A Framework for Joint or Co-ordinated Investment in Refrigerant Transition (RT) and Energy Efficiency (EE)

Nihar Shah, PhD, PE
Lawrence Berkeley National Laboratory

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Lawrence Berkeley National Laboratory

Managed by the University of California for the United States Department of Energy

“Bringing Science Solutions to the World”

- 4,200 employees (>200 UC faculty on staff at LBNL)
- 13 Nobel Prizes + many members of the IPCC – 2007 Nobel Peace Prize
- Buildings energy efficiency including appliance efficiency standards was pioneered by LBNL in the 1970s by Art Rosenfeld and others
- Provides technical support to the U.S. Department of Energy’s Appliance Efficiency Standards program (since the late 1980s)
- Designed superefficient refrigerators (50% more efficient than baseline) during CFC transition
- LBNL collaborates with countries around the world to support energy efficiency programs.
Presentation Outline

• Objectives
• Joint Investment Framework (JIF) Tool
• JIF updates
• Panel Discussion
• Q&A
• Concluding Remarks
Objectives

1. To introduce Montreal Protocol community to publicly available data on cost of efficiency improvement (note: also covered in TEAP EE Task Force report).
2. Using this data to outline a flexible tool for planning and/or evaluation of energy efficiency projects co-ordinated with refrigerant transition.
3. To potentially attract various energy efficiency co-funding streams for Montreal Protocol refrigerant transition projects based on different “cost-effectiveness” perspectives.
4. To get feedback from Montreal Protocol community to improve design and features of the Joint Investment Framework/tool and on next steps.
Joint Investment Framework: How to co-ordinate EE and Refrigerant Investments?

• Refrigerant transition has an impact on EE**
• “indirect” climate benefits from EE energy savings are not currently considered in Montreal Protocol project funding
• Not all EE investments are equal, different peak load, climate, energy impacts varying by economy and sector
• Can EE and RT be invested in to the “same”*** level?
• How to maximize benefit while minimizing costs?
• What level of EE should be targeted?
• How to appropriately allocate costs and benefits to EE and RT?

** This implies that just by changing refrigerant in the same equipment, there will be higher (or lower) efficiency. This needs to be accounted for when planning further EE investment, beyond this level.

*** There could be various views on what “same” might mean, e.g. monetary value or CO₂eq GHG benefit or other metric.
<table>
<thead>
<tr>
<th><strong>Energy Efficiency (EE)</strong></th>
<th><strong>Refrigerant Transition (RT)</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Standards and labels updated every few years</td>
<td>Sectoral transition over decades</td>
</tr>
<tr>
<td>Many different efficiency levels available on any market for any sector</td>
<td>only one or a few refrigerants per sector</td>
</tr>
<tr>
<td>&quot;continuous&quot;</td>
<td>&quot;step change&quot;</td>
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<tr>
<td>Various possible funding sources</td>
<td>Transition for A5 Parties Funded by Montreal Protocol</td>
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</table>

Suggests co-ordinated or joint investment planning could begin by considering RT investment first followed by some amount of “cost-effective” EE investment.
What is the refrigerant transition project? – e.g. R410A to R452B in mini-split ACs sold in country X (T&D Loss of 15%, Hours of use: 4.4 hrs/day, Carbon Intensity of 0.81 kg CO₂e/kWh)

Joint Investment Framework Decision Tree

Economy, equipment, Ref. Change

Drop in Replacement?

No

Refrigerant

incremental cost of ref. replacement

Yes

No additional Costs for RT

E.g. R410A to R452B → EE increase of 3-5% (“refrigerant efficiency”)

Note: 1. This is distinct from “equipment efficiency” improvements shown later

2. There may be additional costs if alternative refrigerant is flammable

3. For A5 Parties, this would be paid for by Montreal Protocol even in the absence of funding for EE by Montreal Protocol as the refrigerant itself is more efficient than the baseline refrigerant

→ Should not be double-counted for EE investment i.e. 3-5% EE increase should be added to “equipment efficiency” improvement from the cost curve to calculate total EE improvement.
Impact of refrigerant on EE: Example of R410A alternatives

