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

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Shaffie Law and Policy

Global and National Environmental Solutions

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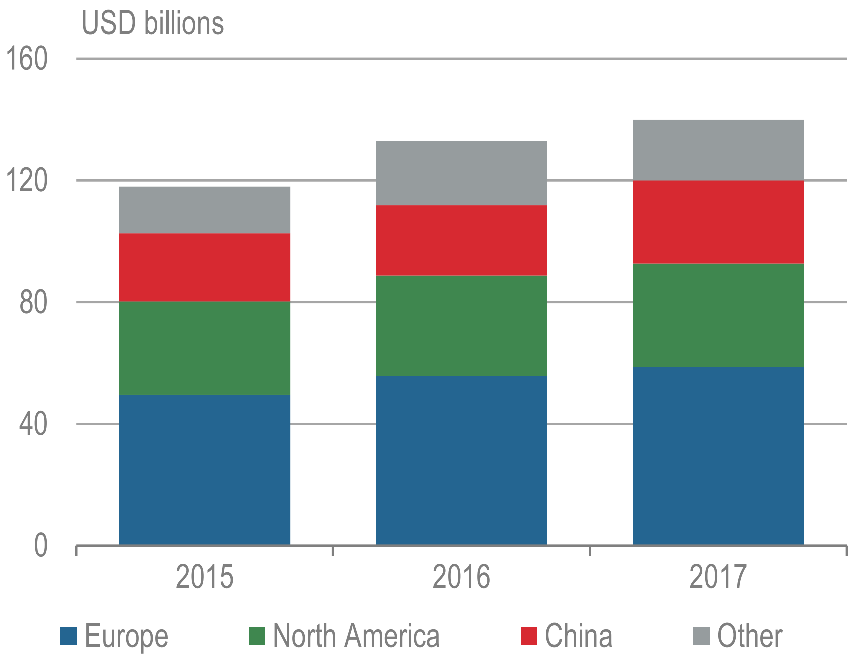
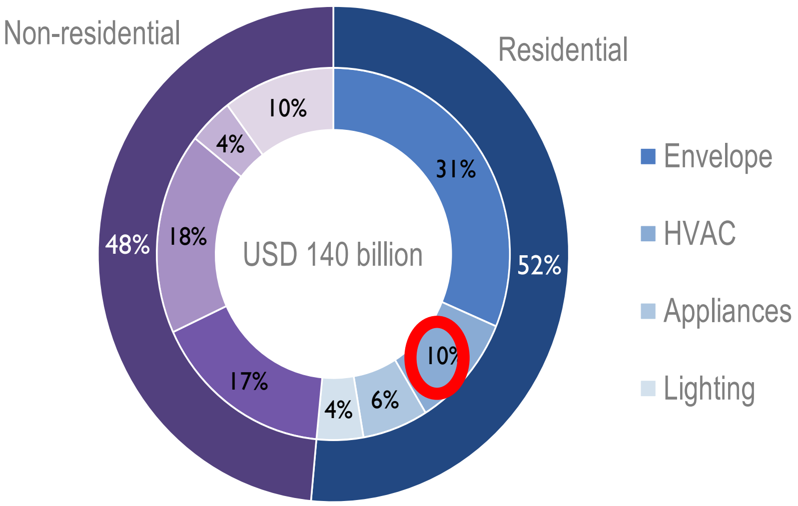
Global Energy Efficiency Investment by region and sector

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



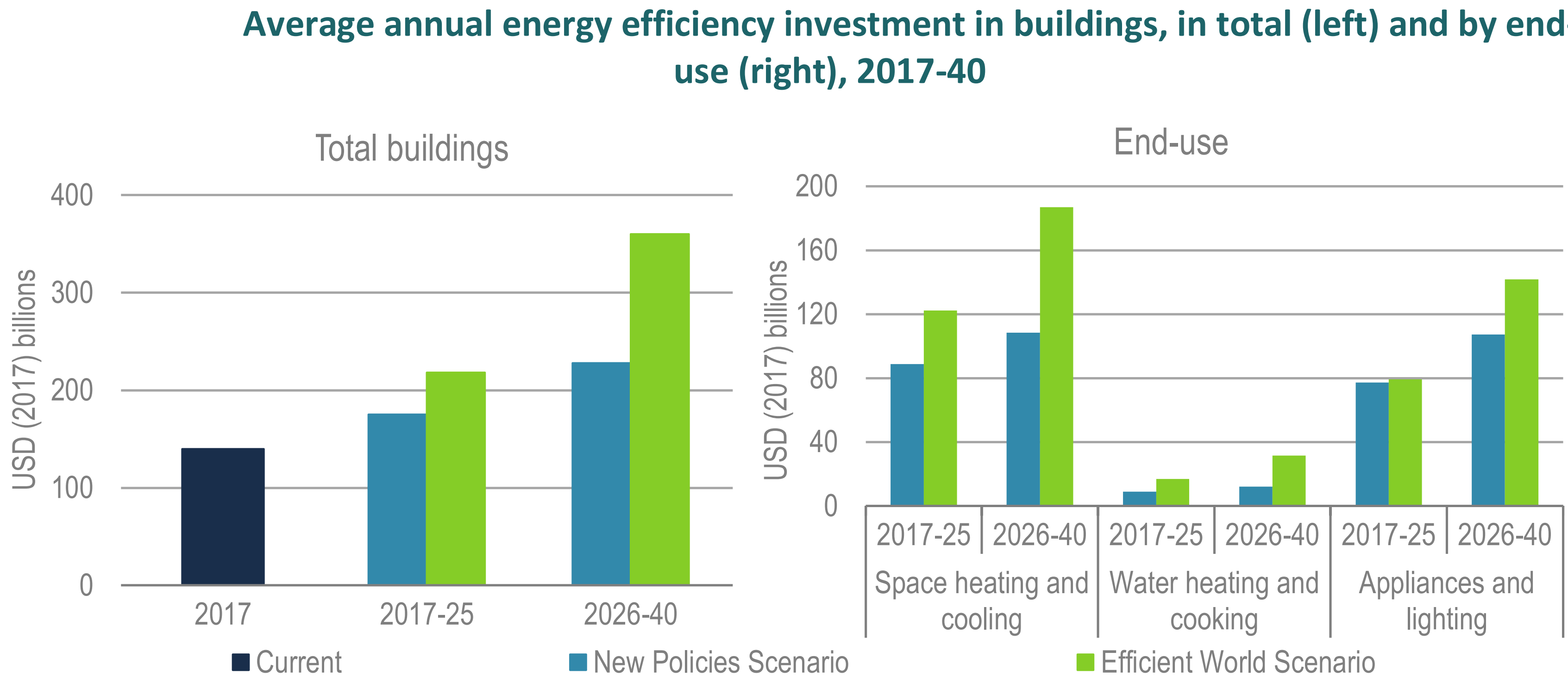


Note: Total energy efficiency spending is the expenditure on products and services that deliver energy efficiency in a building. Incremental energy efficiency investment is additional cost compared with a baseline or business-as-usual expenditure.

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



Source: EE Marketing Report IEA 2018

- 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.

Montreal Protocol 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?"

Energy Efficiency Finance-related Concerns

- **There is a push and acceptance of need to look outside Montreal Protocol for financing energy efficiency**
- Need additional “financial architecture”
- “So difficult to coordinate different sources of finance for more comprehensive sector transformation”
- Multiple donors with different governance structures, many stakeholders to align, etc.
- “A series of financial instruments are needed”
- Clarity on what the Montreal Protocol will finance
- More information on source of EE finance to complement HFC reduction in cooling sectors (comfort cooling, cold chain)
- There are more than just policy options – what else is needed to convert policy into action (design of finance incentive is key; e.g. utility EE rebate programs, ESCO model etc.)
- “Lots of room for innovation in finance”
    - We have seen projects financed under special windows going back as far as the 1990’s, demonstration that co-financing works in the MP context
- “Increase visibility of challenge” / “The blind spot”

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

Research featured in: New York Times, Washington Post, Economist, Forbes Magazine, NPR

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:

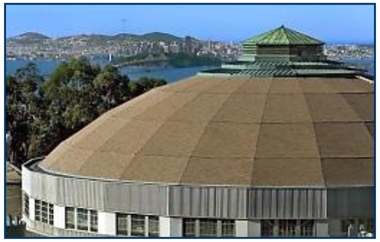
- "Benefits of Leapfrogging" study that first quantified the benefits of energy efficiency of room ACs in tandem with the HFC Phasedown under the Kigali Amendment
- Revision of India's mini-split AC standard with India's Bureau of Energy Efficiency: 2015-2016
- Co-authored LBNL memo to EESL on bulk procurement program for ACs in India in 2016
- Product Specific Technical Analysis for Super-efficient Appliance Deployment (SEAD) Initiative: 2010-present

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 Ingredients

- Cost-effectiveness metrics (\$/CO_2 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

Joint Investment Framework: How to co-ordinate EE and Refrigerant Investments?

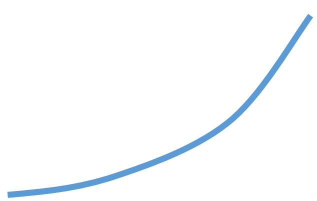
- Refrigerant transition has an impact on EE**
- "indirect" climate benefits from EE energy savings are not currently considered in Montreal Protocol project funding
- Not all EE investments are equal, different peak load, climate, energy impacts varying by economy and sector
- Can EE and RT be invested 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?

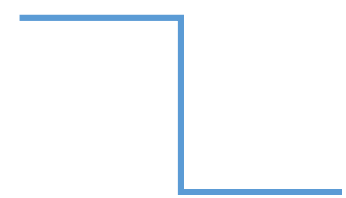
** This implies that just by changing refrigerant in the same equipment, there will be higher (or lower) efficiency. This needs to be accounted for when planning further EE investment, beyond this level.

