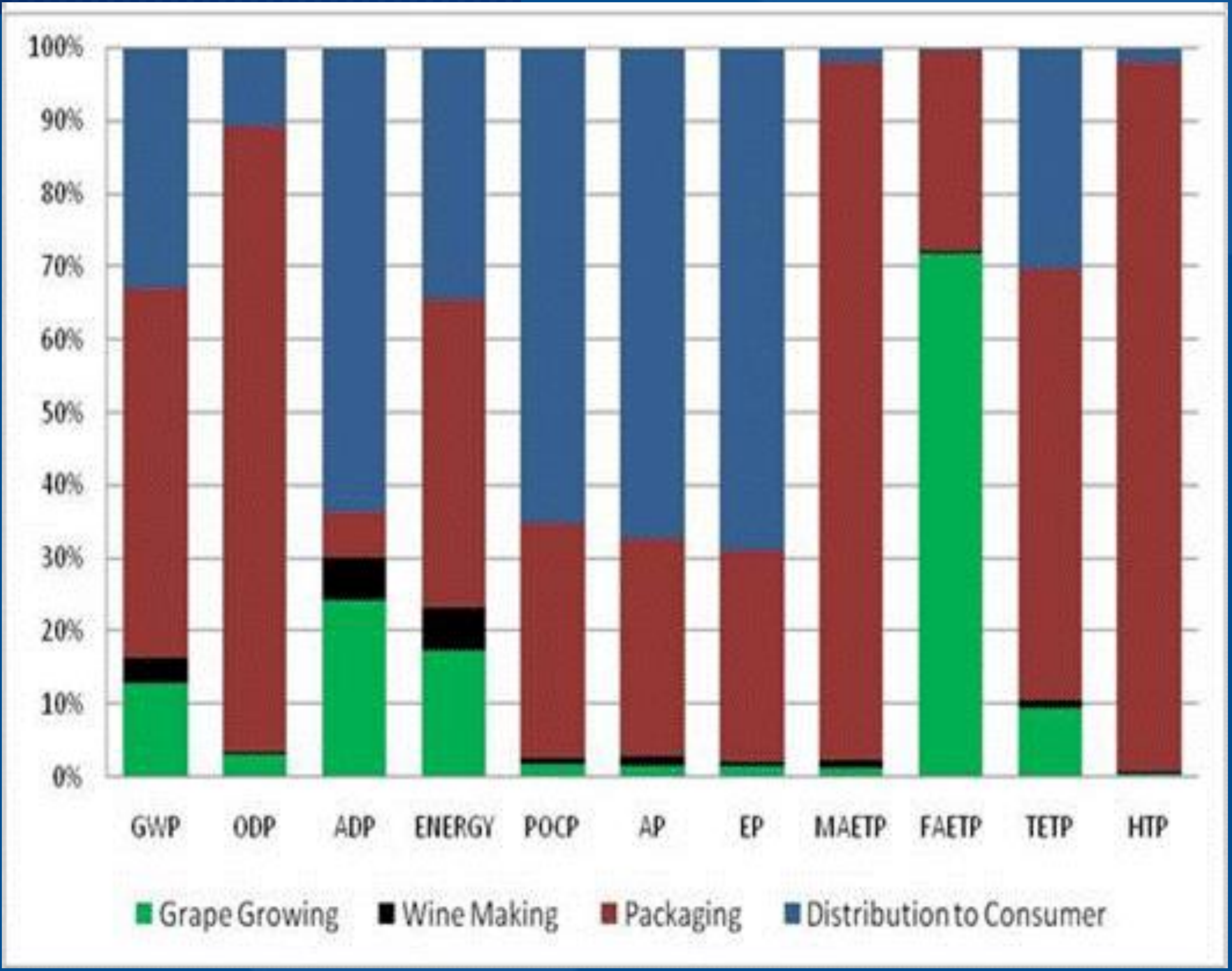
Category	Criterion
Safety	Refrigerant safety
	Refrigeration system safety
	Equipment safety risk
	Operating charge
Cost	Capital cost
	Refrigerant cost
	Operating cost
	Maintenance cost
	Life-cycle cost
Environmental	Global warming potential (GWP)
	Carbon foot print or Total equivalent warming impact (TEWI)
	Water use
	Water disposal
	Chemical usage for treatment
Operations and Maintenance	System complexity
	Refrigerant
	Redundancy
	Resiliency
	Required space/footprint
	Serviceability
	Expandability
	Ability to accommodate future expansion
Regulatory	Applicable regulations or standards at time of construction
	Applicable regulations or standards during operation
Technology	State of maturity
	Equipment life expectancy
	Supplier stability



- Scorecards
- Single issue footprints

  e.g. carbon, water
- LCA approaches preferred
- Issues
  - comparing impacts (weighting)
  - global vs local impacts
  - data availability & reliability

Wine LCA



100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
GWP
ODP
ADP
ENERGY
POCP
AP
EP
MAETP
FAETP
TETP
HTP
Grape Growing
Wine Making
Packaging
Distribution to Consumer

Carbon Footprint for Refrigerated Facility Over a 15 year Lifetime

	Impact Factor (kg CO_2 eq./kg)	Amount or Annual Consumption (kg or tonnes)	Carbon Footprint (kg CO_2 eq.)	% of Total
Direct Emissions				
Refrigerant Leakage (R407C)				
- Annual	1774	1,125	1,995,750	
- End of life	1774	225	399,150	
Total Direct Emissions			2,394,900	2%
Indirect Emissions				
Facility Construction Materials			11,969,440	10%
- aggregate	0.0052	23,000	119,600	
- concrete	0.077	25,000	5,175,000	
- steel (structural/racking)	0.75/1.8	2,300/2000	5,325,000	
- polystyrene	3.29	330	1,085,700	
- plastic	2.8	3,900	10,920	
- road transport of above	0.18	kg/tonne-km	253,220	
Refrigeration System Equipment			172,807	0.1%
- refrigerant manufacture	16.7	2,625	43,838	
- steel	1.8	43,000	77,400	
- aluminium	12.6	2,000	25,200	
- copper	3	7,000	21,000	
- plastic	2.8	1,200	3,360	
- road transport of above	0.18	200	2,010	
Lubricating Oil	23	1850	58,650	0.1%
Water Use	0.001	23,000	345,000	0.3%
Energy Use (kWh pa)	0.788 kg/kWh	6,600,000 kWh pa	78,012,000	67%
Product Losses (0.05% pa)	3	50,000	22,950,000	20%
Total Indirect Emissions			113,507,898	98%
Total Emissions			115,902,798	100%

refrigerant choice (→ Refrigerant Leakage)

design decisions (→ Facility Construction Materials, Refrigeration System Equipment)

refrigerant choice

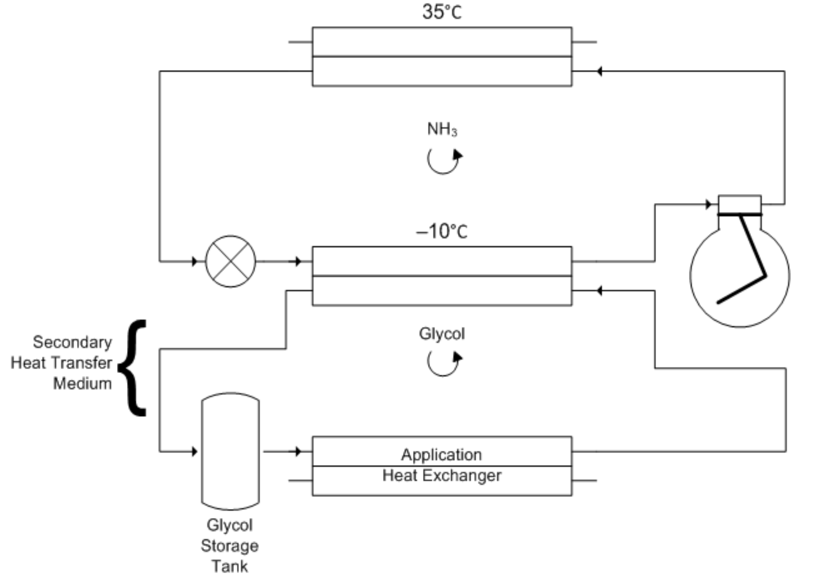
design & operating decisions (→ Energy Use)

refrigeration priority (→ Product Losses)

Sustainability Strategies

- Minimise need for refrigeration
  - insulation
  - ambient cooling
- Manage resources used for refrigeration
  - design/equipment decisions (e.g. water vs air-cooled condenser)
  - energy efficiency
- Minimise impacts
  - design/equipment decisions (type of materials)
  - refrigerant choice (e.g. low GWP)
  - energy sources (e.g. renewable)

