

Modeling the Greenhouse Gas Emissions Impacts of Refrigeration Systems

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SFSU School of Engineering

- San Francisco State University (SFSU) Industrial Assessment Center (IAC):



provides energy-efficiency audits for small- to medium-sized manufacturing facilities

- Education in HVAC engineering, building energy simulation
- Life cycle assessment (LCA) experience with bio-derived transportation fuels

California ARB Research Project

“Low-GWP Commercial Refrigeration Feasibility and Cost-Benefit Engineering Evaluation”

- Objective: determine the feasibility, cost, and greenhouse gas (GHG) reduction benefits of using low-global warming potential (GWP) refrigeration systems in supermarkets and grocery stores
- Subcontractors:



- Project scheduled to begin in August 2014

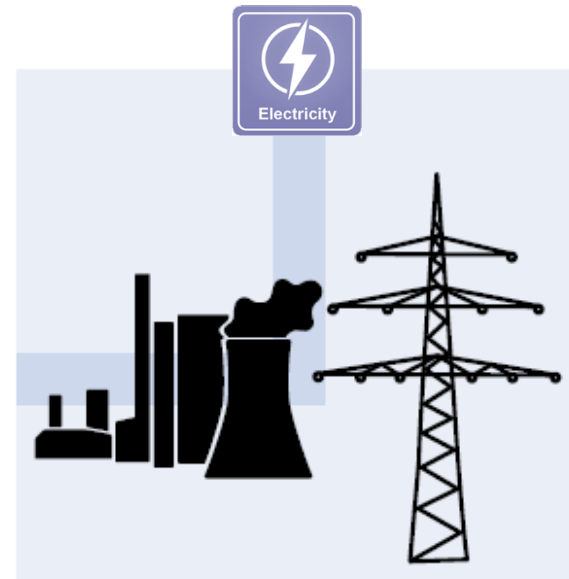


Greenhouse Gas (GHG) Emissions from Refrigeration Systems

- Direct release of refrigerants into the atmosphere
- Indirect emissions associated with energy consumption



Source: Fluke Corporation



TEWI vs. LCCP

Total Equivalent Warming Impact

Considers direct and indirect GHG emissions that occur:

- while refrigeration system is in use
- during recovery/recycling of refrigerant (at system end-of-life)