*** There could be various views on what "same" might mean, e.g. monetary value or CO_2eq GHG benefit or other metric.

Energy efficiency and refrigerant transition

Energy Efficiency(EE)	Refrigerant Transition(RT)
Standards and labels updated every few years	Sectoral transition over decades
Many different efficiency levels available on any market for any sector	only one or a few refrigerants per sector
"continuous"	"step change"
Various possible funding sources	Transition for A5 Parties Funded by Montreal Protocol





Suggests co-ordinated or joint investment planning could begin by considering RT investment *first* followed by some amount of "cost-effective" EE investment

Joint Investment Framework Decision Tree

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 CO_2e/kWh)

Economy, equipment, Ref. Change

↓

Drop in Replacement?

No → **incremental cost of ref. replacement**

Refrigerant

Yes ↓

No additional Costs for RT

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

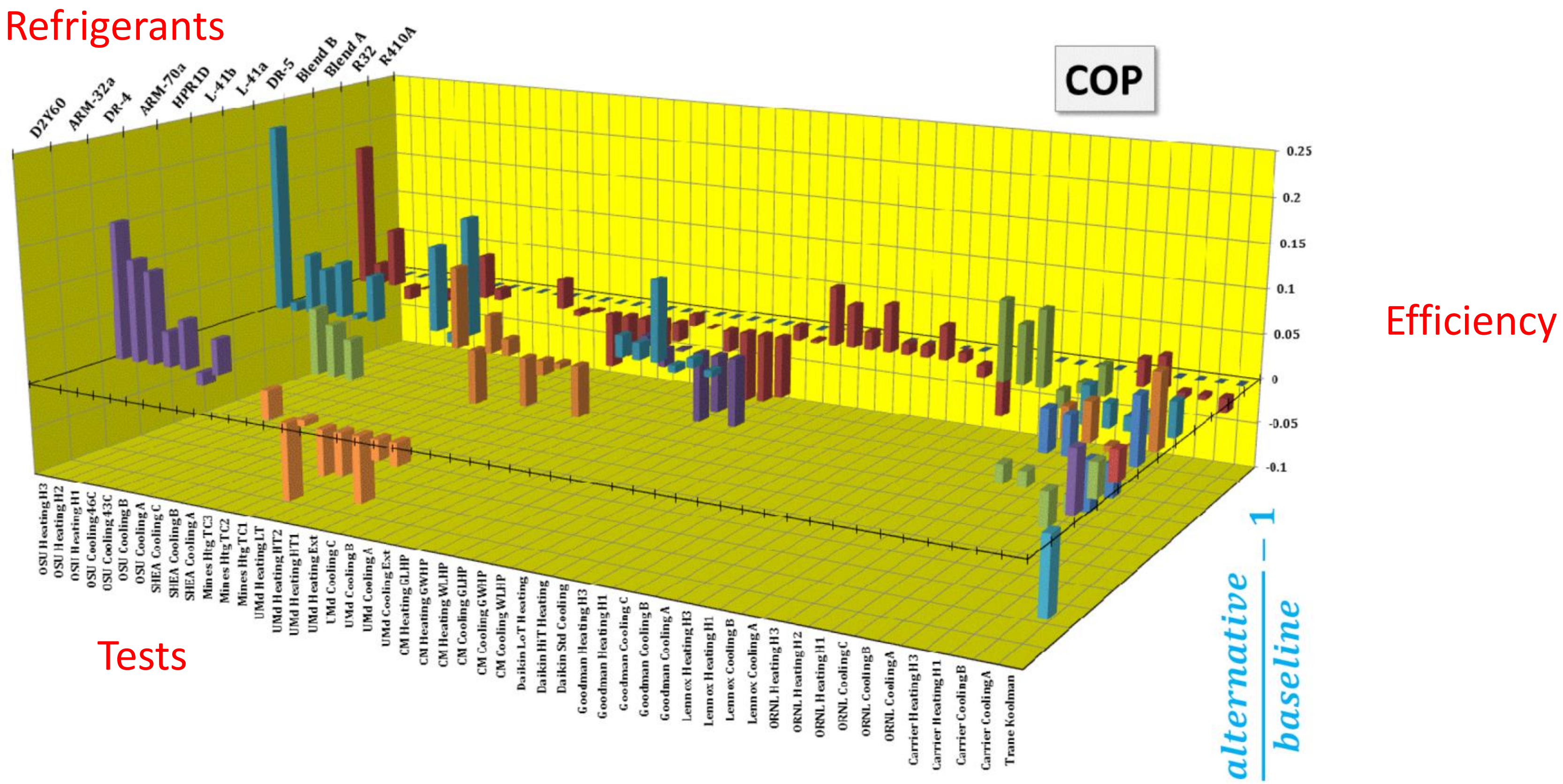
Note: 1. This is distinct from "equipment efficiency" improvements shown later

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

3. For A5 Parties, this would be paid for by Montreal Protocol <u>even in the absence of funding for EE by Montreal Protocol</u> 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

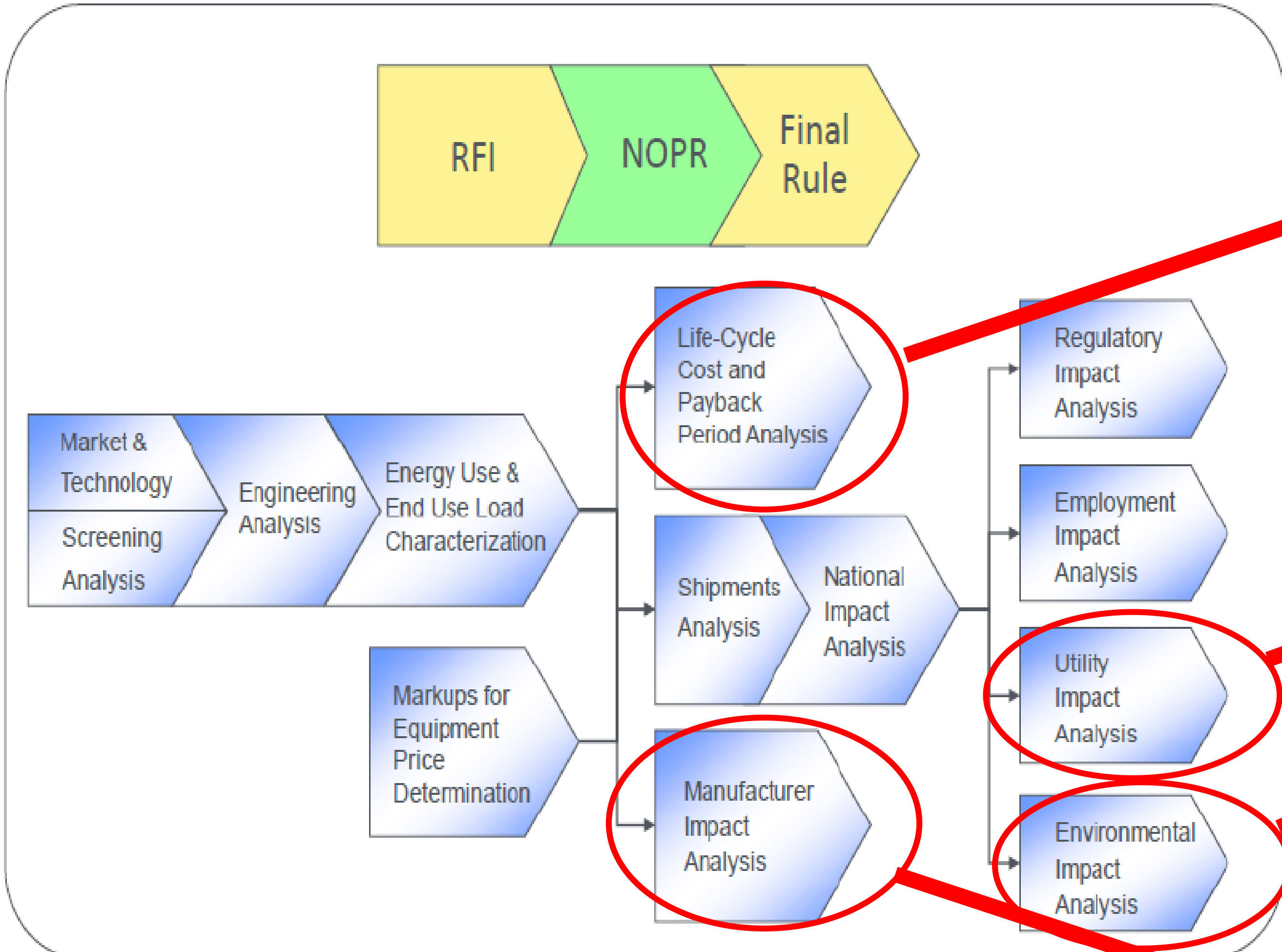


Source: AHRI low-GWP Alternate Refrigerant Evaluation Program (AREP)

Refrigerant impact on EE can be obtained from:

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

DOE Efficiency Standards Process and JIF metrics



JIF “consumer” cost effectiveness metric

JIF “utility” cost effectiveness metric

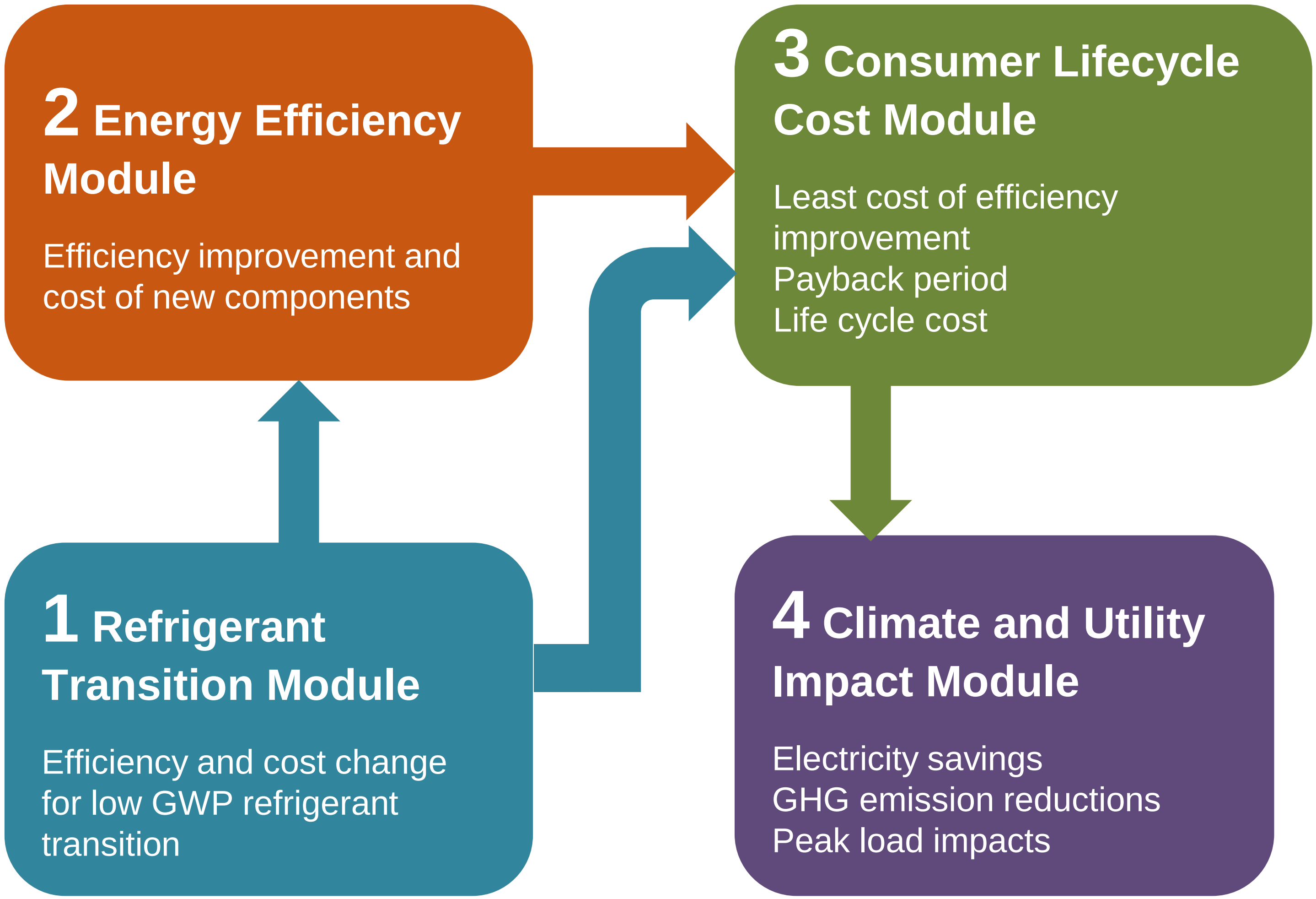
JIF “climate” cost effectiveness metric

JIF Investment needed

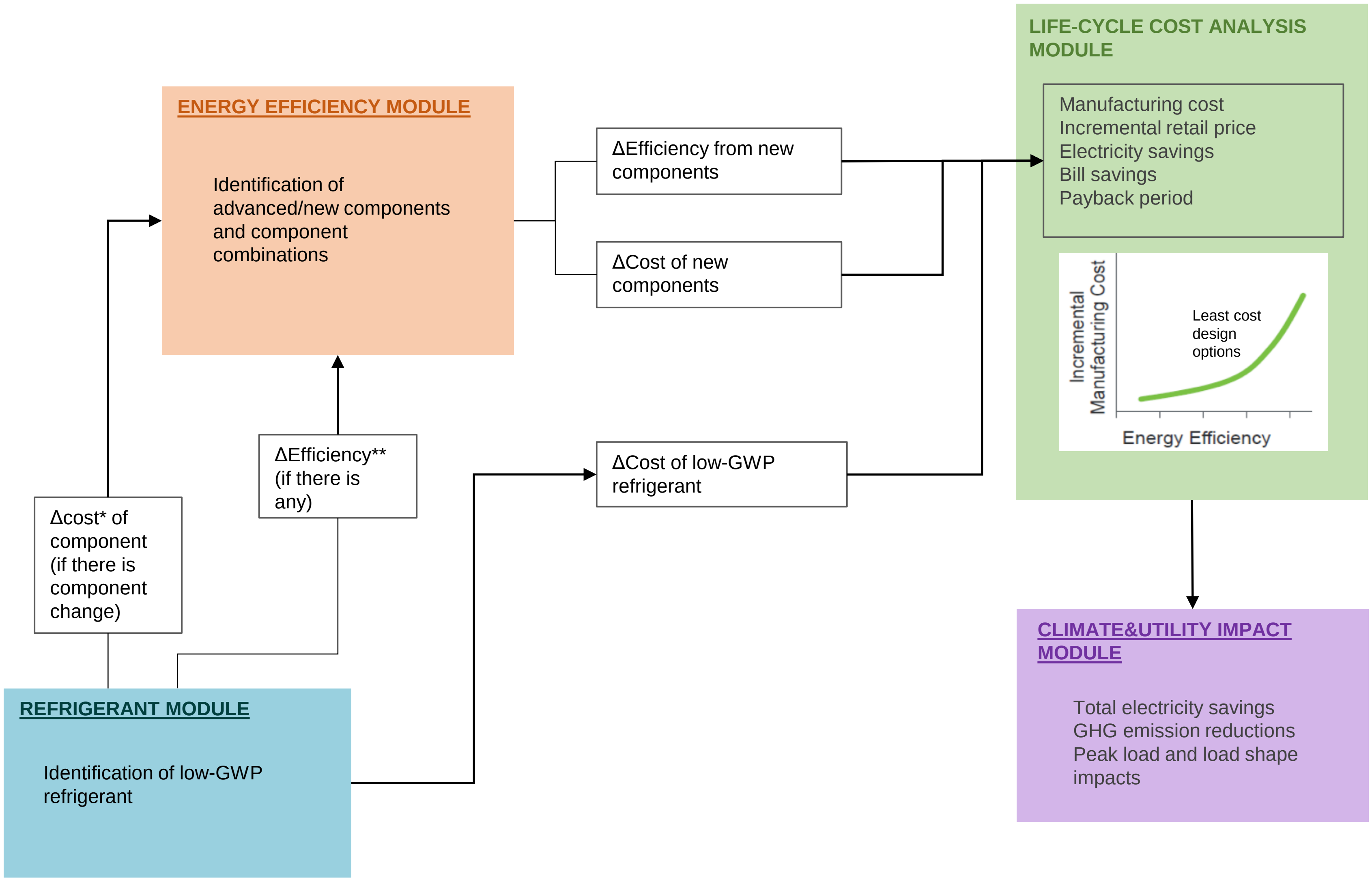
Source: http://www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0007-0035

Note: these are publicly available for various equipment types at various levels of efficiency

Joint Investment Framework: *Summary of the Methodology*



Joint Investment Framework: *Details of the Methodology*



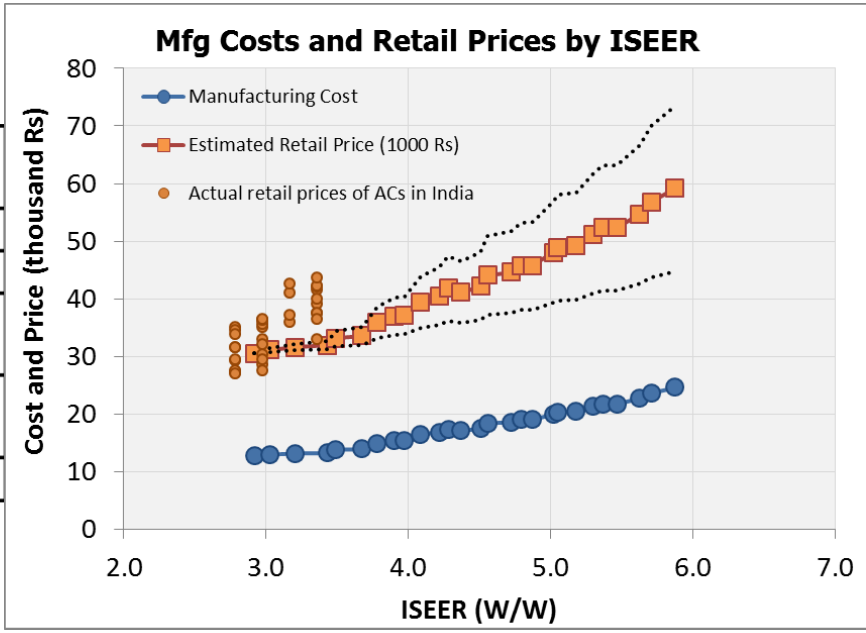
* <u>ΔCost</u>: Incremental cost; ** <u>ΔEfficiency</u>: ± change in efficiency

Cost vs Efficiency Example: mini-split ACs in India

Table 2.8 Efficiency improvement options, energy savings and manufacturing cost for a 5.27 kW mini-split AC in India [Shah et al, 2016]

Technology	Energy Saving Compared with Baseline	Incremental Manufacturing cost (Rs)
Improved compressors	5.5% – 15%	100 – 860
Variable speed compressors	21% – 23%	1,800 – 8,100
Variable speed drives for fans and compressors	26%	3,150 – 9,450
Heat Exchanger improvement	7.5% – 24%	735 – 11,000
Expansion valve	3.5% – 6.5%	125 – 2250