Winery Refrigeration



- Primary/Secondary Systems
- Constraints
  - high refrigeration load during vintage
  - low temperature stabilisation
  - poor transport & transfer properties of glycol
  - energy penalty due to extra temp. difference and secondary pumps
- Advantages
  - use primary refrigerants in their optimal temp. ranges
  - can minimise & isolate charges of high GWP, flammable or toxic refrigerants
  - "safe" refrigerants as secondaries

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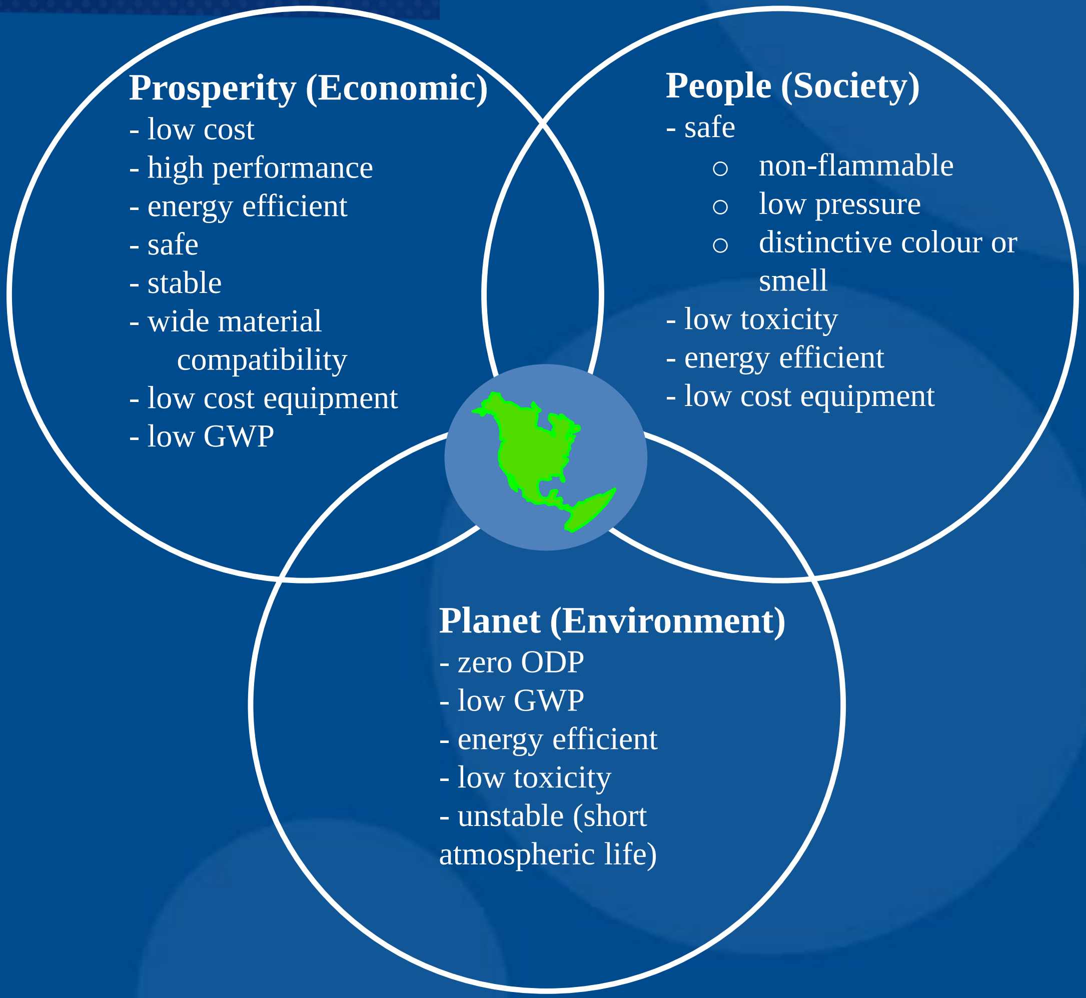
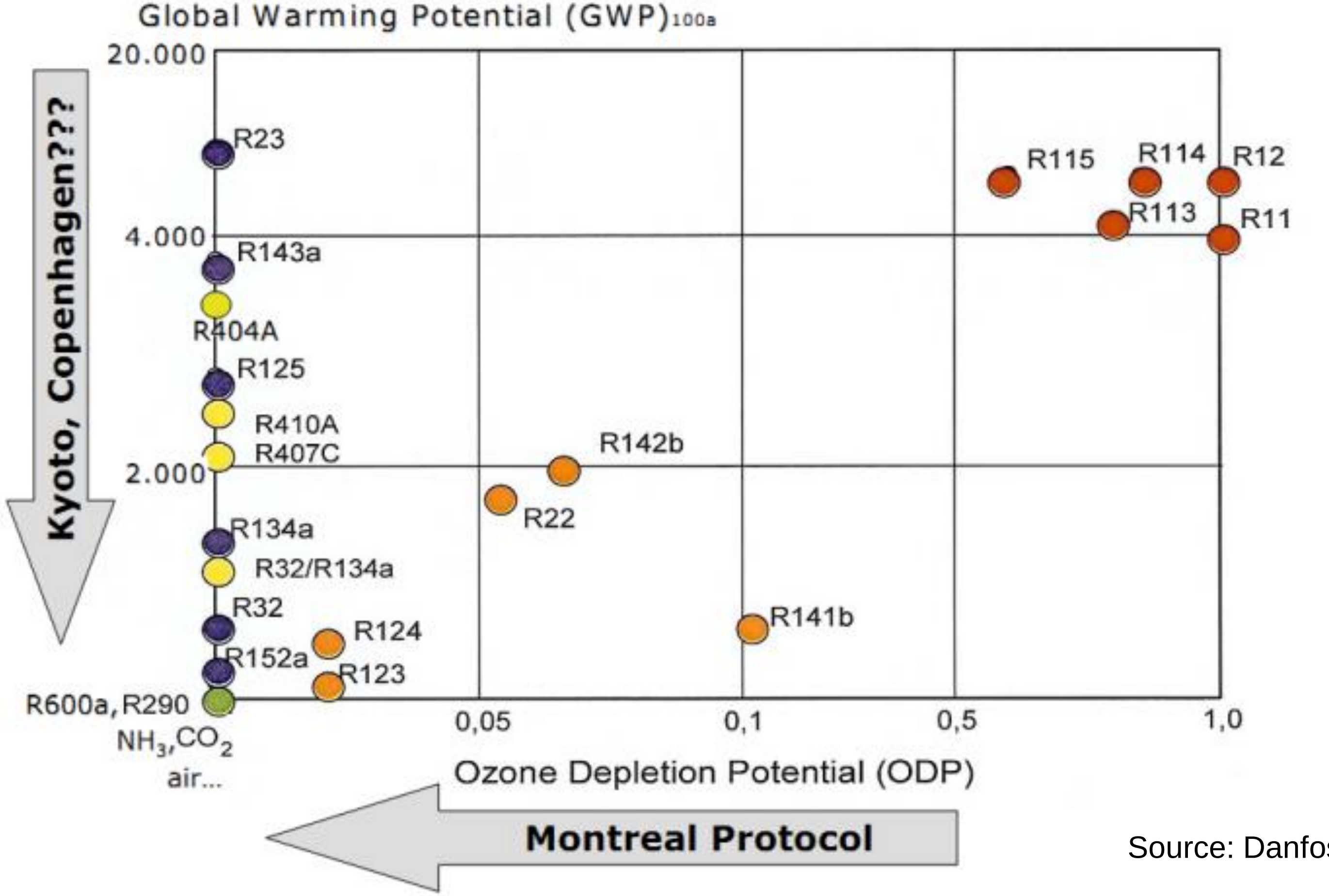
The Perfect Refrigerant