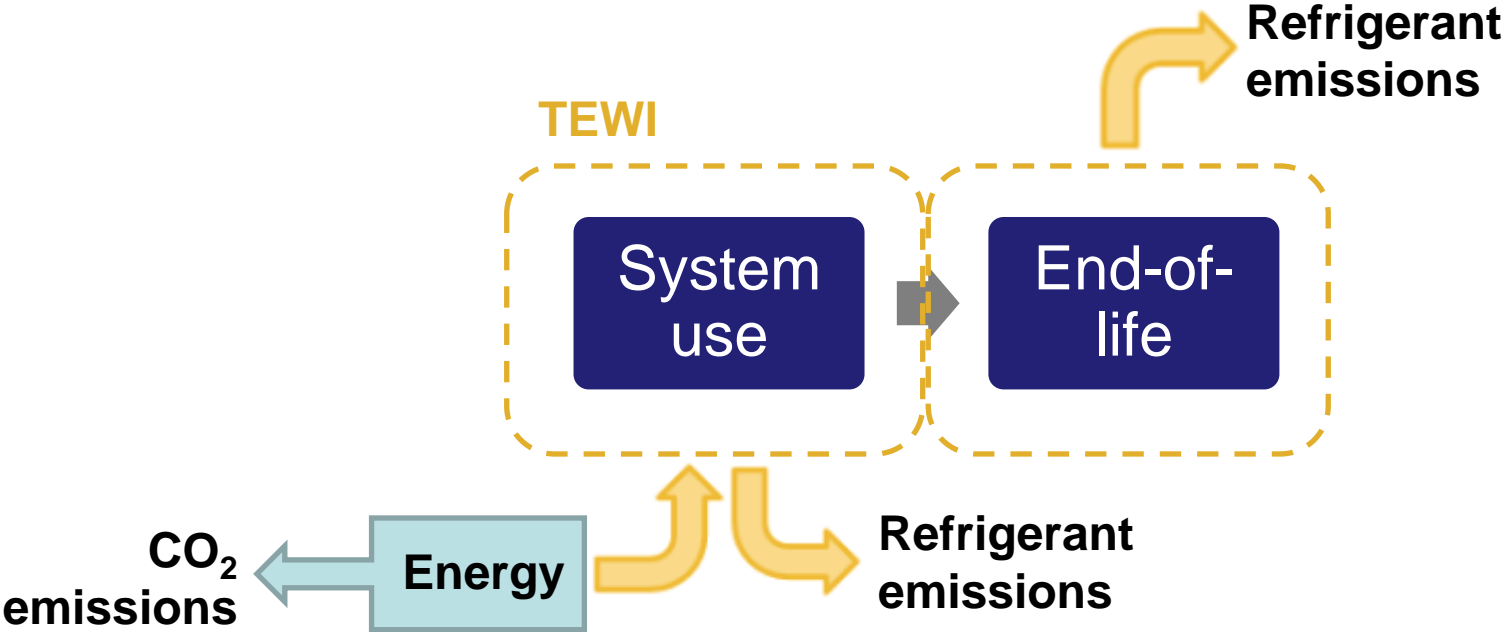
Life Cycle Climate Performance

TEWI, *plus* direct and indirect GHG emissions from:

- Refrigerant production and distribution
- Component/system manufacturing, distribution, and recovery/recycling

