Review of Life Cycle Climate Performance Analysis and IIR Working Party

Yunho Hwang, Ph.D.
Chair of LCCP WP
Vice President of Commission B1
Associate Chair of Center for Environmental Energy Engineering at The University of Maryland
Introduction

• The Center for Environmental Energy Engineering (CEEE), is a leader in research and education in environmentally responsible, economically feasible integrated energy conversion systems for buildings and transportation. Research focuses in particular on air-conditioning, refrigeration and heat pumping and integrated cooling heating and power systems.

• The International Institute of Refrigeration (IIR) is the only independent intergovernmental science and technology based organization which promotes knowledge of all refrigeration fields from cryogenics to air conditioning, including liquefied gas, the cold chain, refrigeration processes and equipment, refrigerants and heat pumps.
Introduction

**Lean and Green:** $f_{\text{min}} \ (\text{LCCP})$

**Drivers**
- Increasing Population
- Energy Unbalance
- Climate Changes
- Environmental Regulations

**Air Conditioning & Refrigeration**

**Goals**
- Provide Thermal & Food Safety
- Minimize Environmental Impacts

**With Low GWP Refrigerants**
- With Minimum Charge
- With Zero Leakage
- With Improved Energy Efficiency
- With Green Energy
Introduction: Env. Index History

- **ORNL (1991)**
  - Life cycle analysis for alternative refrigerants
  - Total Equivalent Warming Impact (TEWI)

- **Papasavva (1997)**
  - Expanded TEWI to Life Cycle Warming Impact (LCWI)

- **Andersen (1999)**
  - Montreal Protocol, Technology & Economic Assessment Panel
  - Coined: Life Cycle Climate Performance (LCCP)
Introduction: Env. Index

• Total Equivalent Warming Impact (TEWI)
  – Uses CO$_2$ as a baseline for comparison
  – Useful for comparing relative global warming impacts of alternative refrigerants under controlled assumptions
  – Numerous assumptions

  \[ \text{TEWI} = \text{GWP (direct)} + \text{GWP (indirect)} \]

• Life Cycle Climate Performance (LCCP)
  – Rigorous approach to identifying and quantifying direct and indirect environmental impact

  \[ \text{LCCP} = \text{TEWI} + GWP \text{ (Indirect)} [\text{energy consumption expressed as CO}_2\text{-eq emissions from chemical production & transport, manufacturing components & vehicle assembly and end-of-life}] + GWP \text{ (direct)} [\text{chemical refrigerant emissions including atmospheric reaction products, manufacturing leakage, and end-of-life}] \]
Environmental Impacts of Refrigerants

**Refrigerant MANUFACTURING**

- **Direct Emissions**
  - CO₂
  - HFC
  - Transportation

- **Indirect Emissions**
  - CO₂
  - HFC
  - Mine
  - Transportation

**Raw Materials**


**Refrigerant USE**

- Atmospheric degradation products
  - TFA
  - HCOF
  - COF₂
  - HF

- To be Included in the analysis

**End-use of chemicals**

- Recycling

**Refrigerant End-of-Life**

- Breakdown

- End-of-Life
Introduction

• Life Cycle Climate Performance

  • Direct Emissions
    • Regular emissions
    • Irregular emissions
    • Service emissions
    • End-of-life emission
    • Leakage during production & transport

  • Indirect Emissions
    • Energy consumption of the system
    • Energy to make system/components
    • Energy to produce refrigerant
    • Energy to transport
    • Energy for end-of-life, recycling/recovery of system and refrigerant
Tools Available

- Automotive Peer reviewed, contribution from 50 experts.
Tools Available

- **IPU’s Pack Calculation II for TEWI and LCC**

![Pack Calculation II](image)

- **AHRTI’s Residential HP LCCP (2011) – Excel**

<table>
<thead>
<tr>
<th>Data Set / Runs</th>
<th>Refrigerant</th>
<th>Location</th>
<th>Heating Region</th>
<th>Power Generation Division</th>
<th>System Type</th>
<th>System Matl</th>
<th>EOL</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>R-134a</td>
<td>St Louis</td>
<td>III</td>
<td>Pacific Noncontiguous</td>
<td>Single stage</td>
<td>HP_Equip_Simple</td>
<td>EOL(simple)</td>
</tr>
<tr>
<td>2</td>
<td>R-410A</td>
<td>Washington, DC</td>
<td></td>
<td></td>
<td>Single stage</td>
<td>HP_Equip_Detailed</td>
<td>EOL(detailed)</td>
</tr>
<tr>
<td>3</td>
<td>R-410A</td>
<td>Seattle</td>
<td></td>
<td></td>
<td>Two stage</td>
<td>HP_Equip_Simple</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>R-410A</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>R-410</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Tools Available

- University of Maryland and ORNL team developed a web-based interactive LCCP modeling program for supermarket refrigeration based on user inputs (2012):
  - Users choose from 3 system types and 4 refrigerants
  - Utilizes 16 different locations in the US
  - 13 systems inputs; 25 component inputs
  - Output includes total direct emissions and indirect emissions
Tools Available