Refrigerant impact on EE can be obtained from:

- AHRI Alternate Refrigerant Evaluation Program (AREP)
- ORNL High Ambient Temperature Testing Program
- PRAHA/EGYPRA etc.
- Others

Source: AHRI low-GWP Alternate Refrigerant Evaluation Program (AREP)
DOE Efficiency Standards Process and JIF metrics


Note: these are publicly available for various equipment types at various levels of efficiency
Joint Investment Framework: Summary of the Methodology

2 Energy Efficiency Module
Efficiency improvement and cost of new components

3 Consumer Lifecycle Cost Module
Least cost of efficiency improvement
Payback period
Life cycle cost

4 Climate and Utility Impact Module
Electricity savings
GHG emission reductions
Peak load impacts

1 Refrigerant Transition Module
Efficiency and cost change for low GWP refrigerant transition
Joint Investment Framework: Details of the Methodology

ENERGY EFFICIENCY MODULE
Identification of advanced/new components and component combinations

ΔEfficiency from new components

ΔCost of new components

ΔEfficiency** (if there is any)

ΔCost of low-GWP refrigerant

REFRIGERANT MODULE
Identification of low-GWP refrigerant

ΔCost* of component (if there is component change)

LIFE-CYCLE COST ANALYSIS MODULE
Manufacturing cost
Incremental retail price
Electricity savings
Bill savings
Payback period

Incremental Manufacturing Cost
Least cost design options

CLIMATE & UTILITY IMPACT MODULE
Total electricity savings
GHG emission reductions
Peak load and load shape impacts

* ΔCost: Incremental cost; ** ΔEfficiency: ± change in efficiency
Cost vs Efficiency Example: mini-split ACs in India

Retail price estimates based on “bottom-up” engineering analysis are aligned with actual retail prices of ACs on the Indian market. Note: also referred to in TEAP EE Task force report.

These were used for designing the new standard for ACs in India in 2016 and also for designing the specifications for EESL’s bulk procurement of ACs in India in 2016-2017.

Support multiple cost-effectiveness analyses:

- JIF “Consumer” perspective: “classical” Consumer Least Lifecycle Cost (LLCC)
- JIF “Utility” perspective: Utility Peak Load minimizing
- JIF “Climate” perspective: CO2 eq level of Refrigerant Transition Investment
<table>
<thead>
<tr>
<th>Component</th>
<th>Baseline Mfg Cost (Yuan)</th>
<th>Incremental Mfg Cost (Yuan)</th>
<th>Retail Price Increase from Base Case (Yuan)</th>
<th>Energy Savings from Baseline</th>
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<td>Baseline Compressor</td>
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<td>410</td>
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<td>Inv AC</td>
<td>Alternating Current Compressor with variable speed drive</td>
<td>481</td>
<td>261</td>
<td>522.0</td>
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<tr>
<td>Inv DC</td>
<td>Direct Current Compressor variable speed drive +compressor</td>
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<td>All DC</td>
<td>Variable speed drives for fans and compressor</td>
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<td>Baseline Heat Exchanger (HE)</td>
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<td>HE 1</td>
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<td>Low-GWP Refrigerant</td>
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**Preliminary**

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<th>AC_CCM_Model (lower_cost)</th>
<th>AC_CCM_Model (higher_costx)</th>
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**Inputs**
Joint Impact Model - Summary

The analyzed results are for a standard model with 1.0 refrigerant ton cooling capacity.

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<th>Technical Baseline Parameters</th>
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<td>Country</td>
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Joint Investment Framework: **Structure and Data**

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<th>Energy savings (%) - compared to Baseline</th>
<th>CHINA</th>
<th>Combined Efficiency Improvement</th>
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**Preliminary**
Consumer Perspective: Least Lifecycle Cost for mini-split ACs in China

- Least lifecycle cost occurs at roughly 5.2 APF for ACs in China, i.e. ~44% energy savings.
- Depends on electricity price, hours of use assumptions.