Source: Shah et al, 2016



- 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

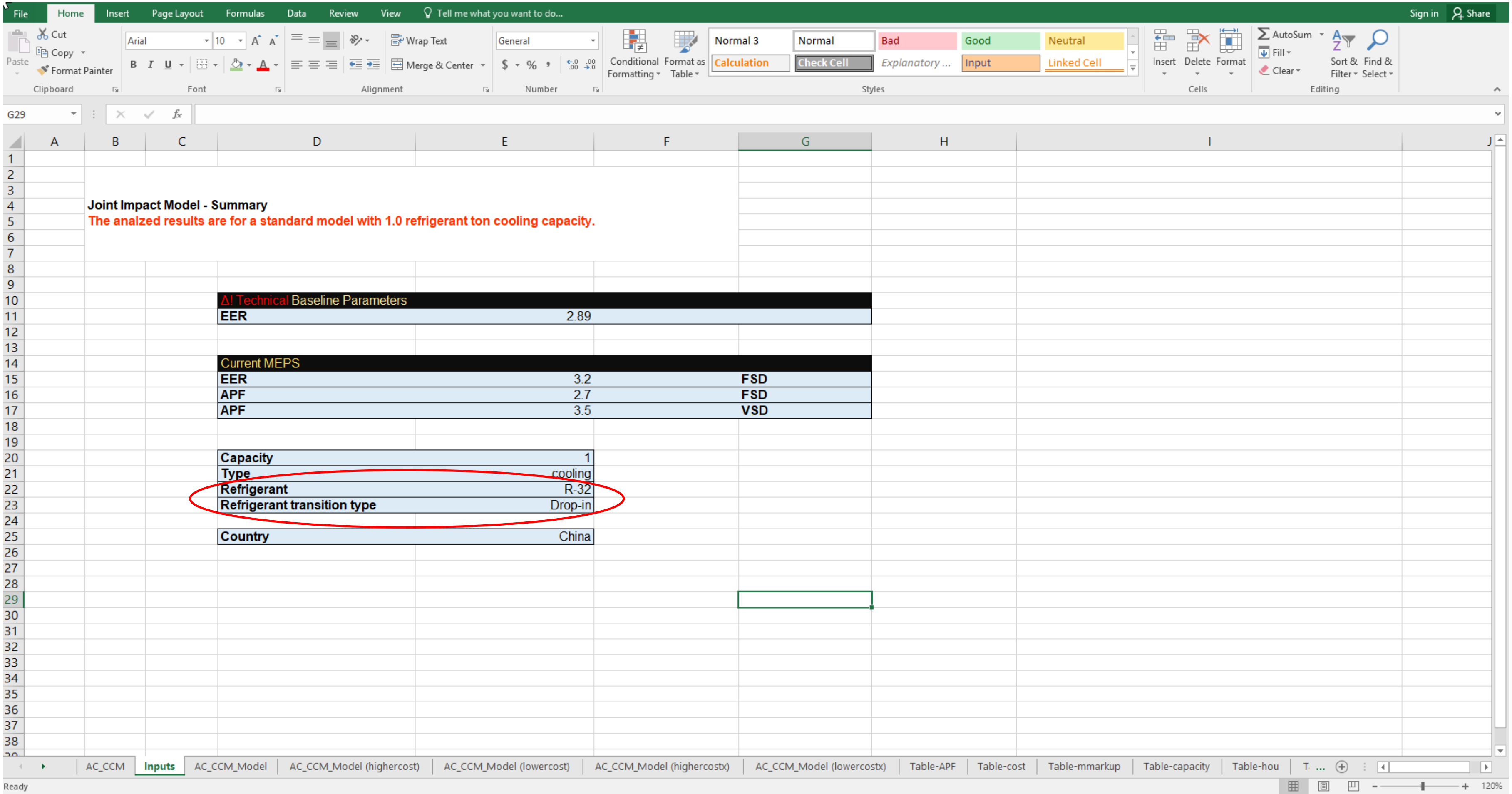
Joint Investment Framework: Structure and data

∆! Inputs available for user's modification. Red cells are available for user's modification.					
	Component	Baseline Mfg Cost (Yuan)	Incremental Mfg Cost (Yuan)	Retail Price Increase from Base Case (Yuan)	Energy Savings from Baseline
Baseline Compressor	2.8 EER Compressor	220			
Compressor 1	3.0 EER Compressor	235	15	30	5.0%
Compressor 2	3.2 EER Compressor	245	25	50	10.0%
Compressor 3	3.4 EER Compressor	260	40	80	15.0%
Compressor 4	3.6 EER Compressor	425	205	410	20.0%
Inv AC	Alternating Current Compressor with variable speed drive	481	261	522.0	23.0%
Inv DC	Direct Current Compressor variable speed drive +compressor	560	340	680	25.0%
All DC	Variable speed drives for fans and compressor	685	465	930	28.0%
Baseline Heat Exchanger (HE)	-	304			
HE 1	UA of both HEs increased by 20%	365	61	121.6	7.0%
HE 2	UA of both HEs increased by 40%	426	122	243.2	13.0%
HE 3	UA of both HEs increased by 60%	486	182	364.8	17.0%
HE 4	UA of both HEs increased by 80%	622	318	636.4	20.0%
HE 5	UA of both HEs increased by 100%	798	494	988	23.0%
Baseline Valve	-				
TXV	Thermostatic Expansion Valve	25	25	50	5.0%
EXV	Electronic Expansion Valve	70	70	140	9.0%
Baseline Refrigerant	R-410A	47			
Low-GWP Refrigerant	R-32	60	13		3.0%

PRELIMINARY

AC_CCM | Inputs | AC_CCM_Model | AC_CCM_Model (highercost) | AC_CCM_Model (lowercost) | AC_CCM_Model (highercostx)