- Databases:
  - NREL LCE database, eGRID, TMY3 weather data,…

- System Model
  - System Performance Models:
    - ORNL HPDM, VapCyc, in-house models
    - Performance maps based on catalog data or experiments
    - Can iterate with Load Model for more sophisticated modeling

- LCCP Calculation Methodology
  - Emission & Weather Database

- Load Model
  - Interfaces for std. data communication
  - Hourly Load Data:
    - Energy Plus, DOE-2, TRNSYS, simplified load profiles,
    - hourly load profile via text file

- Components will be developed as “Open Source”.
- Other components can be open-source or proprietary
Basic Questions for LCCP

• How to harmonize the LCCP methodology?
• How to improve accuracy?
• How to quantify the importance of each contribution (sensitivity)?
• Do we need different versions?
  • Research version for accuracy
  • Public version for easy use
IIR’s LCCP Working Party

• In order to answer to previous questions, the IIR formed a working party to assess the merits of different methods for evaluating the environmental impact of refrigerants and to produce implementation protocols for these methods.

• Goal: Establish the harmonized LCCP evaluation methodology applicable for refrigeration and air conditioning systems
IIR’s LCCP WP Roadmap

1Yr

LCCP WP Start

Group A

1. Collect information on direct and indirect emissions of working fluids

Group B

(Jointly)

2. Establish the LCCP evaluation methodology

3. Evaluate different assumptions on results

4. Assemble such information and disseminate it

5. Investigate pathways for improving LCCP

6. Write a booklet on the LCCP evaluation methodology

2Yr

3Yr

4Yr
## IIR LCCP WP Reference Database

<table>
<thead>
<tr>
<th>Section No.</th>
<th>Details</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.2 Irregular Emissions</td>
<td></td>
<td>?</td>
</tr>
<tr>
<td>3.3 Service Emission</td>
<td>Installation</td>
<td>IPCC, 2006, Guidelines for National Greenhouse Gas Inventories</td>
</tr>
<tr>
<td></td>
<td>Repair service</td>
<td>?</td>
</tr>
<tr>
<td>3.6 Decomposition</td>
<td></td>
<td>Weckert, W., 2008, D-NS, Thesis</td>
</tr>
</tbody>
</table>

**IIR Working Party: Life Cycle Climate Performance Evaluation**
IIR LCCP WP Website

• A new web site of the working party is prepared.

Working Party on LCCP Evaluation

Welcome to the Working party Web page

Since the main part of the global warming contribution from refrigeration equipment (including air conditioning) is due to indirect emissions, the climate performance of refrigerating system during its life cycle is an area of concern. Moreover, its proper evaluation is a key factor in determining the true impacts of working fluids for specific application and geographic location, and will assist in determining next generation working fluids for refrigeration and air-conditioning systems.

The IIR has therefore decided to set up a working party (WP) to assess the merits of different methods for evaluating the Life Cycle Climate Performance (LCCP) for refrigerating systems environmental impact of refrigerants and to produce implementation protocols for these methods, for use by decision makers and refrigeration stakeholders. Yunho Hwang, Vice-President of IIR Commission B1, is the chairman of this new WP, which started from January 2012, after approbation of the Science and Technology Council of the IIR.
The IIR is currently recruiting members from following areas for this WP:

- Commission, private, and corporate members of the IIR
- Experts whose knowledge of the subject will benefit the WP

You are invited!
Conclusions

• LCCP is an important tool in analyzing refrigeration systems and needs a globally harmonized approach

• Analysis must be region specific

• Increased R&D of more efficient components and systems will aid in use of more flammable and/or toxic refrigerants

• Additional safety measures will ensure low-GWP refrigerants deliver same level of performance in safe manner
How can you catch a rabbit?

• According to WikiHow.com:
  • With a Simple Snare Loop
  • With a Trapping Pit
  • With a mall Mammal Trap
What will happen if you try to catch two rabbits at the same time?

- Priority
- Right Target
- Focus
New Approach

- Single objective optimization: \( \min (\text{distance } R1) \)
- Multi-objective optimization: \( \min (\text{distance } R1, \text{distance } R2) \)
- Static weighted aggregation: \( \min (w_1 \cdot dR_1 + w_2 \cdot dR_2) \)
- Evolutionary dynamic weighted aggregation:
  - changing the \( w_1 \) gradually from 0 to 1 (or 1 to 0) during optimization.
New Approach

\[ f_{\text{min}} (LCCP) \]
Questions

• **IIR LCCP WP:**

• **GreenMAC LCCP:**
  - http://www.epa.gov/cppd/mac/

• **AHRI LCCP Tool for Residential AC:**

• **UMD/ORNL LCCP Tool for Supermarket Refrigeration:**
  - http://lccp.umd.edu/ornllccp/