Source: Shah et al, 2018 (forthcoming)
Climate Perspective: CO₂ Equivalent of RT investment

- Calculate CO₂ equivalent of direct and indirect emissions from refrigerant change: R410A → R452B
- GWP: R410A (1924) → R452B (698) (IPCC AR5)
- Efficiency: R452B ~5% better than R410A (AHRI AREP)
- Use metric such as Total Equivalent Warming Impact (TEWI) or LifeCycle Climate Performance (LCCP)
- ~18.4% emissions reduction from total “baseline” emissions going from R410A to R452B for an AC used ~4.4 hrs/day.
- CO₂ Equivalent: ~23% improvement in “equipment efficiency” gives the same ~18.4% emissions reduction in total emissions as the switch from R410A to R452B.
Joint Investment Framework Decision Tree (cont)

Using testing program results, make calculation:

E.g. R410A to R452B → EE increase of 3-5%

Ref change cause increase/decrease in efficiency?

Account for change in efficiency

Investor perspective?

Investor perspective?

Consumer (bill savings)

Utility (GW avoided)

Climate (CO2 eq. GHG avoided)

Investor #1: e.g. ESCO

Investor #2: e.g. World Bank

Investor #3: e.g. GCF

Cost curve

Investment amount

Consumer: ~44% efficiency improvement i.e. ~5.2 APF

Utility: ~52% efficiency improvement i.e. ~6.0 APF

Climate or CO2 equivalent: ~23% equipment efficiency improvement + ~5% improvement from refrigerant transition = ~28% efficiency improvement ~4.0 APF
Joint Investment Framework Decision Tree (contd.)

At the “cost-effective” efficiency level identified
Use “Manufacturer Impact Analysis” results to calculate EE investment needed:
E.g. “Industry wide” conversion costs for different EE levels in US in 2015, also in TEAP EE Task Force report

<table>
<thead>
<tr>
<th>SEER (W/W)</th>
<th>Capital Conversion Costs (2015 US$ million)</th>
<th>2015 Shipments(^7) (million units/year)</th>
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</thead>
<tbody>
<tr>
<td>4.2</td>
<td>61</td>
<td>6.5</td>
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<td>4.4</td>
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<tr>
<td>4.7</td>
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<tr>
<td>5.6</td>
<td>373</td>
<td>6.5</td>
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</table>

Source: DOE 2016
Summary

Starting from a refrigerant transition project, based on a particular type of EE investor perspective (consumer, climate or utility) interested in co-funding EE we are now able to:

• Identify a corresponding EE “project”,
• a corresponding benefit ($, GW, or CO2 eq)
• a corresponding “target efficiency level”
• a corresponding “investment need” or $ amount
Summary

• Kigali Amendment offers an opportunity to simultaneously improve energy efficiency along with refrigerant transition

• Significant co-benefits: energy security, climate, peak load ~ $billions saved.

• Co-ordination of efficiency improvement along with refrigerant transition would likely lower costs in comparison to separate implementation.

• Refrigerant transition is “step change” while energy efficiency improvement is “continuous”

• Refrigerant transition has an impact on energy efficiency that can be accounted for from testing results.

• Cost vs efficiency data is useful in calculating multiple “cost-effective” levels of efficiency improvement: Consumer, climate, utility etc. which could map to different energy efficiency funding sources.
• Type of investor and structure of investment might dictate which perspective is most useful in designing energy efficiency investment with refrigerant transition.

• Publicly available data from US DOE, EU Ecodesign program and others may be useful in designing and planning co-ordinated EE investments in tandem with the refrigerant transition.

• Data can be customized for economy and sector-specific investments adjusting for: labor cost, electricity price, discount rate, refrigerant leakage rate, climate, hours of use, income, carbon intensity etc.

• Next step: Developing JIF further to be responsive to Parties’ needs
Questions for Parties

• What features of JIF are most useful vs “nice to have”?
• What other EE investor “cost-effectiveness” perspectives should be included?
• What applications should be prioritized?
  • Project design?
  • Project evaluation?
  • Design of EE co-funding vehicle?
  • Extension of Multilateral Fund Climate Impact Indicator (MCII) methodology?
• What equipment should be prioritized?
  • Fridges?
  • Chillers?
  • Rooftop ACs?
• Who should (eventually) own JIF?
Acknowledgements

• Agustin Sanchez Guevara, Government of Mexico
• Emilia Battaglini, World Bank
• Alex Hillbrand, Natural Resources Defense Council
• Ambereen Shaffie, Shaffie Law and Policy
• Nihan Karali, Lawrence Berkeley National Laboratory
• Liz Coleman, Lawrence Berkeley National Laboratory
Thank You!