Primary Refrigerants

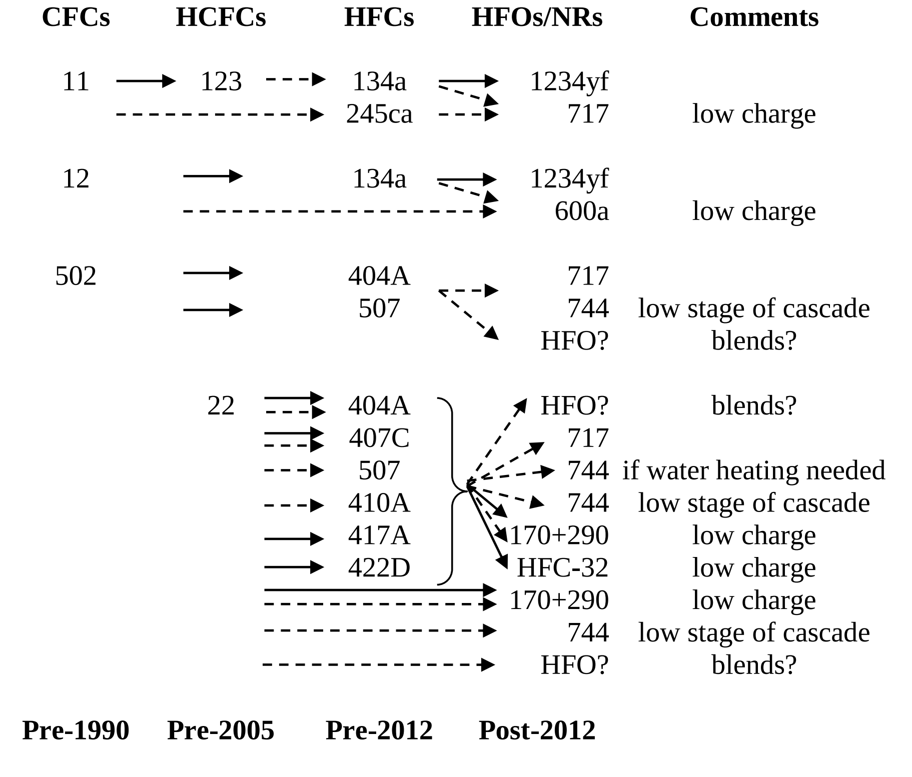


Source: Danfoss

Refrigerant Families

Criteria	HCFCs	HFCs	HFOs	NRs
Refrigerant Cost (no levy)	low/medium	medium	high	low
System Cost	medium	medium	medium	high
Capacity	good	good	good	very good
Energy Efficiency	good	good	good	very good
ODP	yes	no	no	no
GWP (ETS)	high	high	low	very low
Safety (e.g. flammability, toxicity, high pressure)	good	generally good	good except flammability	often significant risks
Oil Compatibility	traditional	synthetic	synthetic	wide

Future Options



- Drive for low GWP refrigerants
- CFC → HCFC → HFC → HFO
  or NR (HC, ammonia, CO_2)
- Flammability harder to avoid
  - reduction in leakage
  - reduction in charge
- Likely replacements have concerns
  - compatibility with existing systems (e.g. CO_2 - high pressure)
  - performance (e.g. mixtures with glides, transcritical CO_2)
  - cost (e.g. HFOs)
  - safety (e.g. HCs or HFOs)
  - flood of blends

Low GWP or Efficient?

Refrigerant	**HFC-404A**	**Alternative**
GWP	3260	150
Charge (kg)	5	5
Leakage (% pa)	5	5
Energy Use (kWh pa)	25,000	+5%
TEWI (kg CO_2)	388,855	394,388 (+1.4%)
ETS + Energy Cost ($)	656+37,500 = 38,156	30+39375 = 39,405(+3.3%)

- 15 year equipment life
- 90% refrigerant recovery
- electricity emission factor of 1 kg CO_2/kWh
- electricity cost of $0.1/kWh

- If charge & leakage low, then GWP less important than efficiency

Secondary Refrigerants

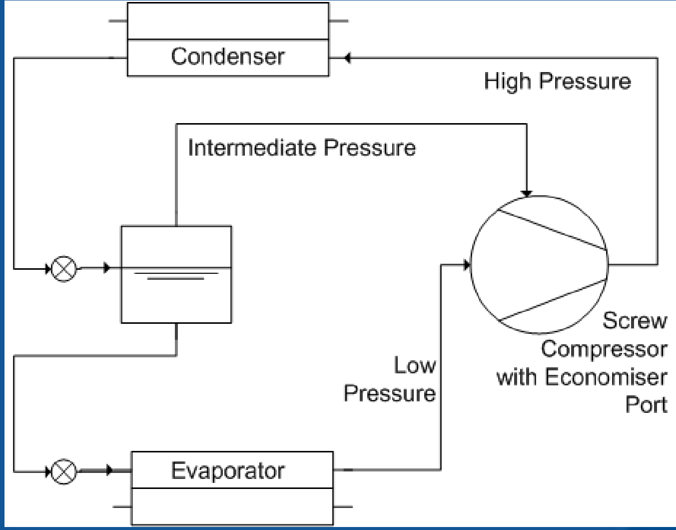
- Desired
  - low viscosity (pumping power)
  - high heat capacity (low flow and low temp. change)
  - high conductivity (small heat transfer surfaces)
  - cheap, safe, stable, non-corrosive
- Glycols & Brines!
- CO_2 - evaporating secondary
  - very low flow, low pumping power, high heat transfer
  - high pressure!
- Water or ice slurry except freezing limit

Technology Options

- Economisers
- Evaporative vs air cooled condensers
- VSDs
- Low charge (NR) packages
- Thermal Storage
- Heat Recovery
- Alternatives for vintage peak
- Take advantage of glides

Technology Options

- Economiser/parallel compression
  - 5-10% reduced compressor energy for most refrigerants
- Low charge packages
  - < 0.1 kg/kW possible
  - isolate & control flammable & toxic but efficient refrigerants
  - possible plug and play for vintage
- Vintage peaks
  - import ice or ice makers
  - permanent infrastructure for non-vintage loads
  - two temperature levels



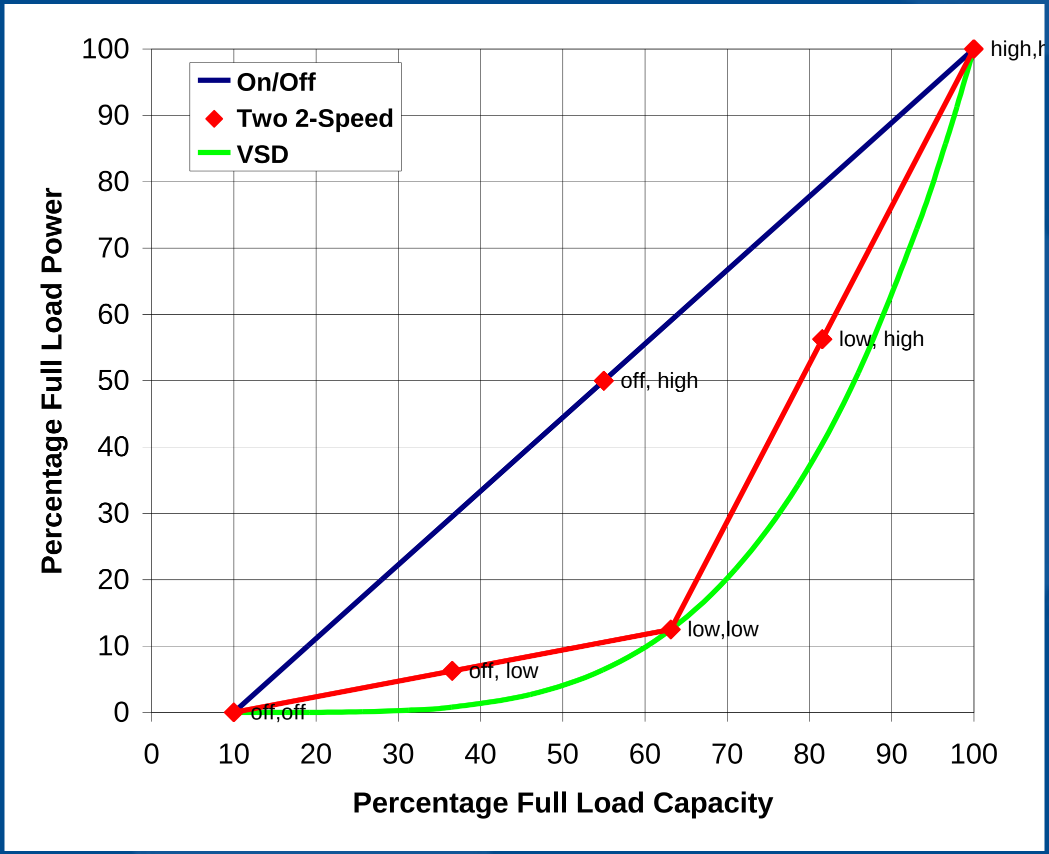
Condenser Options

Type	Air Cooled	Water Cooled Evaporative
Temperature Approach (2-3% savings per ^{o}C)	Dry Bulb (e.g. 35^{o}C)	Wet Bulb (e.g. 20^{o}C)
Fan/Pump Power	High	Low
Maintenance	Low	High
Water Use	Low	Medium/High
Water Treatment	No	Yes
Legionella Risk	No	Yes
Noise	Medium/High	Medium
Cost	Medium	High