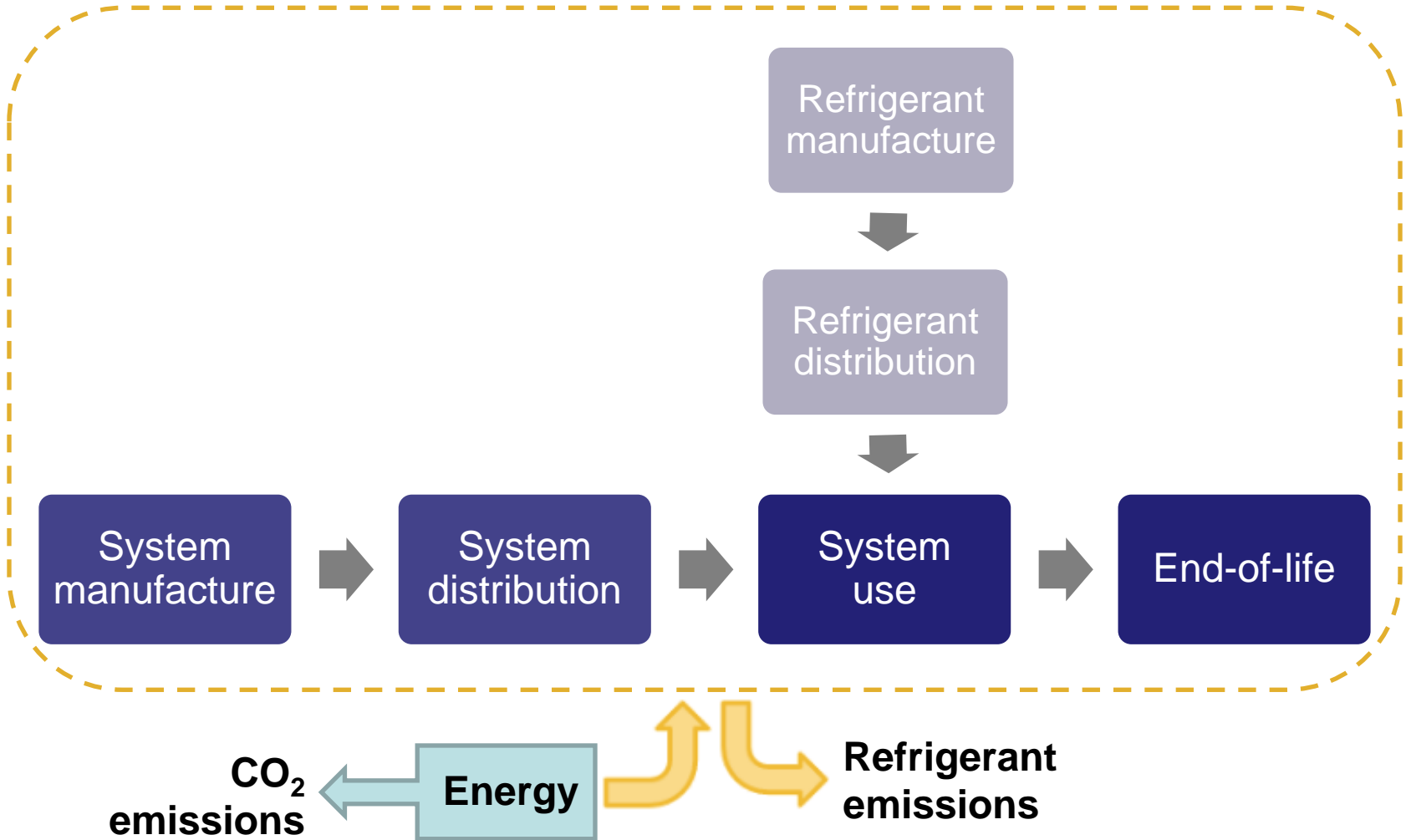


Total Equivalent Warming Impact



Life Cycle Climate Performance

LCCP



Modeling Challenges

- Must be predictive – i.e., cannot rely on in-use data for electricity consumption, leak repair, refrigerant recharge, etc.
- Should be capable of modeling advanced-technology systems and alternative refrigerants
- Must address impacts of varying (local) climates on refrigeration system operation
- Requires accurate input data or calculation methodology for refrigerant leak rates



Existing Modeling Tools: IPU Pack Calculation Pro

TEWI only; evaluates *costs* as well

The screenshot displays the 'Pack Calculation Pro' software interface. The window title is 'Pack Calculation Pro'. The menu bar includes 'File', 'Options', and 'Help'. Below the menu bar is a toolbar with icons for file operations. The main workspace is divided into several sections:

- System 1 (reference)**: A red header bar.
- System configuration**: Includes 'Suction side' and 'Discharge side' tabs.
- Reference system**: A radio button is selected.
- One stage**: Includes 'Two one stage', 'Cascade', 'Two stage', and 'Heat pump' tabs. Under 'Two stage', there are radio buttons for 'Two stage transcritical', 'Two stage open intercooler', 'Two stage closed intercooler', and 'Two stage liquid injection'. The 'Two stage transcritical' option is selected.
- MT Options**: Includes a checkbox for 'Flooded evaporators'.
- LT Options**: Includes a checked checkbox for 'Flooded evaporators'.
- Schematic Diagram**: A central diagram showing a refrigeration cycle with components like compressors, condensers, evaporators, and intercoolers, labeled with 'LT' and 'MT'.
- System 1, MT**:
 - Refrigerant: R744
 - Button: 'Select compressors from database...'
 - Compressors list: Bitzer 4FTC-20K (three entries).
 - Pack capacity Q_e/Q_c : 169.3 kW / 272.6 kW
 - At Custom, MBP ($T_e/P_{gc} = -10.0$ °C / 95.0 bar)
- System 1, LT**:
 - Refrigerant: R744
 - Button: 'Select compressors from database...'
 - Compressors list: Bitzer 2EC-6.2K (three entries).
 - Pack capacity Q_e/Q_c : 60.6 kW / 73.8 kW
 - At Custom, LBP ($T_e/T_c = -35.0$ / -10.0 °C)

Existing Modeling Tools: AHRTI'S LCCP Model

Spreadsheet based,
LCCP; developed for
residential heat-
pump systems

	A	B	C
1	Calculation Settings		
2			
3	TMY3 Data Folder Path		C:\AHRTI LCCP HP\Tmy3data
4			
5			
6	Input Parameters		
7	Case Number		1
8	Case Name		System A
9	Location		SAN FRANCISCO, CA
10	Refrigerant		R410A
11	HP Data Worksheet		HPData-SS-FF-EN
12	Results Output Sheet		Results
13			
14			
15			
16			
17			
18	Summary Results		
19	Status		Success
20	Total Lifetime Emission [kg CO2-Eq.]		51849
21	Total Direct Emission [kg CO2-Eq.]		8524
22	Emission - Ref. Leakage [kg CO2-Eq.]		7103
23	Emission - Ref. Loss at EOL [kg CO2-Eq.]		1421
24	Emission - Decomposition [kg CO2-Eq.]		0
25	Total Indirect Emissions [kg CO2-Eq.]		43325
26	Emissions - Energy Consumption [kg CO2-Eq.]		42785
27	Emissions - Equipment Mfg[kg CO2-Eq.]		517
28	Emissions - Equipment EOL [kg CO2-Eq.]		23
29	TMY3 Location		SAN FRANCISCO INTL AP



Existing Modeling Tools: LCCP (ORNL/UMCP)

For supermarket refrigeration and residential heat pumps; web-based tool available

Life Cycle Climate Performance - Supermarket Refrigeration



CEEE

LCCP INPUT PARAMETERS

RUN

Select System Type Select Load Profile Select City

[Load-profile curve](#)

SYSTEM INPUTS

[Load sample values](#)