Questions?
Suggestions?
Requests?
Contact:
nkshah@lbl.gov
Shaffie Law and Policy
Global and National Environmental Solutions

https://www.shaffielaw.com
Global Energy Efficiency Investment by region and sector

Figure 3.5  Buildings incremental investment by region, 2015-17 (left) and by sector and end-use (right)

Note: Total energy efficiency spending is the expenditure on products and services that deliver energy efficiency in a building. Incremental energy efficiency investment is additional cost compared with a baseline or business-as-usual expenditure.

Source: EE Marketing Report IEA 2018

- ~$14 Billion of energy efficiency investment from 2015-2017 was spent on HVAC
- While a majority was spent in the EU and North America, ~$40-60 billion was spent in the rest of the world with ~10% spent on HVAC.
Investment in EE for HVAC expected to grow

Figure 3.6  Average annual energy efficiency investment in buildings, in total (left) and by end-use (right), 2017-40

- Global government and utility energy efficiency spending is expected to grow from $25.6 billion in 2017 to $56.1 billion in 2026. (Source: Navigant, Market Data: Global Energy Efficiency Spending, 2017)
- Growth of energy efficiency investment is expected to be highest in space heating and cooling: $80-180 billion annually from 2017-2040.

Source: EE Marketing Report IEA 2018
Parties’ EE Finance Needs

• The parties at the 30th MOP discussed energy efficiency investment, in part responding to the section of the TEAP report focused on financing

• TEAP EE Task Force Report spoke to need:
  • To “develop appropriate liaison with main funding institutions with shared objectives…enable timely access to funding for MP-related projects” with EE component
  • To “investigate funding architectures that could build on and complement the current, familiar funding mechanisms under the MP”

• Parties echoed this, and added:
  • “Could we identify existing or potential mechanisms that would help MLF coordinate with other financing institutions (measures, approaches, modalities) that could assist us in joining financing flows?”
  • “What are the barriers to funding flows?”
  • “How do we overcome those barriers and unlock funding?”
Why a Joint Investment Framework?

• Several considerations influenced our thinking on the JIF - including the following (we invite you to add to this):

• The MLF is already funding the incremental costs of the refrigerant transition (RT) for A5 Parties

• Energy efficiency (EE) investments are already significant and expected to grow further

• Co-funding allows both funders of EE and RT to save money and maximize benefits from investment:
  • For manufacturers by redesigning/retooling for EE and RT together, rather than multiple times
  • For consumers by lowering their energy costs
  • For utilities by reducing overall and peak electricity demand, when producing electricity is often the most costly, and increasing economic benefits from power generation (each W provides more services)
Considerations that Influenced Design of JIF

• Institutions invest in energy efficiency for different reasons
  • better consumer payback on mortgages
  • electricity savings
  • GHG emissions reductions
  • peak load or utility investment savings
  • Other

• Definitions of energy efficiency are different → is there a way to carve out a narrower subset of energy efficiency activities that can be co-funded with refrigerant transition projects? E.g. can it be focused on HVAC &R equipment rather than building envelope?

• Methodologies and assumptions are different (discount rates, baselines, EE metrics, hours of use, electricity prices, grid CO2 intensity, level of efficiency targeted etc.)
Nihar Shah, PhD, PE

- Deputy Leader, International Energy Studies Group, Lawrence Berkeley National Laboratory
- Chair of UN Environment United for Efficiency (U4E) Air Conditioner Task Force
- Member of Energy Efficiency Task Force of the Technical and Economic Assessment Panel (TEAP) of the Montreal Protocol
- Member of US-India HFC Task Force in 2016
- Member of Energy Efficiency Advisory Council to Lennox Industries