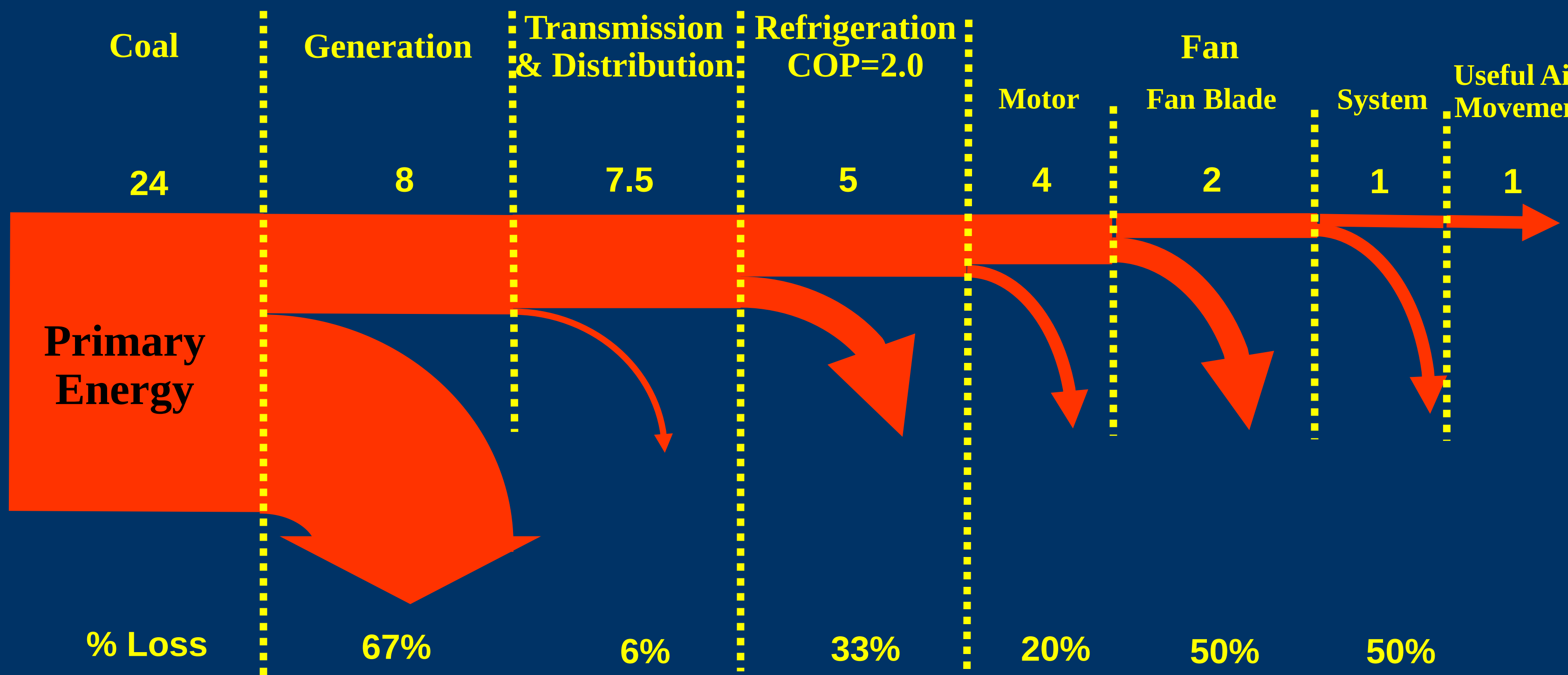
- sound case for air cooled
  - short vintage peak
  - over-capacity outside vintage allows tight approach

Pump & Fan VSDs

- Ramp together if in parallel
- Margin extra energy benefits below 50%

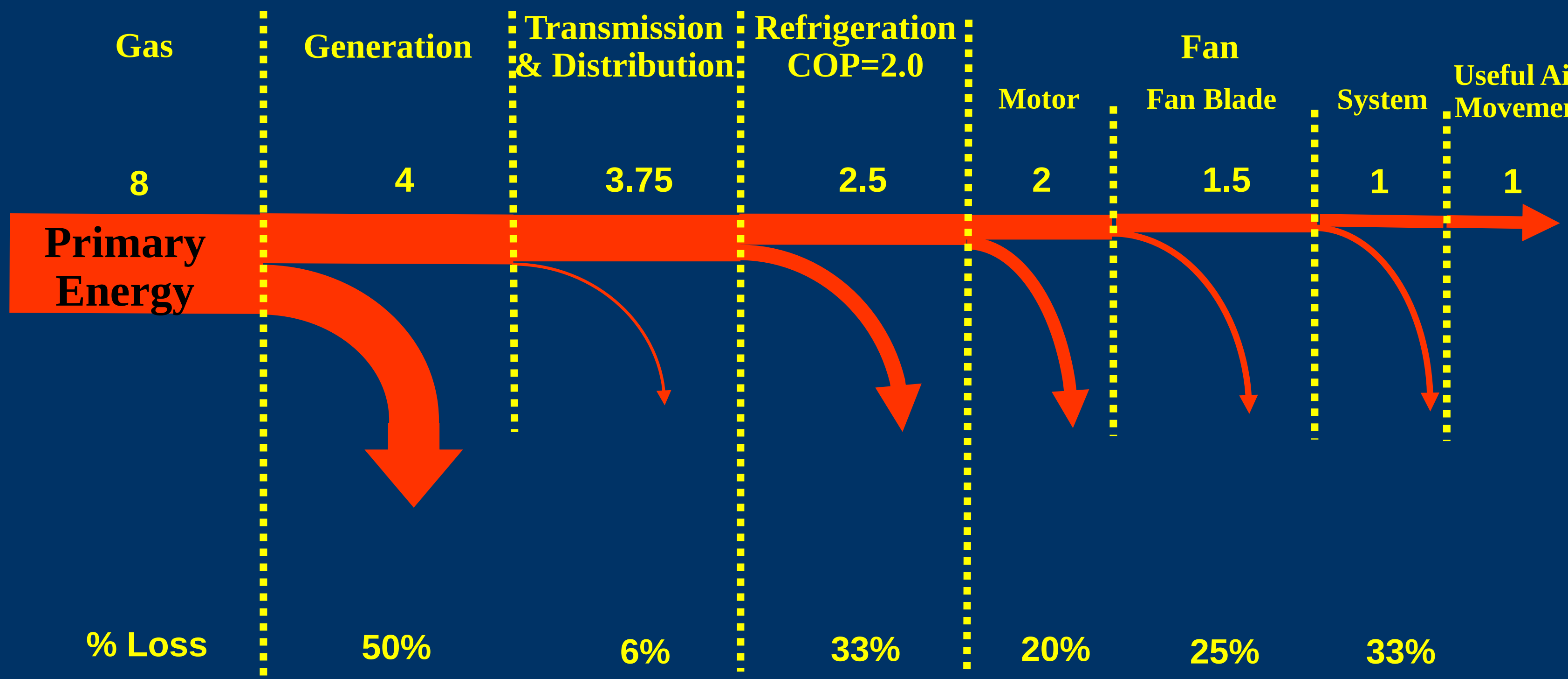


Fan (pump) via Coal Power Station



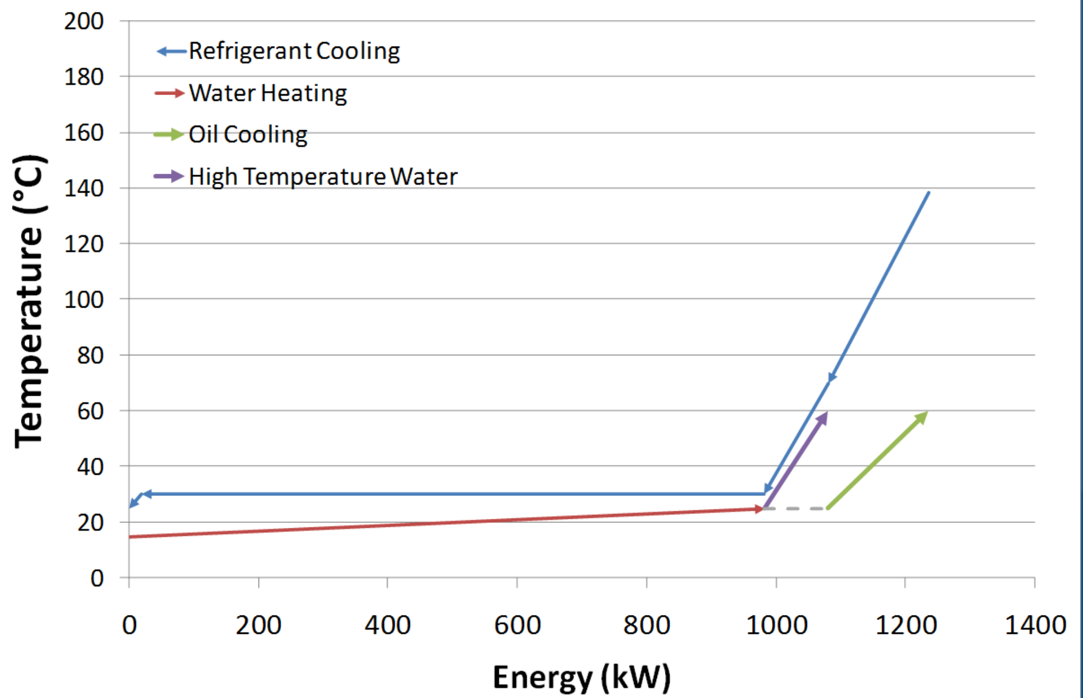
- system inefficiencies – extra pressure drops