Joint Investment Framework: Structure and Data



Joint Investment Framework: *Structure and Data*

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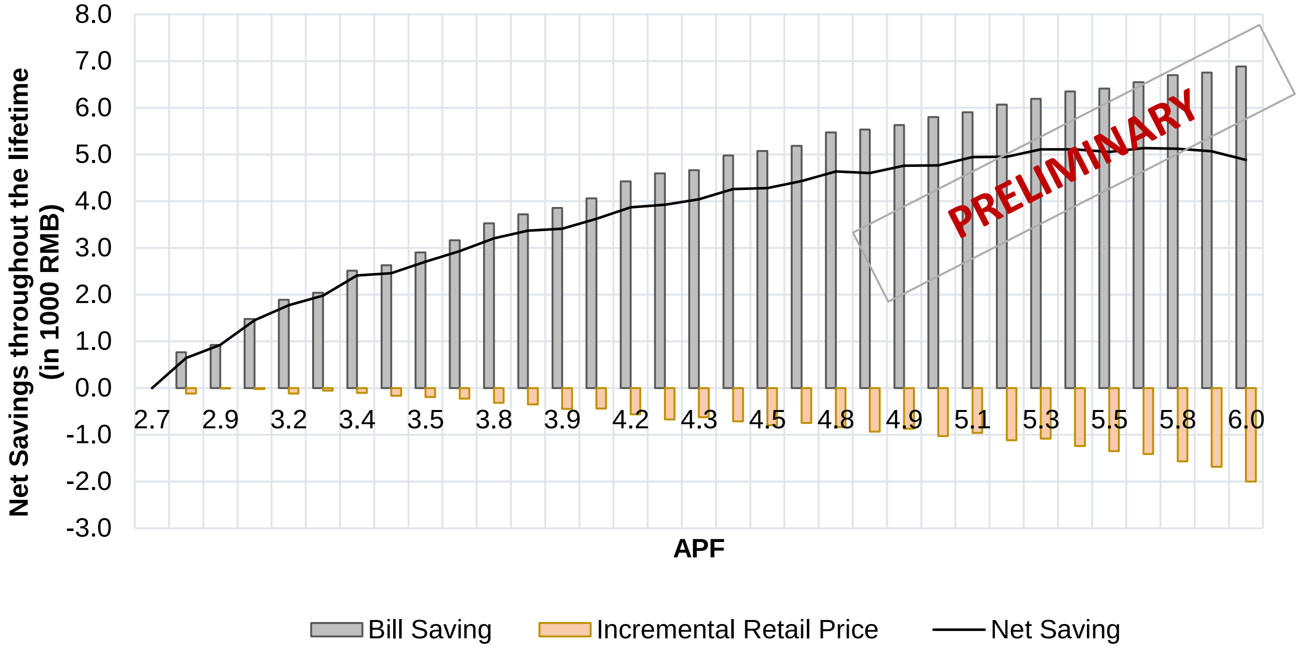
	A	B	C	D	E	F	G	H	I	K
1	Energy savings (%) - compared to Baseline				CHINA					
2	d	t	rt		Compress	VSD	HE	Valve	Refrigerant	Combined Efficiency Improvement
363	design_360	cooling	1_0RT	design_360cooling1_0RT	0.0%	0.0%	0.0%	0.0%	3.0%	3.0%
364	design_361	cooling	1_0RT	design_361cooling1_0RT	0.0%	0.0%	7.0%	0.0%	3.0%	9.8%
365	design_362	cooling	1_0RT	design_362cooling1_0RT	0.0%	0.0%	13.0%	0.0%	3.0%	15.6%
366	design_363	cooling	1_0RT	design_363cooling1_0RT	0.0%	0.0%	17.0%	0.0%	3.0%	19.5%
367	design_364	cooling	1_0RT	design_364cooling1_0RT	0.0%	0.0%	20.0%	0.0%	3.0%	22.4%
368	design_365	cooling	1_0RT	design_365cooling1_0RT	0.0%	0.0%	23.0%	0.0%	3.0%	25.3%
369	design_366	cooling	1_0RT	design_366cooling1_0RT	0.0%	0.0%	0.0%	5.0%	3.0%	7.9%
370	design_367	cooling	1_0RT	design_367cooling1_0RT	0.0%	0.0%	7.0%	5.0%	3.0%	14.3%
371	design_368	cooling	1_0RT	design_368cooling1_0RT	0.0%	0.0%	13.0%	5.0%	3.0%	19.8%
372	design_369	cooling	1_0RT	design_369cooling1_0RT	0.0%	0.0%	17.0%	5.0%	3.0%	23.5%
373	design_370	cooling	1_0RT	design_370cooling1_0RT	0.0%	0.0%	20.0%	5.0%	3.0%	26.3%
374	design_371	cooling	1_0RT	design_371cooling1_0RT	0.0%	0.0%	23.0%	5.0%	3.0%	29.0%
375	design_372	cooling	1_0RT	design_372cooling1_0RT	0.0%	0.0%	0.0%	9.0%	3.0%	11.7%
376	design_373	cooling	1_0RT	design_373cooling1_0RT	0.0%	0.0%	7.0%	9.0%	3.0%	17.9%
377	design_374	cooling	1_0RT	design_374cooling1_0RT	0.0%	0.0%	13.0%	9.0%	3.0%	23.2%
378	design_375	cooling	1_0RT	design_375cooling1_0RT	0.0%	0.0%	17.0%	9.0%	3.0%	26.7%
379	design_376	cooling	1_0RT	design_376cooling1_0RT	0.0%	0.0%	20.0%	9.0%	3.0%	29.4%
380	design_377	cooling	1_0RT	design_377cooling1_0RT	0.0%	0.0%	23.0%	9.0%	3.0%	32.0%
381	design_378	cooling	1_0RT	design_378cooling1_0RT	5.0%	0.0%	0.0%	0.0%	3.0%	7.9%
382	design_379	cooling	1_0RT	design_379cooling1_0RT	5.0%	0.0%	7.0%	0.0%	3.0%	14.3%
383	design_380	cooling	1_0RT	design_380cooling1_0RT	5.0%	0.0%	13.0%	0.0%	3.0%	19.8%
384	design_381	cooling	1_0RT	design_381cooling1_0RT	5.0%	0.0%	17.0%	0.0%	3.0%	23.5%
385	design_382	cooling	1_0RT	design_382cooling1_0RT	5.0%	0.0%	20.0%	0.0%	3.0%	26.3%
386	design_383	cooling	1_0RT	design_383cooling1_0RT	5.0%	0.0%	23.0%	0.0%	3.0%	29.0%
387	design_384	cooling	1_0RT	design_384cooling1_0RT	5.0%	0.0%	0.0%	5.0%	3.0%	12.5%
388	design_385	cooling	1_0RT	design_385cooling1_0RT	5.0%	0.0%	7.0%	5.0%	3.0%	18.6%
389	design_386	cooling	1_0RT	design_386cooling1_0RT	5.0%	0.0%	13.0%	5.0%	3.0%	23.8%
390	design_387	cooling	1_0RT	design_387cooling1_0RT	5.0%	0.0%	17.0%	5.0%	3.0%	27.3%
391	design_388	cooling	1_0RT	design_388cooling1_0RT	5.0%	0.0%	20.0%	5.0%	3.0%	30.0%
392	design_389	cooling	1_0RT	design_389cooling1_0RT	5.0%	0.0%	23.0%	5.0%	3.0%	32.6%
393	design_390	cooling	1_0RT	design_390cooling1_0RT	5.0%	0.0%	0.0%	9.0%	3.0%	16.1%
394	design_391	cooling	1_0RT	design_391cooling1_0RT	5.0%	0.0%	7.0%	9.0%	3.0%	22.0%
395	design_392	cooling	1_0RT	design_392cooling1_0RT	5.0%	0.0%	13.0%	9.0%	3.0%	27.0%
396	design_393	cooling	1_0RT	design_393cooling1_0RT	5.0%	0.0%	17.0%	9.0%	3.0%	30.4%
397	design_394	cooling	1_0RT	design_394cooling1_0RT	5.0%	0.0%	20.0%	9.0%	3.0%	32.9%
398	design_395	cooling	1_0RT	design_395cooling1_0RT	5.0%	0.0%	23.0%	9.0%	3.0%	35.4%
399	design_396	cooling	1_0RT	design_396cooling1_0RT	10.0%	0.0%	0.0%	0.0%	3.0%	12.7%
400	design_397	cooling	1_0RT	design_397cooling1_0RT	10.0%	0.0%	7.0%	0.0%	3.0%	18.8%
401	design_398	cooling	1_0RT	design_398cooling1_0RT	10.0%	0.0%	13.0%	0.0%	3.0%	24.0%
402	design_399	cooling	1_0RT	design_399cooling1_0RT	10.0%	0.0%	17.0%	0.0%	3.0%	27.5%
403	design_400	cooling	1_0RT	design_400cooling1_0RT	10.0%	0.0%	20.0%	0.0%	3.0%	30.2%
404	design_401	cooling	1_0RT	design_401cooling1_0RT	10.0%	0.0%	23.0%	0.0%	3.0%	32.8%
405	design_402	cooling	1_0RT	design_402cooling1_0RT	10.0%	0.0%	0.0%	5.0%	3.0%	17.1%

PRELIMINARY

AC_CCM_Model (highercost) | AC_CCM_Model (lowercost) | AC_CCM_Model (highercostx) | AC_CCM_Model (lowercostx) | Table-APF | Table-cost | Table-mmarkup

Consumer Perspective: Least Lifecycle Cost for mini-split ACs in China



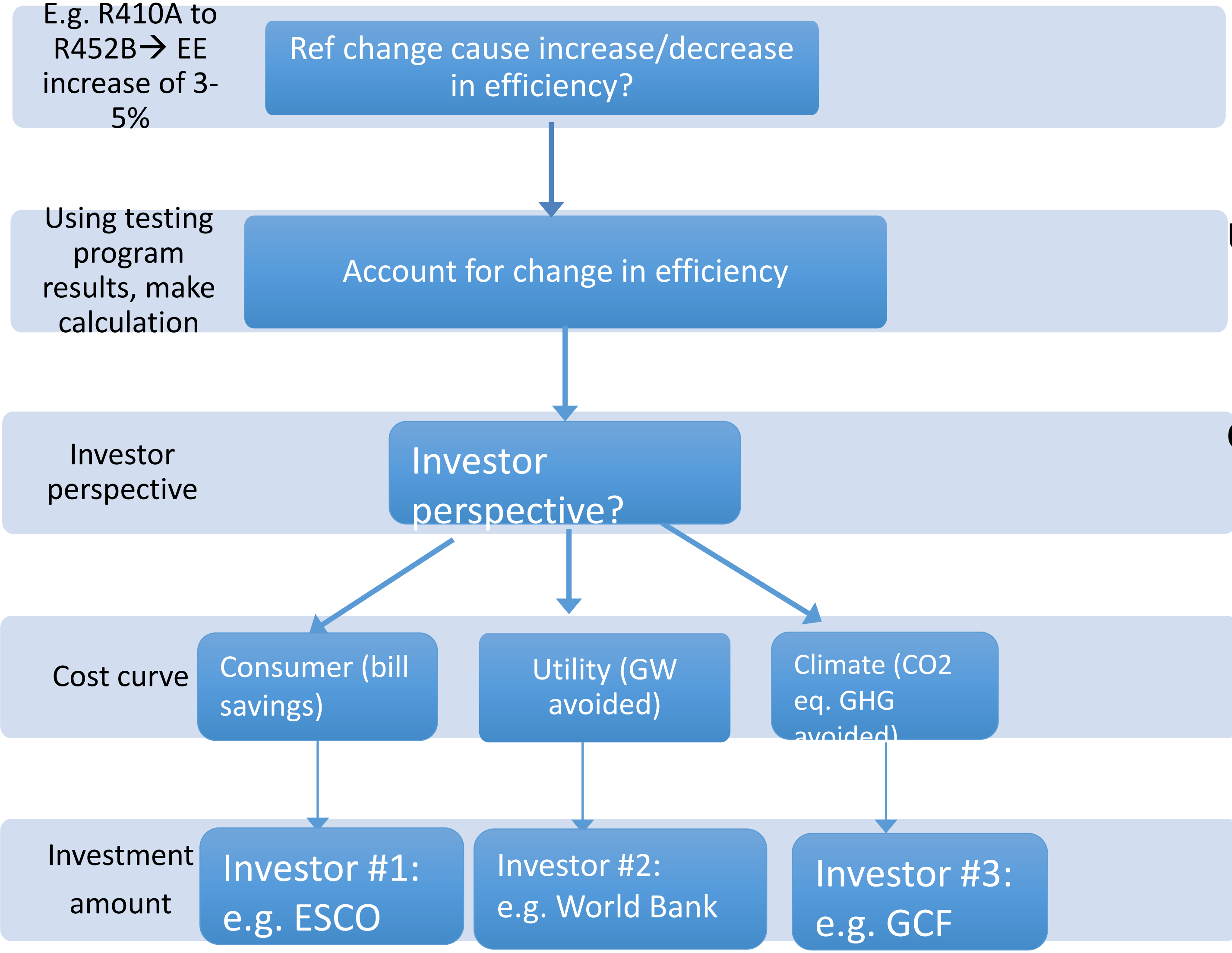
Source: Shah et al, 2018 (forthcoming)

- 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.

Climate Perspective: CO_2 Equivalent of RT investment

- Calculate CO_2 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.
- CO_2 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)



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

SEER (W/W)	Capital Conversion Costs (2015 US$ million)	2015 Shipments[7] (million units/year)
4.2	61	6.5
4.4	205.6	6.5
4.7	337.9	6.5
5.6	373	6.5

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 CO_2 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.