LBNL Lead and Principal Investigator for:
- Kigali Cooling Efficiency Program: AC standards and complementary policies in Brazil, China, Egypt, Mexico and collaboration with UN Environment on Rwanda and the Caribbean on room ACs and refrigerators
  
  Kigali Cooling Efficiency Program: UN Environment United for Efficiency (U4E) Air Conditioner “model MEPS” to be presented to 147 “Article 5” Parties by UN Environment in 2019

- Revision of China’s AC standards for mini-split ACs and VRF ACs: ongoing

LBNL Lead for:
- “Benefits of Leapfrogging” study that first quantified the benefits of energy efficiency of room ACs in tandem with the HFC Phasedown under the Kigali Amendment
- Revision of India’s mini-split AC standard with India’s Bureau of Energy Efficiency: 2015-2016
- Co-authored LBNL memo to EESL on bulk procurement program for ACs in India in 2016
- Product Specific Technical Analysis for Super-efficient Appliance Deployment (SEAD) Initiative: 2010-present
Extra Slides
• Similar publicly available cost-efficiency relationships can be useful for various market transformation programs including EE investment projects and EE S&L programs.
• Energy savings estimates are common across economies, but EE metrics and test procedures vary.
• Costs are also largely similar in the globalized market but could vary based on labor, shipping, tax and other conditions and can be customized for different markets.
• Similar curves generated by US DOE and EU Ecodesign for various equipment every 2-3 years

## “Types” of efficiency improvement

<table>
<thead>
<tr>
<th></th>
<th>Explanation</th>
<th>Factors</th>
<th>Magnitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Refrigerant</td>
<td>Alternate Low-GWP refrigerants being considered are more efficient</td>
<td>~5%</td>
</tr>
<tr>
<td>B</td>
<td>Replacement</td>
<td>New equipment is more efficient than old equipment</td>
<td>~10-50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• decline in performance over the life</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Current standards are more stringent</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Current technology is more efficient</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Market Transformation (e.g. standards, labeling, incentives, awards etc.)</td>
<td>Best performing equipment on the market are 40-50% more efficient than average</td>
<td>~20-40%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Best available technology is significantly more efficient</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Variable speed drives</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>1-(0.95x0.7x0.7)</td>
<td>&gt;50%</td>
</tr>
</tbody>
</table>

Only A and C should be considered as B will continue to happen

A: “refrigerant efficiency” and C: “equipment efficiency”
R410A 1.5 ton mini-split AC with 2.9 W/W Energy Efficiency Ratio (EER).

1.5 tons is most popular cooling capacity in many global markets e.g. 60-65% of market in India.

2.9 EER representative of “average” efficiency found on global market, close to many minimum standards (e.g. 2.7 EER in India and 3.1 in China)
Room AC Efficiency and Policies in India

- Bureau of Energy Efficiency’s (BEE) labeling program has a 5-star rating system
  - For appliances with mandatory labeling, 1-star serves as the Minimum Energy Performance Standard (MEPS)
  - Currently, labels are mandatory for fixed speed room ACs and voluntary for variable speed room ACs
  - Starting 2018, fixed and variable speed categories would be merged with mandatory labels for all room ACs

![Graph showing trends in AC efficiency and costs]

- Room AC Efficiency has been improving while costs continue to decline
  - Room AC star labels have been ratcheted up by one star equivalent every two years
  - Between 2006 and 2016, room AC MEPS has increased by 35% (~3% per year)
  - Market average efficiency, slightly higher than MEPS, has improved similarly
  - In the same period, inflation adjusted room AC prices (Wholesale Price Index) relative to the basket of all commodities, have fallen by over 35%
Accelerated Efficiency Improvement Driven by Policy: Japan’s Top Runner Program

- Japan’s Top Runner Program (1997) mandated a sales weighted average fleet COP of 5.3 (W/W) for small room ACs and 4.9 (W/W) for larger room ACs by 2004
  - This was ~60% more efficient than the market average efficiency in 1997
  - The target was determined by the COP of the most efficient AC model in the market
- Between 1995 and 2005, room AC efficiency in Japan improved by ~100% (from COP of 2.55 to 5.10 improving at a rate of 7.2% per year)
  - In the same period, inflation adjusted prices declined by over 80%
- Post-2009, consumer financial incentives (Eco-Point System) helped uptake of efficient ACs
• Energy Frontier Program (2011) sets the energy efficiency criteria for key appliances to be 30-50% more efficient than Grade 1 (most efficient label)