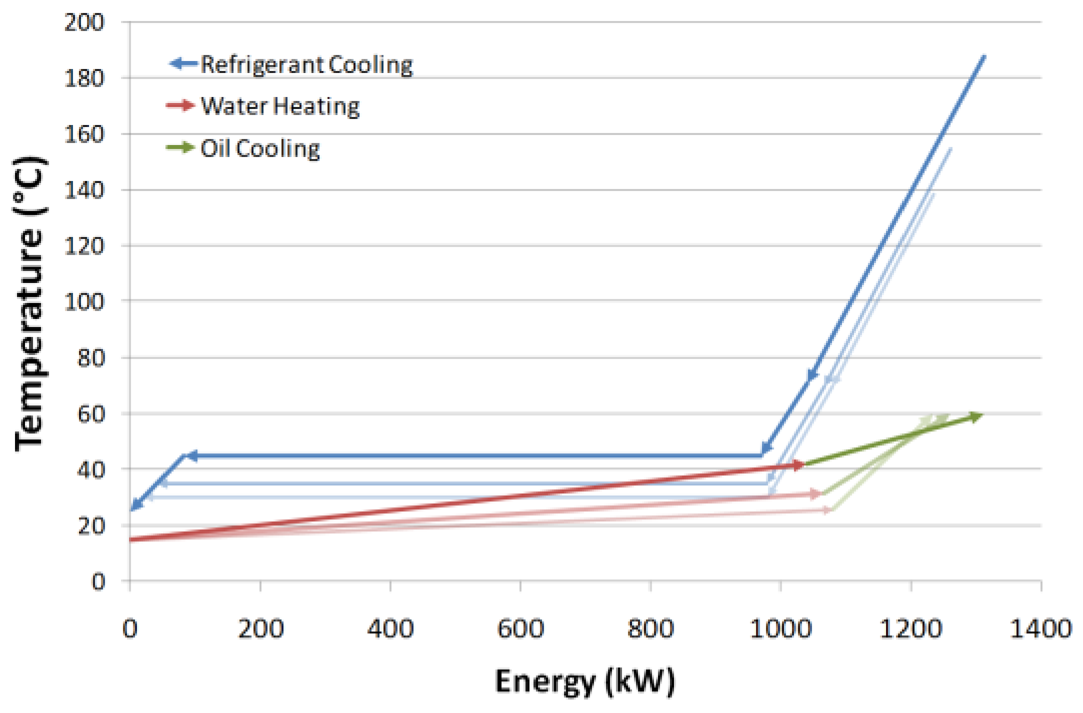
Improved System and Fan (Pump) via CCGT



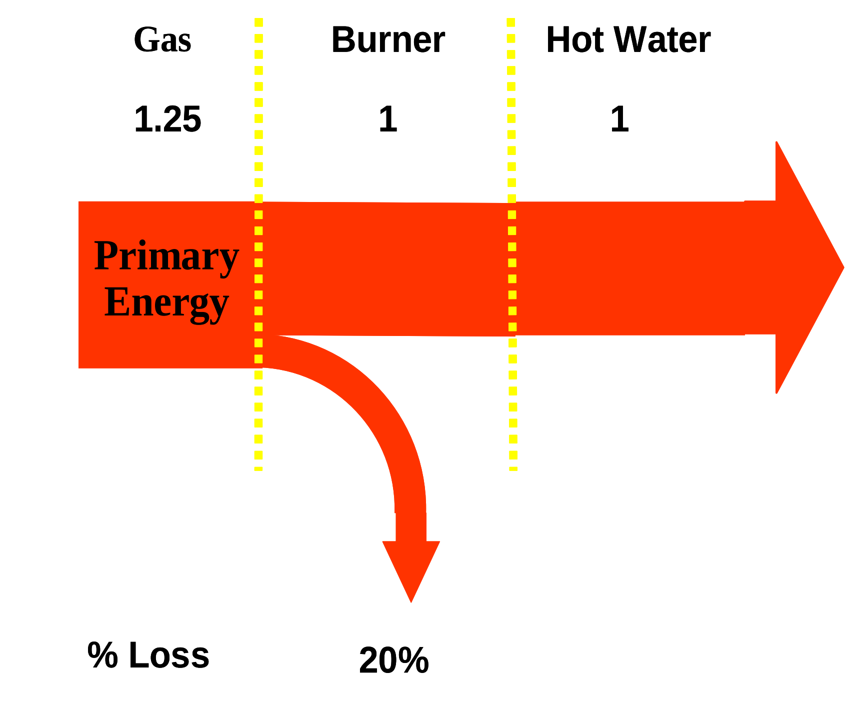
Heat Recovery

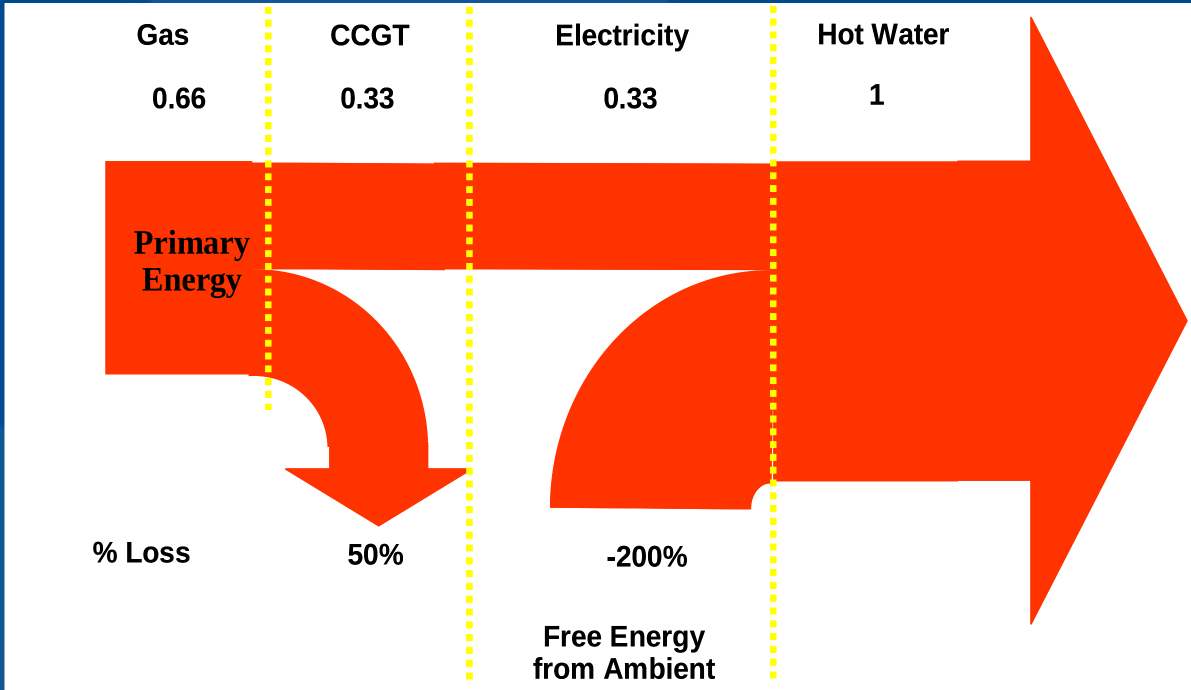
Tc	Increase in Compressor Power	Warm Water Temp.	Increase in Warm Water [1]	Increase in Hot Water [2]
°C	kW	°C	kW	kW
30	0 (0%)	25	-	98
31	5 (2%)	26	-	104
32	10 (4%)	27	82	110
33	15 (7%)	28	151	116
34	21 (9%)	29	210	121
35	26 (11%)	30	261	127
40	52 (22%)	35	439	157
45	79 (34%)	40	544	189