Summary

- 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 funders' and MP Parties' needs

Feedback needed

- 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

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- Nihan Karali, Lawrence Berkeley National Laboratory
- Liz Coleman, Lawrence Berkeley National Laboratory

Thank You!

Questions?

Suggestions?

Requests?

Contact:

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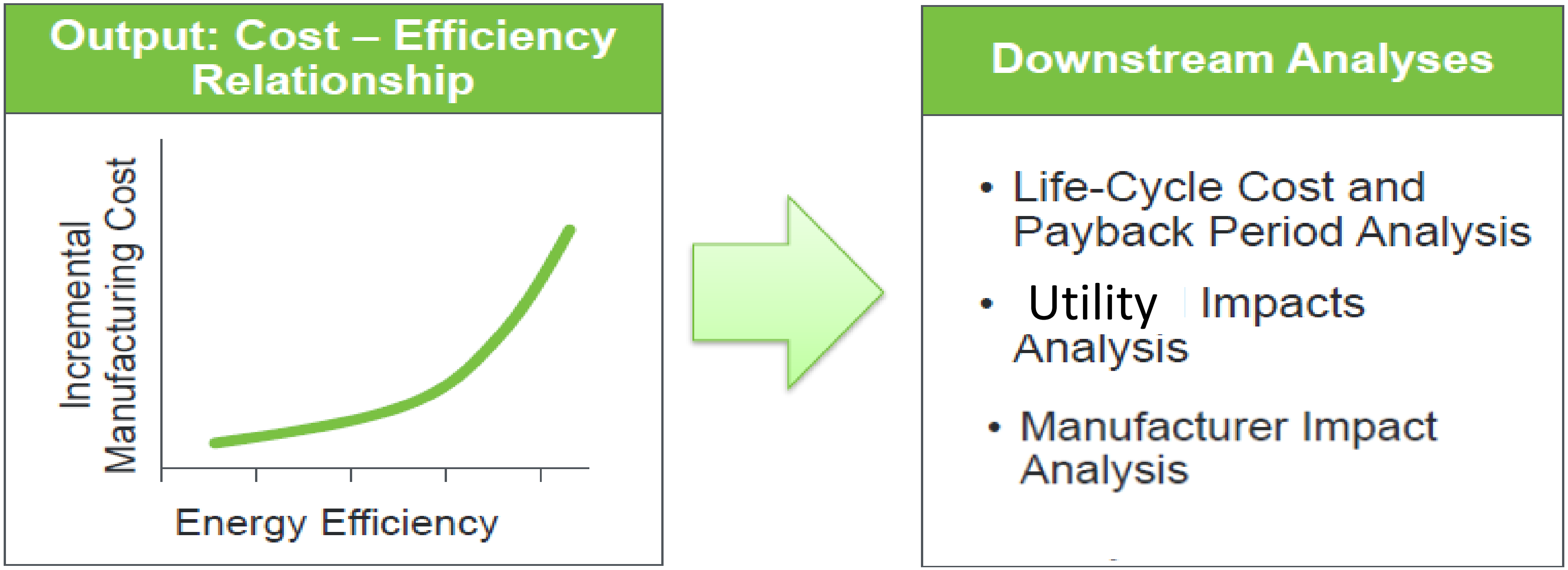
Extra Slides

Overview of DOE Rulemaking process (contd.)



- 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

Source: http://www.regulations.gov/#!documentDetail;D=EERE-2013-BT-STD-0007-0035

"Types" of efficiency improvement

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

Only A and C should be considered as B will continue to happen
A: "refrigerant efficiency" and C: "equipment efficiency"

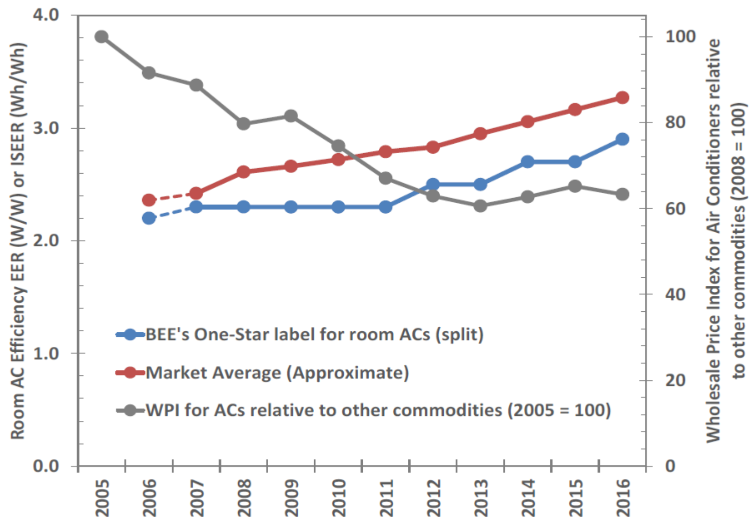
Base Case

Cooling Capacity (tons)	1.5
Appliance Lifetime	10
Power Consumption (kW)	1.81
Energy Efficiency Ratio (W/W)	2.9
Refrigerant Charge (kg)	1.7
Refrigerant Leakage Rate(%/year)	10.0%
End of Life Refrigerant Loss Rate (kg)	100%
Recharge at % loss	35%
Charge/ton of AC capacity (kg/ton)	1.10
Number of recharges	2
Total Lifetime Charge Emitted (kg)	2.81
Total % Charge Emitted	170%

- **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)**

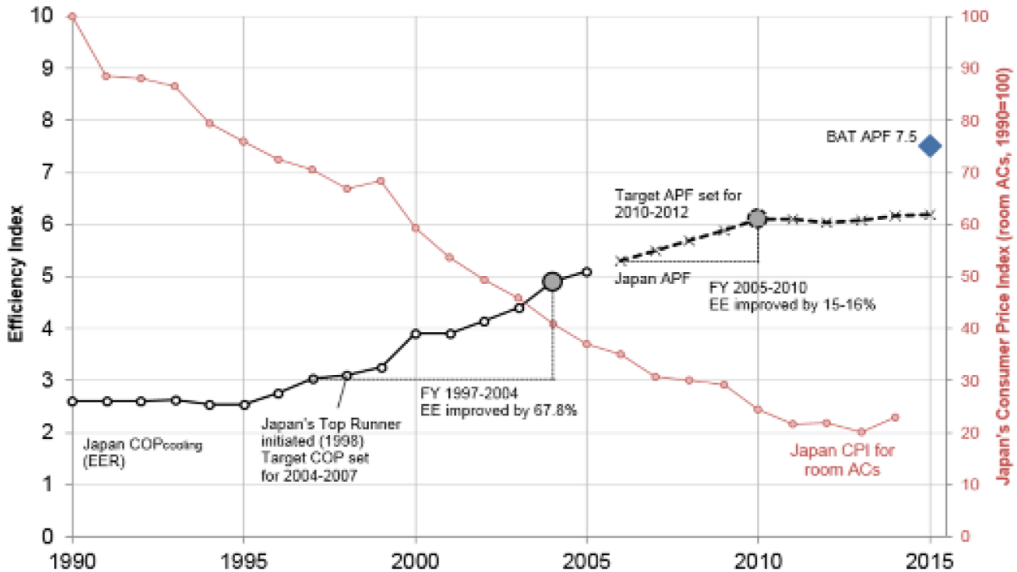
Room AC Efficiency and Policies in India

- 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



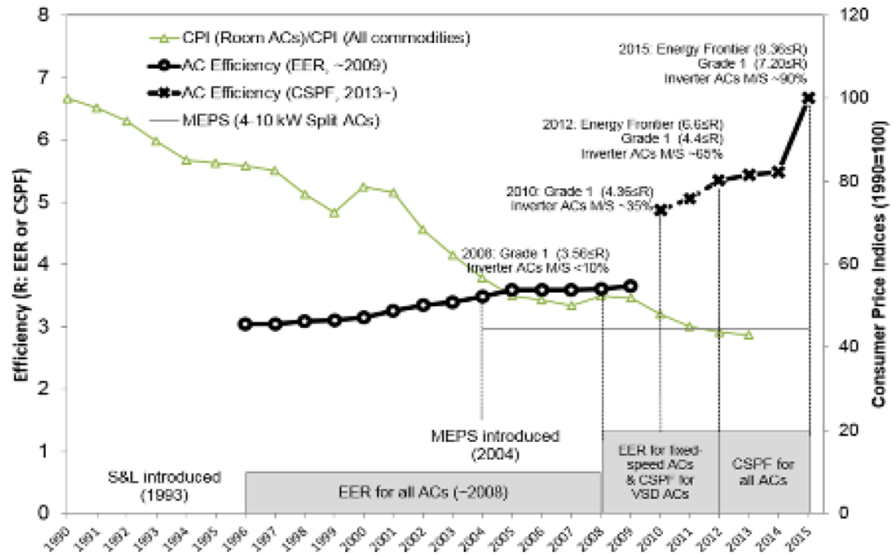
- Room AC Efficiency has been improving while costs continue to decline
  - Room AC star labels have been ratcheted up by one star equivalent every two years
  - Between 2006 and 2016, room AC MEPS has increased by 35% (~3% per year)
  - Market average efficiency, slightly higher than MEPS, has improved 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

Accelerated Efficiency Improvement Driven by Policy: Korea's Energy Frontier Program



- 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)

AHRTI Air-Conditioning, Heating and Refrigeration Technology Institute

Final Report

AHRTI Report No. 09003-01

LIFE CYCLE CLIMATE PERFORMANCE MODEL FOR RESIDENTIAL HEAT PUMP SYSTEMS

Final Report

October 2011

Ming Zhang, Jan Muehlbauer, Vikrant Aute, Reinhard Radermacher

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- 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, at least until electricity grids get cleaner.
- 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