• Between 2008 and 2015, Grade 1 efficiency criteria increased efficiency requirements by over 100% (~12% per year); Energy Frontier is 30-50% above the Grade 1 level
  - Most new models by LG and Samsung meet either the Grade 1 or the Energy Frontier criteria
  - Most efficient room AC model (meets the energy frontier criteria) has CSPF of 9.4

• During this period, inflation-adjusted room AC prices (CPI) continued to decline

• Since 2008, Korea has offered financial incentives for purchase of efficient appliances e.g.
  - Carbon Cashbag program (financial incentives for consumers and advertising etc incentives for manufacturers)
  - Feebates (tax on certain appliances to subsidize purchase of efficient appliances for low-income households)
Joint Investment Framework Ingredients

- Cost-effectiveness metrics ($/CO₂ equivalent, $ invested/$ saved)
- Metrics such as Lifecycle Climate Performance (LCCP) or Total Equivalent Warming Impact (TEWI), to account for direct and indirect refrigerant benefits over the equipment lifetime.
- Manufacturing cost versus efficiency curves such as those used by DOE’s EE standards rulemakings and extended to other countries, e.g., India, and an understanding of incremental cost categories associated with design options for improving efficiency and switching refrigerant.
- Incremental costs of refrigerant transition, e.g., those developed and used by the MLF and IAs.
- Manufacturer impact analyses such as those developed by Berkeley Lab for DOE’s EE standards rulemakings to estimate the cost of retooling manufacturing lines for higher efficiency.
- The efficiency and capacity of alternate refrigerants from testing programs
• AHRTI, 2011: “The program has been utilized to analyze the LCCP of different units with different refrigerants and locations. The program gives consistent results for different scenarios. It appears that all other elements (equipment manufacturing, etc.) in the LCCP composition are negligible except for the direct effect of refrigerant leakage and EOL and the indirect effect of energy consumption.”

• i.e. difference between LCCP and TEWI results is negligible and functionally equivalent

• LCCP requires considerably more data and therefore entails more cost and complexity
AHRI Low-GWP Alternate Refrigerant Evaluation Program (AREP) Phase 1 (2012-2014) R410A alternatives

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Refrigerant</th>
<th>Composition</th>
<th>(Mass%)</th>
<th>Classification</th>
<th>GWP&lt;sub&gt;100&lt;/sub&gt;</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>ARM-70a</td>
<td>R-32/R-134a/R-1234yf</td>
<td>(50/10/40)</td>
<td>A2L*</td>
<td>469</td>
</tr>
<tr>
<td></td>
<td>D2Y60</td>
<td>R-32/R-1234yf</td>
<td>(40/60)</td>
<td>A2L*</td>
<td>271</td>
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<tr>
<td></td>
<td>DR-5</td>
<td>R-32/R-1234yf</td>
<td>(72.5/27.5)</td>
<td>A2L*</td>
<td>491</td>
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<tr>
<td></td>
<td>HPR1D</td>
<td>R-32/R-744/R-1234ze(E)</td>
<td>(60/6/34)</td>
<td>A2L*</td>
<td>407</td>
</tr>
<tr>
<td></td>
<td>L41a</td>
<td>R-32/R-1234yf/R-1234ze(E)</td>
<td>(73/15/12)</td>
<td>A2L*</td>
<td>494</td>
</tr>
<tr>
<td></td>
<td>L41b</td>
<td>R-32/R-1234ze(E)</td>
<td>(73/27)</td>
<td>A2L*</td>
<td>494</td>
</tr>
<tr>
<td></td>
<td>R32</td>
<td>R32</td>
<td>100</td>
<td>A2L</td>
<td>677</td>
</tr>
<tr>
<td></td>
<td>R32/R134a</td>
<td>R-32/R-134a</td>
<td>(95/5)</td>
<td>A2L*</td>
<td>708</td>
</tr>
<tr>
<td></td>
<td>R32/R152a</td>
<td>R-32/R-152a</td>
<td>(95/5)</td>
<td>A2L*</td>
<td>650</td>
</tr>
</tbody>
</table>