Cascade High Stage or Separate Heat Pump



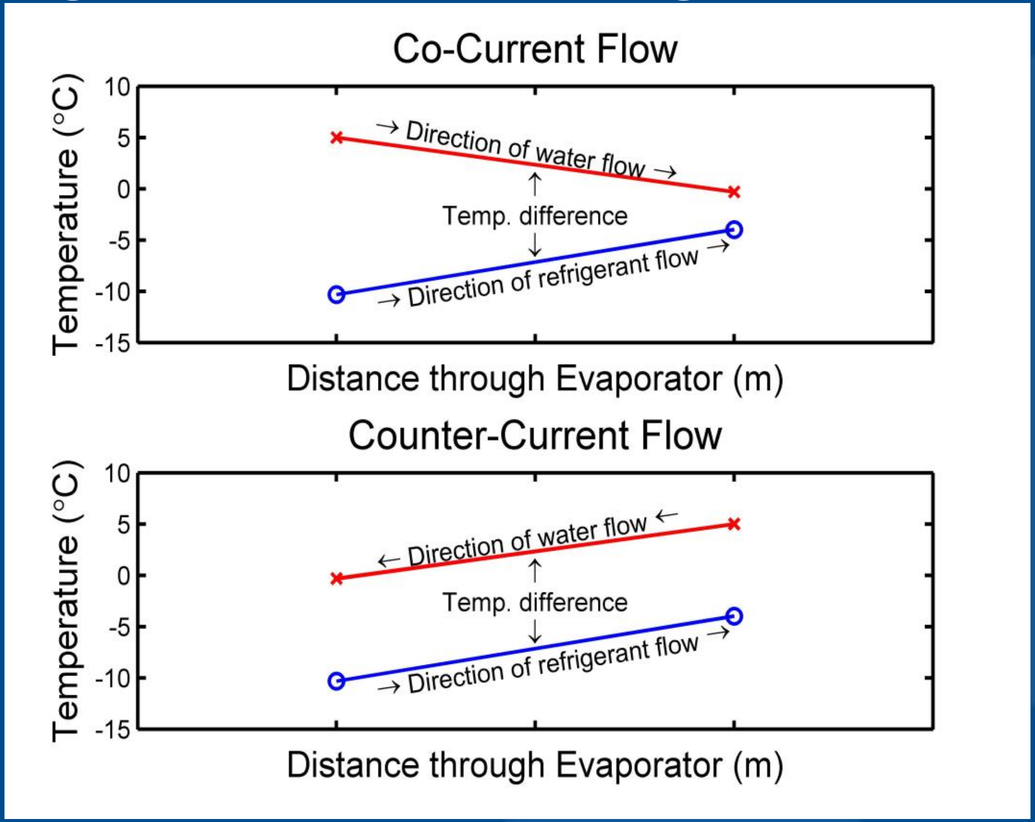


Use of Glide

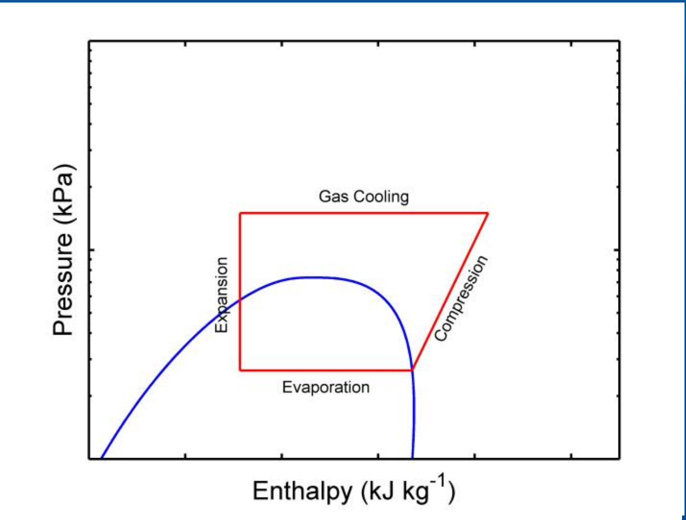
e.g. R407C chiller at 400 kPa.a

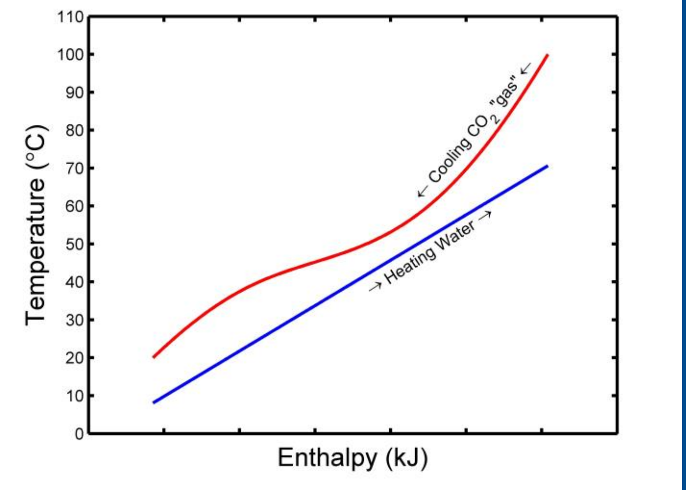
less effect if cross flow or flooded

greater effect if need to get SH

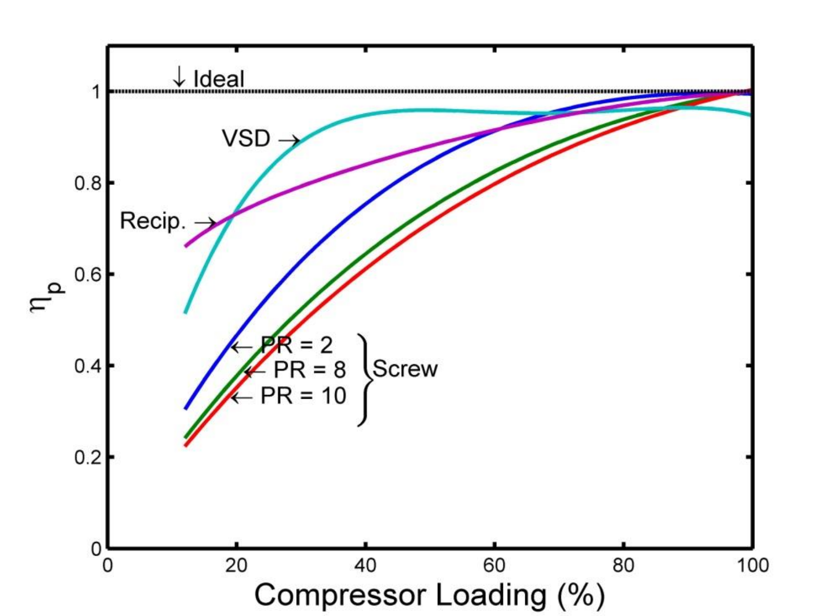


Transcritical CO_2 heat recovery





Energy Efficiency



- Floating head pressure
- Maximise glycol setpoints
- Off-peak downturn in condensers & compressors
- Pumps and Fans
  - minimise flow
  - isolate unused circuits from circulation loop
  - use of VSDs
  - maintain TD on chiller (avoid downward spiral)
  - integrate with storage

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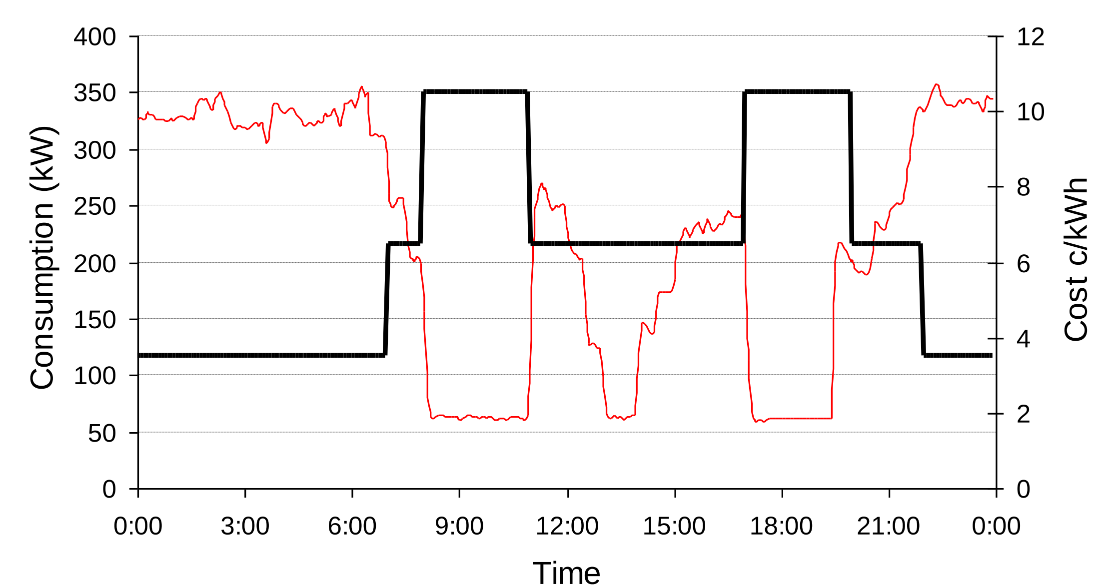
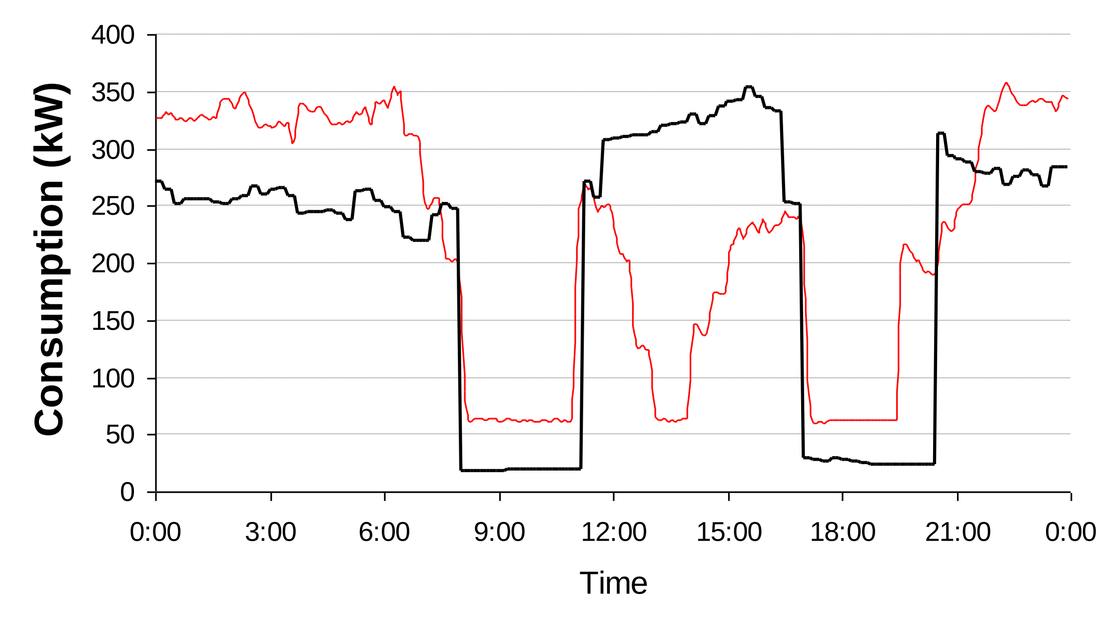
Storage Load Shifting