Baseline	Refrigerant	Composition	(Mass%)	Classification	GWP_{100}
R410A GWP=1924 (IPCC AR5)	ARM-70a	R-32/R-134a/R-1234yf	(50/10/40)	A2L*	469
	D2Y60	R-32/R-1234yf	(40/60)	A2L*	271
	DR-5	R-32/R-1234yf	(72.5/27.5)	A2L*	491
	HPR1D	R-32/R-744/R-1234ze(E)	(60/6/34)	A2L*	407
	L41a	R-32/R-1234yf/R-1234ze(E)	(73/15/12)	A2L*	494
	L41b	R-32/R-1234ze(E)	(73/27)	A2L*	494
	R32	R32	100	A2L	677
	R32/R134a	R-32/R-134a	(95/5)	A2L*	708
	R32/R152a	R-32/R-152a	(95/5)	A2L*	650

*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.**

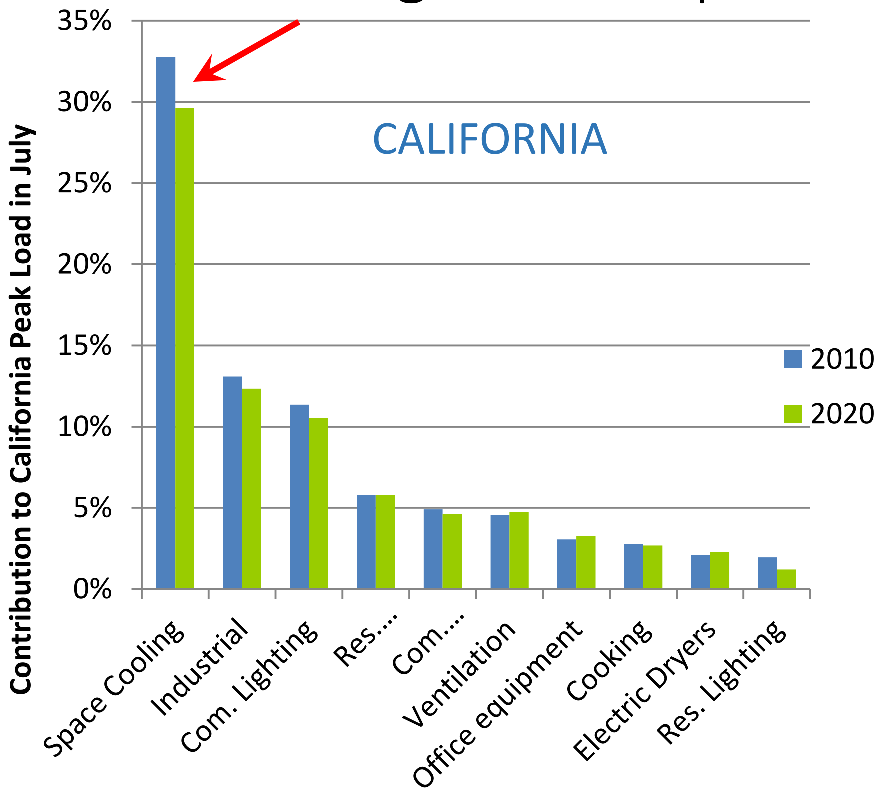
AHRI Low-GWP Alternate Refrigerant Evaluation Program (AREP) Phase 2 (2015-2016) R410A alternatives

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

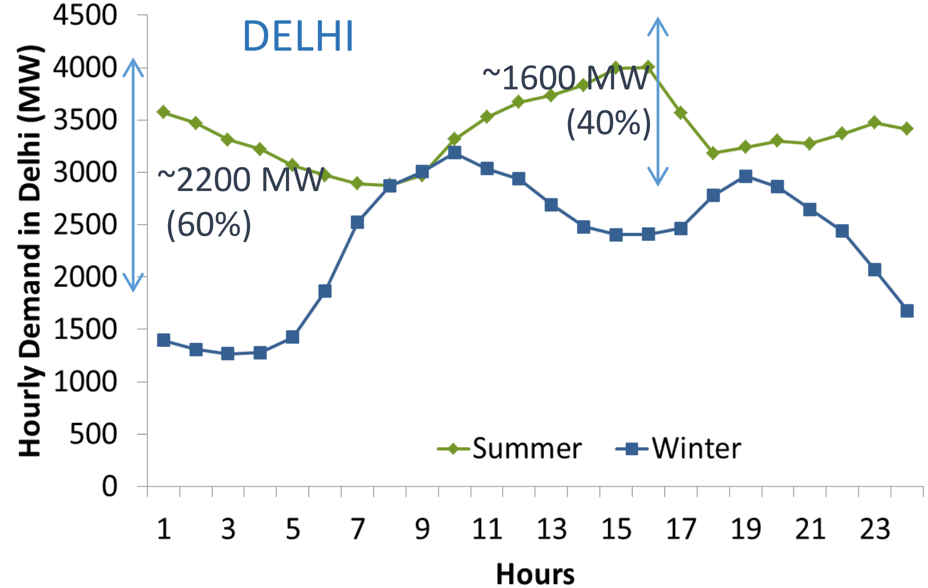
Source: AHRI, 2016

- 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.

Large Grid Impact of Cooling Peak Load



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

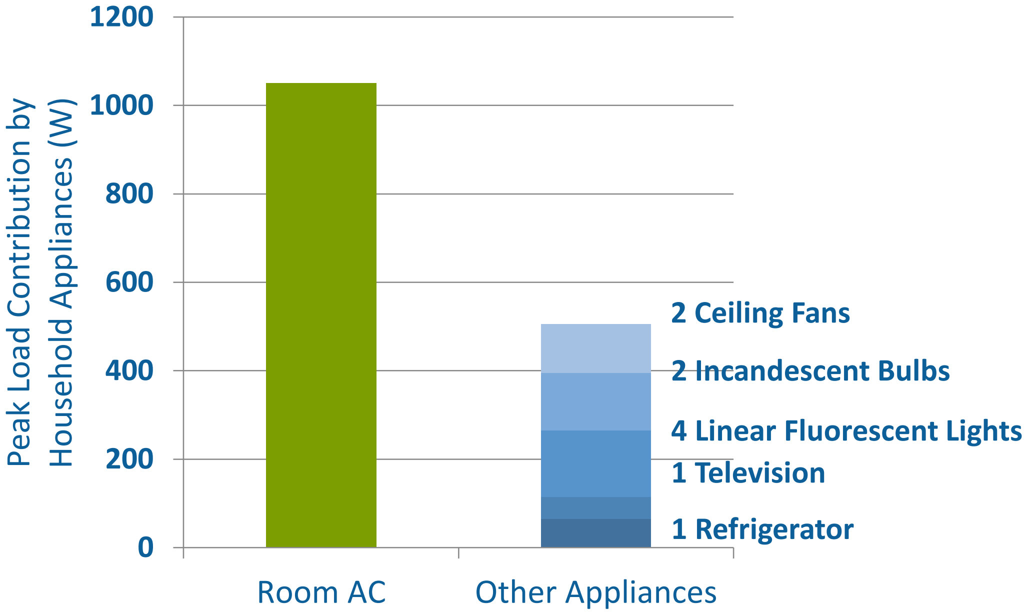


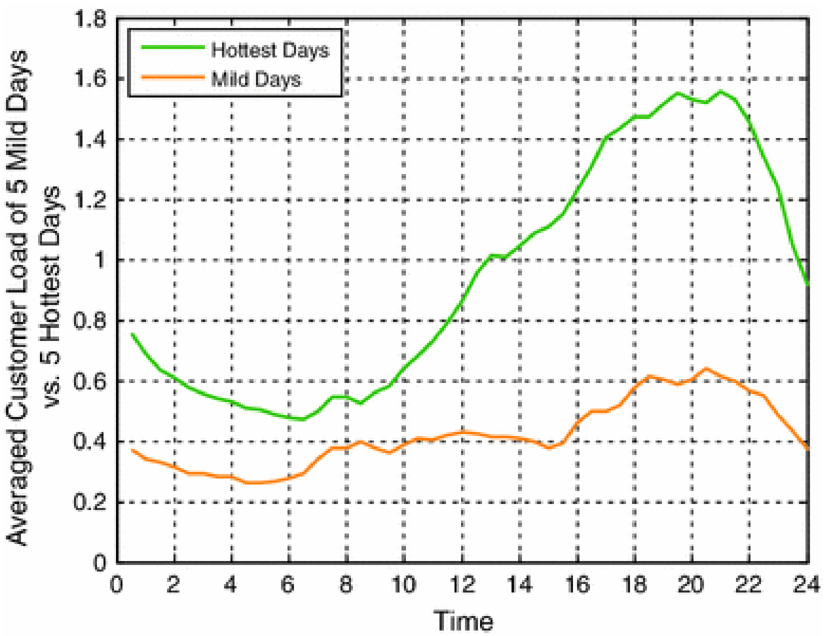
Source: DSLDC, 2012

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.