*estimated safety group rating, a safety group has not yet been assigned by ASHRAE in accordance with requirements of ASHRAE Standard 34-2013

Source: AHRI, 2014

- **Voluntary co-operative research and testing program to identify suitable alternatives to high-GWP refrigerants.**
- **Standard reporting format for candidate refrigerants strongly desired by industry.**
AHRI Low-GWP Alternate Refrigerant Evaluation Program (AREP) Phase 2 (2015-2016) R410A alternatives

Voluntary co-operative research and testing program to identify suitable alternatives to high-GWP refrigerants.

Lowest GWP >450.

Note: all refrigerant blends use R32.

Overall performance of refrigerant should be judged not just on GWP but also on overall efficiency using a metric such as Total Equivalent Warming Impact (TEWI) that can account for both direct and indirect climate benefits.

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Low-GWP Refrigerants</th>
<th>Composition</th>
<th>(Mass%)</th>
<th>Classification</th>
<th>GWP*</th>
</tr>
</thead>
<tbody>
<tr>
<td>R-410A</td>
<td>ARM-71a</td>
<td>R-32/R-1234yf/R-1234ze(E)</td>
<td>68/26/6</td>
<td>A2L</td>
<td>460</td>
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<td></td>
<td>DR-5A (R-454B)</td>
<td>R-32/R-1234yf</td>
<td>68.9/31.1</td>
<td>A2L</td>
<td>466</td>
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<tr>
<td></td>
<td>DR-55</td>
<td>R-32/R-125/R-1234yf</td>
<td>67/7/26</td>
<td>A2L</td>
<td>698</td>
</tr>
<tr>
<td></td>
<td>HPR2A</td>
<td>R-32/134a/1234ze(E)</td>
<td>76/6/18</td>
<td>A2L</td>
<td>600</td>
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<td></td>
<td>L-41-1 (R-446A)</td>
<td>R-32/R-1234ze/R-600</td>
<td>68/29/3</td>
<td>A2L</td>
<td>461</td>
</tr>
<tr>
<td></td>
<td>L-41-2 (R-447A)</td>
<td>R-32/R-1234ze/R-125</td>
<td>68/28.5/3.5</td>
<td>A2L</td>
<td>583</td>
</tr>
</tbody>
</table>

Source: AHRI, 2016
Cooling comprises ~30% of current and forecasted peak load in California...

...and 40%–60% of summer peak load in large metropolitan cities with hot climates, such as Delhi, India.

Source: End-use peak load forecast for Western Electricity Coordinating Council, Itron and LBNL, 2012

Source: DSLDC, 2012
Cooling is the largest contributor to peak load on an appliance basis...

...and can triple load on the hottest days in some areas, e.g., New South Wales, Australia.
Growth in China’s AC market

- The AC ownership rate in urban China went from almost 0% in 1990s to over 100% in ~15 years.
- China today is a ~50 million/year AC market, ~80GW of connected load added per year, ~120 ACs per 100 urban households.

Source: NSSO, 2012, Fridley et al., 2012
Future cooling needs

Source: Davis et al, Proceedings of the National Academy of Sciences, 2015

- India, Indonesia, the rest of South East Asia and Brazil all have much higher cooling needs (indicated as cooling degree days) compared to China.
- AC sales in major emerging economies are growing at rates similar to China circa 1994–1995, e.g., India room AC sales growing at ~10-15%/year, Indonesia at ~5-10%/year (Shah et al., 2013).
- As incomes grow, and urbanization, electrification continue, cooling needs are likely to grow significantly as well.
Coordinated Action: Annual GHG Impact of AC policies in 2030

Transformation of the AC industry to produce super-efficient ACs and low GWP refrigerants in 2030 could provide GHG savings of 0.85 GT/year annually in China, equivalent to over 8 Three Gorges dams and over 0.18 GT/year annually in Indonesia.

Source: Shah et al, 2015