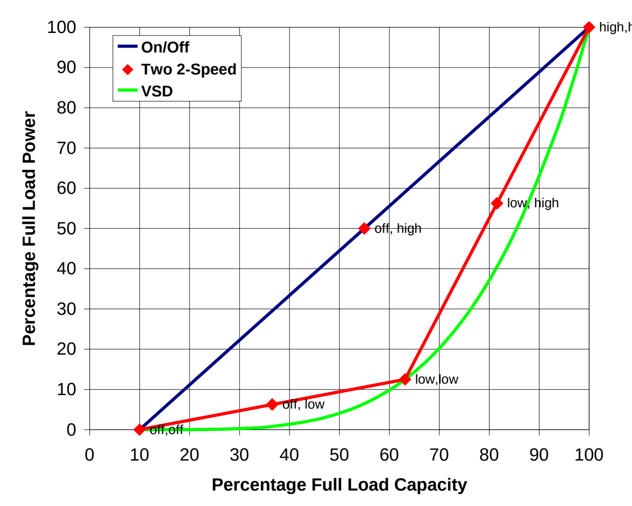
- low tariff periods
- low ambient
- fully load for short period
- latent rather than sensible storage preferred
- stratified rather than multi-tank if sensible?

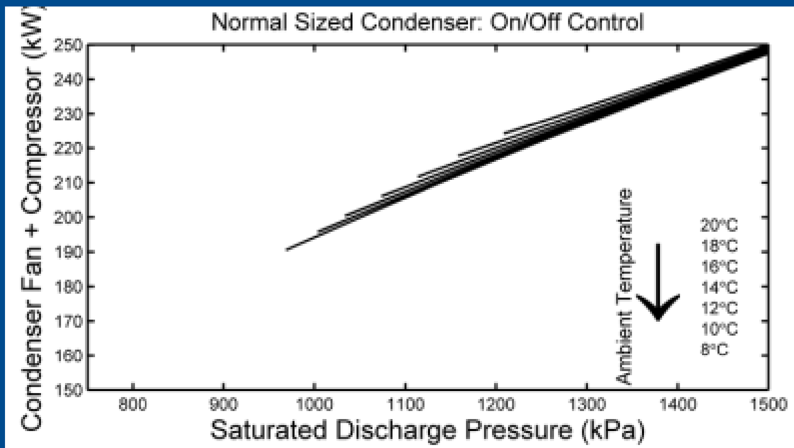


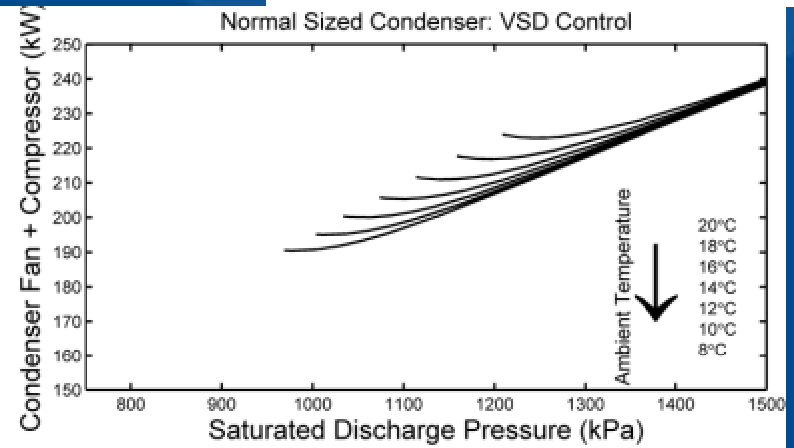


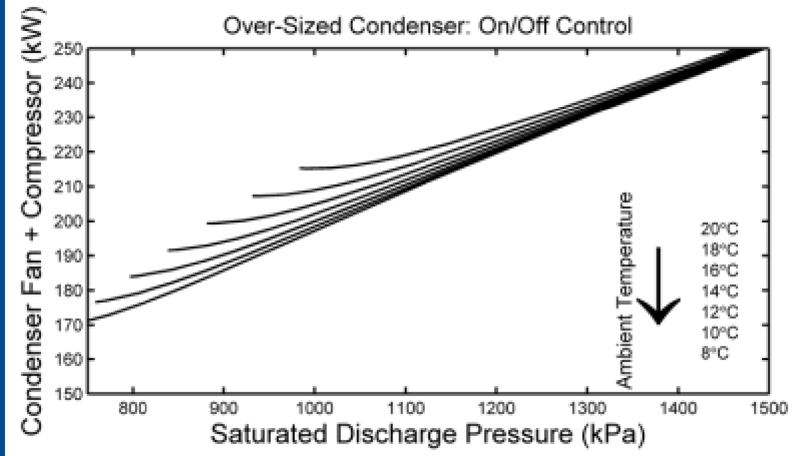
Floating Head Pressure

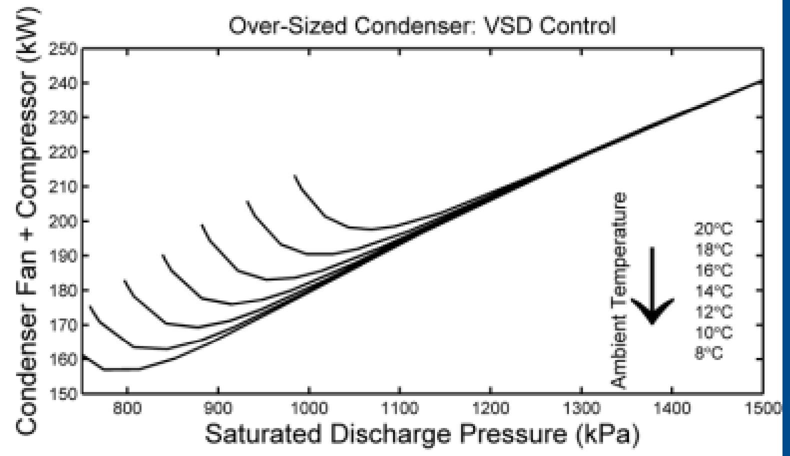
- 2-3% energy savings per ºC











Floating Glycol Temperature

Glycol Temperature	-6°C	-2°C	+2°C
Evaporation Temperature	-10°C	-6°C	-2°C
Relative Energy	0%	-13%	-25%
Relative Capacity	0%	17%	36%

Conclusion

- Refrigeration is small part of wine environmental impact
- Wine quality trumps energy efficiency
- Flammable refrigerants hard to avoid in future
- Optimised design & operation offer significant gains
- Grappling with seasonality is important

Workshop

COST-EFFECTIVE REFRIGERATION WORKSHOP
Palmerston North
Monday 29th Aug to Thursday 1st Sept 2016

Learn more about …

- food refrigeration
- the customer/contractor interface
- chilling and freezing calculations
- refrigerant & equipment selection
- refrigeration plant layout & design
- energy efficiency
- heat load estimation
- absorption refrigeration
- operational efficiency
- water vapour effects
- refrigerants

Who should attend …

- users of refrigeration equipment
- refrigeration equipment suppliers
- refrigeration system designers
- consultants
- contractors