Cooling Contribution to Peak Load – per appliance





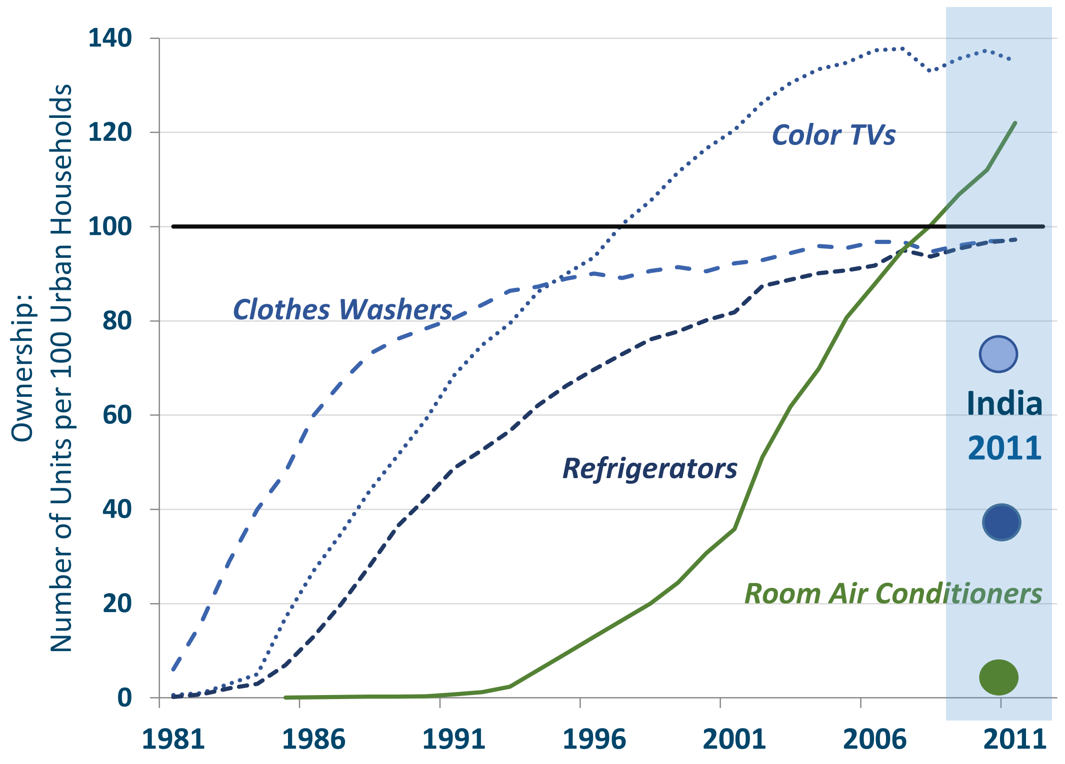
Ausgrid, Australia

Source: Smith et al., 2013

Cooling is the largest contributor to peak load on an appliance basis…

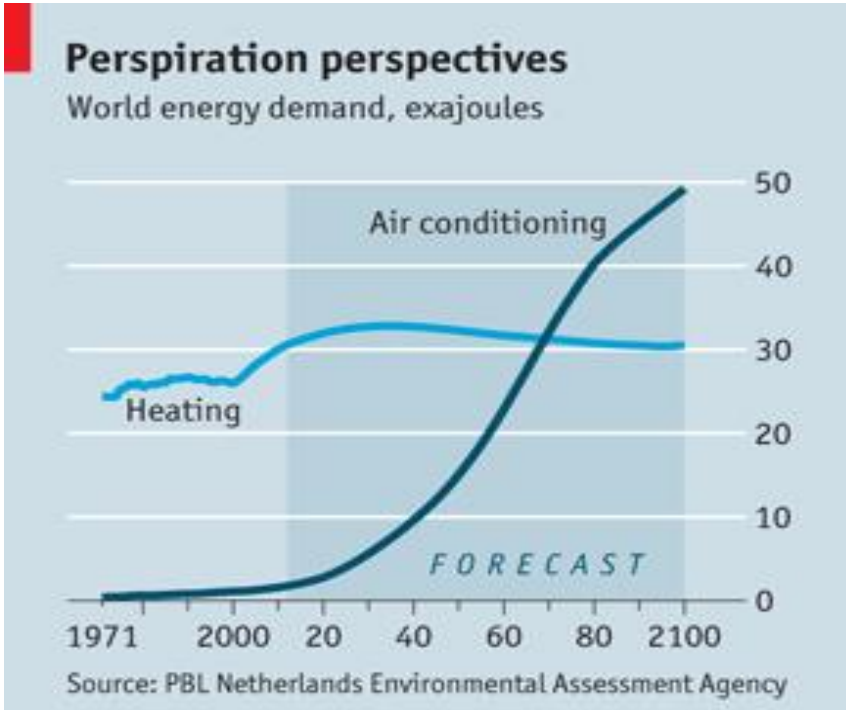
…and can triple load on the hottest days in some areas, e.g., New South Wales, Australia.

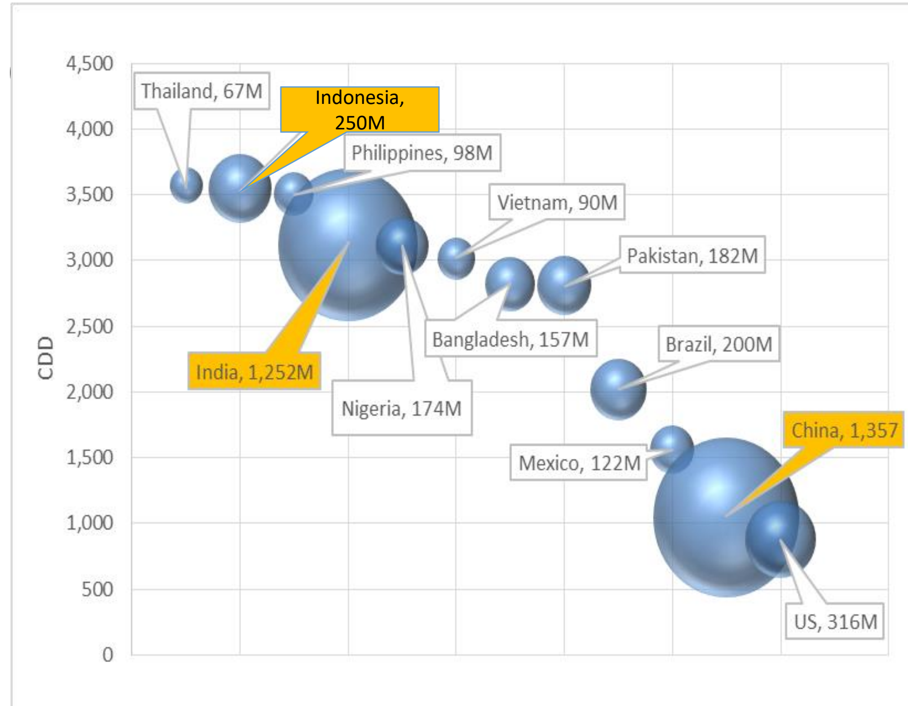
Growth in China's AC market



Source: NSSO, 2012, Fridley et al., 2012

- 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.

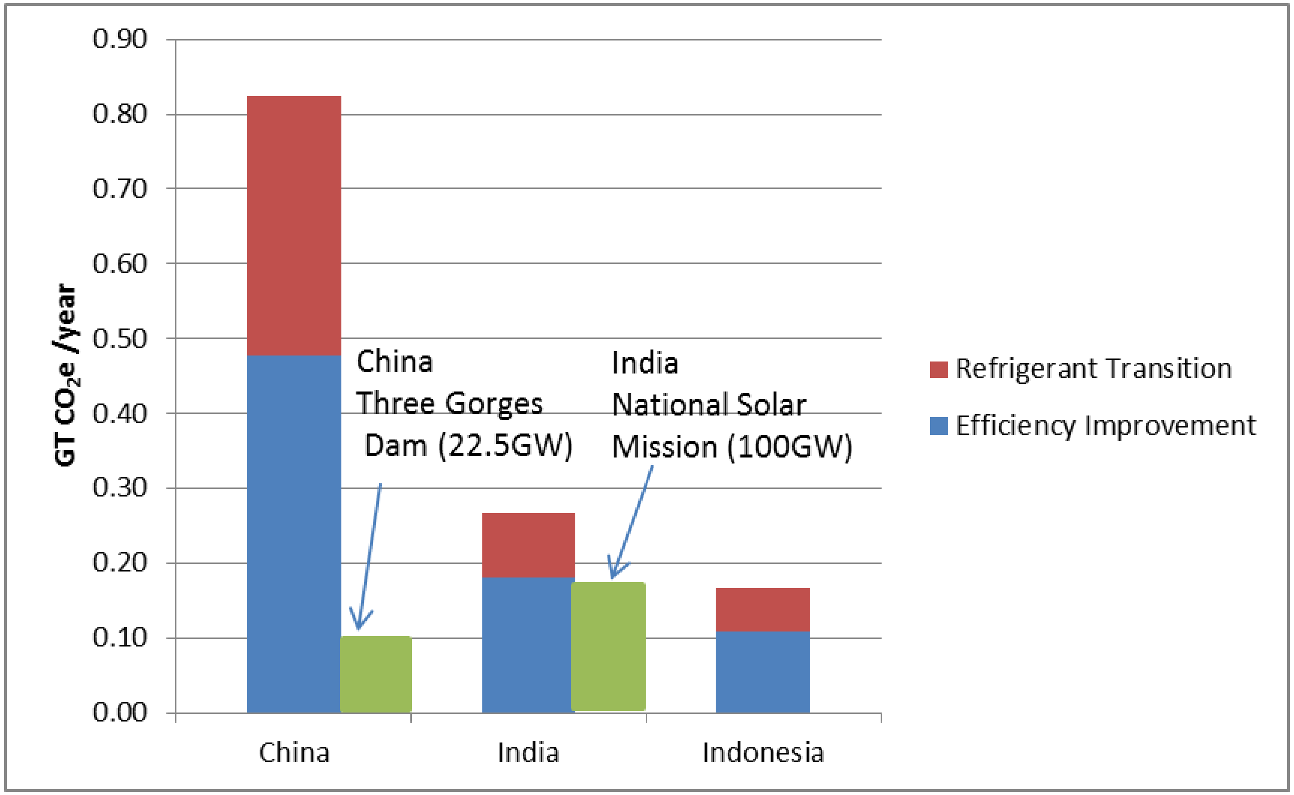




Source: Davis et al, Proceedings of the National Academy of Sciences, 2015

- 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



Source: Shah et al, 2015

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.