Refrigerant [-]	<input type="text" value="R404A"/>	Subcooling at Expansion Device [F]	<input type="text" value="50.4"/>
System Charge [lb]	<input type="text" value="4409.25"/>	Superheat at Evaporator Outlet [F]	<input type="text" value="65.0"/>
Annual Leak Rate [%]	<input type="text" value="5"/>	System Lifetime [yrs]	<input type="text" value="15"/>
Refrigerant Loss-EOL [%]	<input type="text" value="15"/>	Cut-off Temperature [F]	<input type="text" value="55.0"/>
Service Leakage Rate [%]	<input type="text" value="0.05"/>	Service Interval [year]	<input type="text" value="5"/>

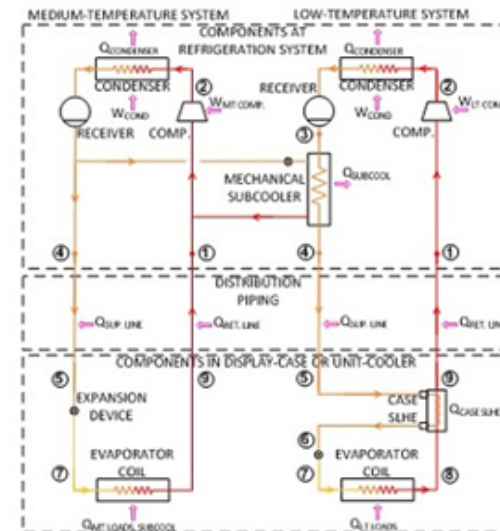
COMPONENT INPUTS [LT SYSTEM PARAMETERS]

[Load HTC values](#)

Suction Line HX Efficiency [%]	<input type="text" value="50.0"/>	Suction Line Temperature Increase [F]	<input type="text" value="50.0"/>
Nominal Load [Btu/hr]	<input type="text" value="300000.0"/>	Liquid Line Temperature Decrease [F]	<input type="text" value="13.5"/>

COMPRESSOR

Isentropic Efficiency [%]	<input type="text" value="65"/>	RPM [-]	<input type="text" value="3600"/>
Volumetric Efficiency [%]	<input type="text" value="80"/>	Displacement [in ³]	<input type="text" value="7.75"/>
Number of compressors [-]	<input type="text" value="10"/>		



Existing Modeling Tools: GREEN-MAC-LCCP

Spreadsheet-based tool for *mobile* air conditioning systems; well established and peer reviewed