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Questions

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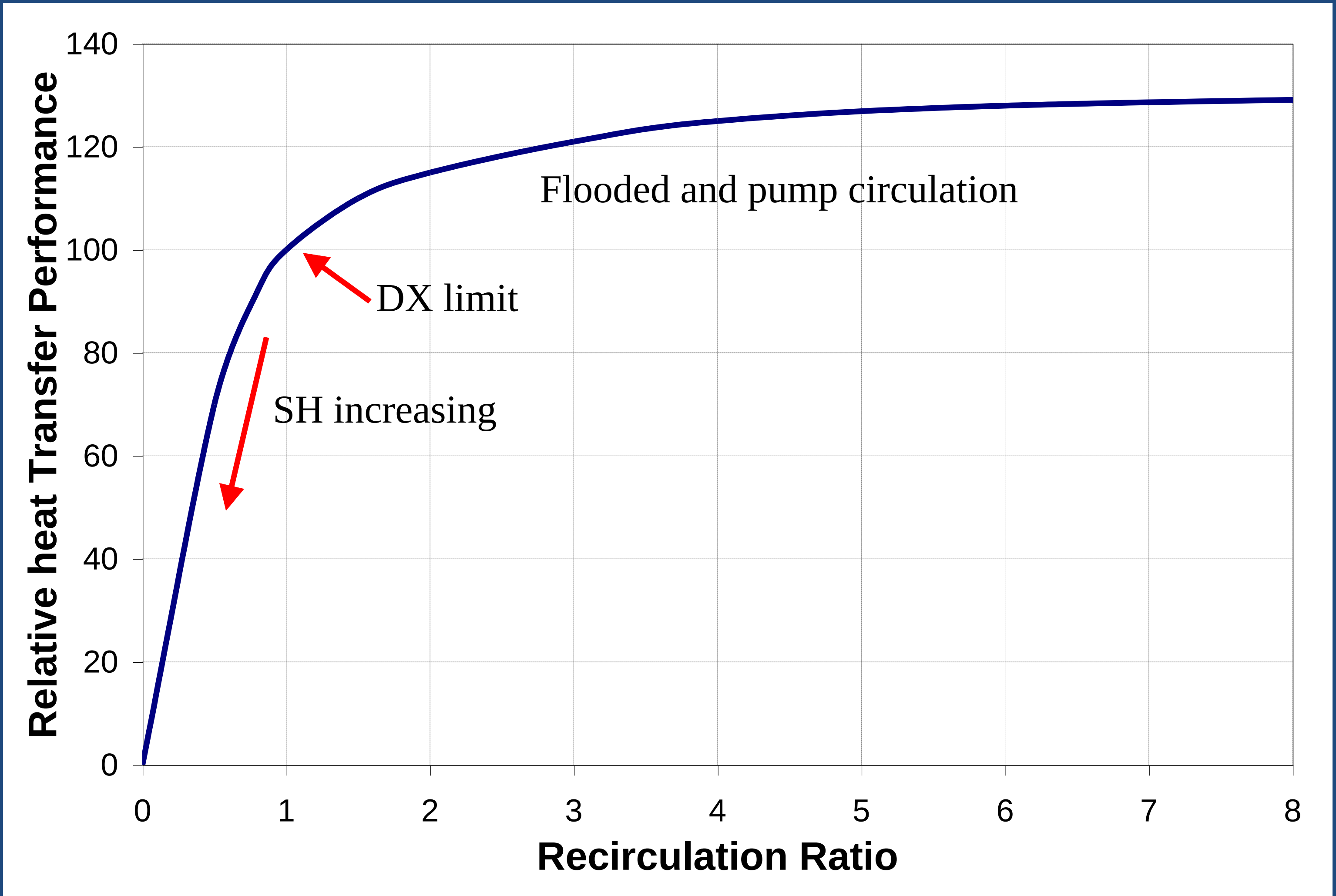
Refrigerant Overfeed



ASHRAE Classification

Safety Group Classification		
Higher Flammability	A3	B3
Lower Flammability	A2	B2
	A2L	B2L
No Flame Propagation	A1	B1
	Lower Toxicity	Higher Toxicity

The 2L refrigerants have a burning velocity of 10 cm/s or slower.

REFRIGERANTS
SAFETY GROUP CLASSIFICATIONS

Toxicity classification:

Class A: toxicity has not been identified at concentrations ≤ 400 ppm, based on TLV.

Class B: there is evidence of toxicity at concentrations below 400 ppm, based on TLV.

Flammability Classification:

Class 1: No flame propagation in air at 21°C and 1,01 bar;

Class 2: Lower flammability limit (LFL) > 0.10 kg/m3 at 21°C and 1,01 bar and heat of combustion < 19 000 kJ/kg;

Class 3: Highly flammable LFL ≤ 0.10 kg/m3 at 21°C and 1,01 bar or heat of combustion ≥ 19 000 kJ/kg.

UNEP, ECA meeting, 2008

What changes are anticipated with the new 2L flammability classification?

ASHRAE 15	ISO 5149
Adherence to current charge limits based on RCL	Charge limit based on occupancy class, type, direct / indirect system, location
Potential prescription ventilation openings is being considered	Ventilation opening shall be kept as low as possible
Possible increased ventilation in 2L machinery rooms	Ventilation rate: (—) —
Other	Mechanical ventilation (continuous or detector-controlled) & alarm at 25% LFL

Source: Reindl, 2011

Oils

LUBRICANTS

	Traditional oils			New lubricants		
	Mineral oil (MO)	Alkyl-benzene (AB)	Poly-alphaolefin (PAO)	Polyol ester (POE)	Polyvinyl-ether (PVE)	Poly-alkil-glycol (PAG)
(H)CFC	Good suitability	Good suitability	Application with limitations	Application with limitations ▲	No suitable	No suitable
HFC + blends	No suitable	Application with limitations	No suitable	Good suitability	Good suitability T	Application with limitations ▲
Hydrocarbons	Good suitability	Application with limitations	Good suitability	Good suitability	No suitable	Application with limitations ▲
NH3; R723	Good suitability	Application with limitations	Good suitability	No suitable	No suitable	Application with limitations ▲

Good suitability
Application with limitations
No suitable
▲ Critical with moisture
T Under testing

Recommended by Bitzer GmbH

UNEP, ECA meeting, 2008

Refrigerant	Formula	ODP	GWP	Oil Compatibility	Levy ($/kg)	Other Weaknesses
CFCs						
R11	CCl_3F	1.0	4000	M	-	MP phaseout
R12	CCl_2F_2	1.0	8500	M	-	MP phaseout
R502	115 (51%), 22 (49%)	0.23	5590	M	-	MP phaseout
HCFCs						
R22	$CH\ Cl\ F_2$	0.055	1700	M,AB	-	MP phaseout
R123	$C_2H\ Cl_2F_3$	0.02	93	M,AB,POE	-	MP phaseout
HFCs						
R32	CH_2F_2	0.0	650	POE	15	A2L
R125	C_2HF_5	0.0	2800		64	
R134a	$C_2H_2F_4$	0.0	1300	POE,PAG	30	
R143a	$C_2H_3F_3$	0.0	3800		87	A2L
R152a	$C_2H_4F_2$	0.0	140		3	A2L
R245ca	$C_3H_3F_5$	0.0	560		13	
R404A	125 (44%), 134a (4%), 143a (52%)	0.0	3260	POE	75	
R407C	32 (23%), 125 (25%), 134a (52%)	0.0	1530	POE	35	High glide
R410A	32 (50%), 125 (50%)	0.0	1730	POE	40	High P
R417A	125 (46.6%), 134a (50%), 600 (3.4%)	0.0	1960	M,AB,POE	45	Medium glide
R422D	125 (65.1%), 134a (31.5%), 600a (3.4%)	0.0	2620	M,POE	60	Medium glide
R507	125 (50%), 143a (50%)	0.0	3300	POE	76	
HFOs						
R1234yf	$C_3H_2F_4$	0.0	4	POE	0.1	A2L, high cost
R1234ze	$C_3H_2F_4$	0.0	6	POE	0.1	High cost
Perfluorocarbons (PFs)						
R218	C_3F_8	0.0	7000		161	Long EAL
Natural Refrigerants (NRs)						
R170 - ethane	C_2H_6	0.0	~5	M,AB,POE	-	A3
R290 - propane	C_3H_8	0.0	~5	M,AB,POE	-	A3
R600a - isobutane	C_4H_{10}	0.0	~5	M,AB,POE	-	A3
R717 - ammonia	NH_3	0.0	<1	M	-	B2L, low P, no copper
R718 - water	H_2O	0.0	<1			0^{o}C limit, very low P
R744 – CO_2	CO_2	0.0	1	M	-	Low critical temp., high P
R1270 - propylene	C_3H_6	0.0			-	A3