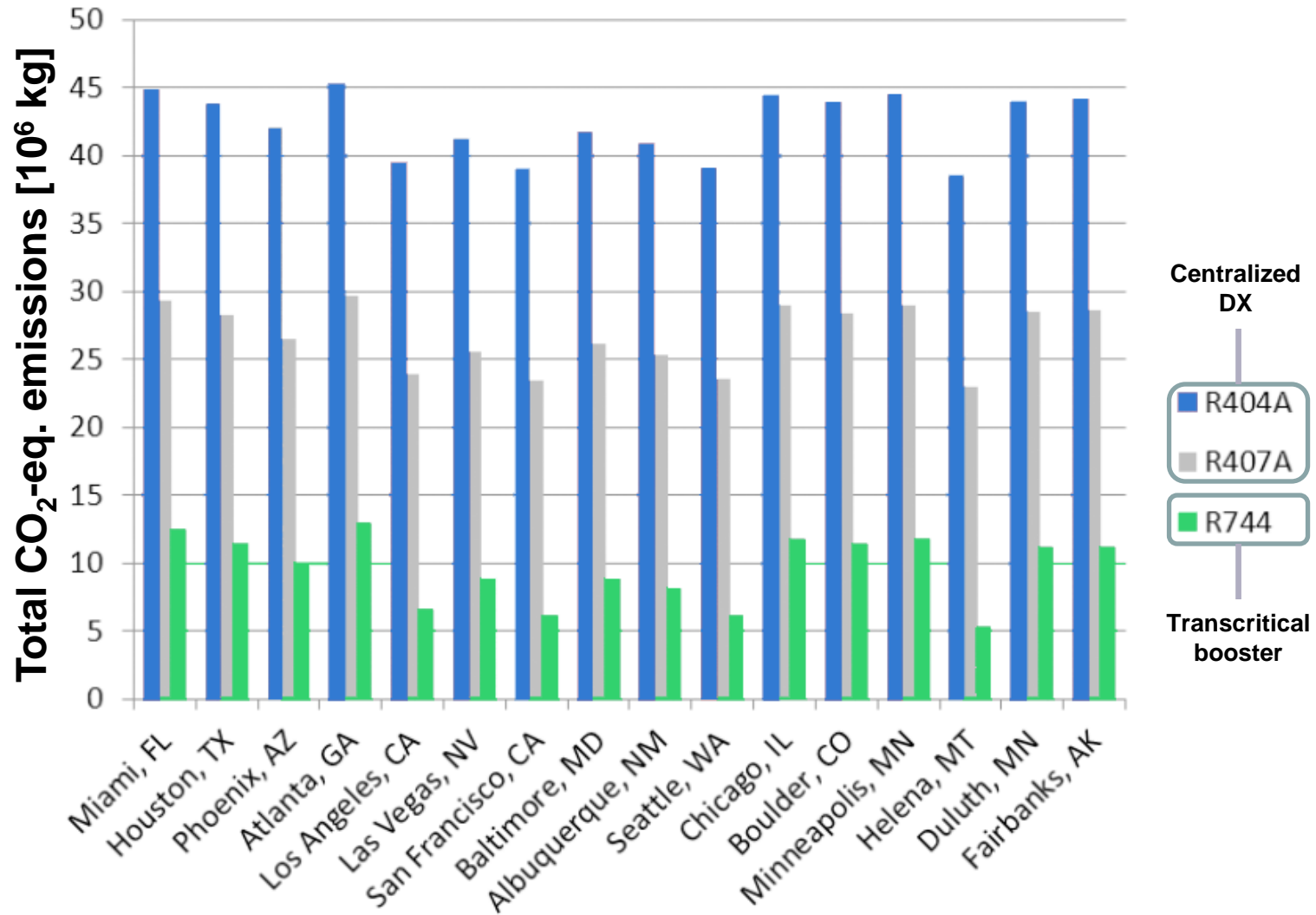
	A	B	C	D
1				
2	Baseline-R-134a	United States	United States	United States
3	REFRIGERANT LEAKAGES & SERVICE	Phoenix	Houston	Boston
4	<i>(function of climate)</i>			
5	Avg. Annual Temp (6AM-24PM)	24.3	21.1	11.0
6	Lifetime [yrs]	9	9	9
7	Refrigerant Charge [g]	550	550	550
8	Estimated loss before Service is required	200	200	200
9				
10	REGULAR and IRREGULAR			
11	Regular Leakage [g/y]	13.4	11.0	5.7
12	Irregular (Accidental) Leakage [g/y]	17	17	17
13	SERVICE			
14	Calculated Number of Services	1.4	1.3	1.0
15	Year of Recharge	6.6	7.2	8.8
16	Actual Number of Services	1	1	1
17	<i>Leaks from Professional Service</i>			
18	Loss in each service [g]	35	35	35
19	Loss from Can Heels per service [g]	5	5	5
20	Service loss[g/lifetime]*	40	40	40
21	<i>Leaks from DIYers Service</i>			
22	Loss in each service [g]	52	52	52
23	Loss from Can Heels per service [g]	108	108	108
24	Service loss[g/lifetime]*	160	160	160
25	% DIYes	25%	25%	25%
26	<i>Weighted Leaks due to Service</i>	70	70	70
27	END-OF-LIFE			
28	EOL with refrigerant capture[g/lifetime]	48	50	55
29	EOL without refrigerant capture[g/lifetime]	476	498	545
30	Vehicles in Collision			
31	<i>Weighted EOL Leaks</i>	305	319	349
32	Assembly Plants (fixed loss) [g/lifetime]	3.5	3.5	3.5
33	TOTAL LEAKAGE LOSS			
34	Total Refrigerant Loss	652	644	627
35	Lifetime Refrigerant Charge	1202	1194	1177
36	Lifetime NEW Refrigerant	754	754	754

Modeling Tool Comparison and Development

	TEWI	LCCP	stand-alone program	spreadsheet-based	Comments
IPU Pack Calculation Pro	✓		✓		Includes cost analysis
AHRTI LCCP		✓		✓	Developed for residential heat-pump systems
ORNL/UMCP LCCP		✓	✓		Web-based tool available
GREEN-MAC-LCCP		✓		✓	For <i>mobile</i> air-conditioning systems

International Institute of Refrigeration (IIR) Working Party on LCCP Evaluation has been established to assess different methods and to develop and promote a recommended methodology

Representative Model Results: LCCP (ORNL/UMCP)



Source: Abdelaziz et al. 2012.





Thank you!

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