

Availability of Efficient Space Cooling

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Lawrence Berkeley National Laboratory

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Bureau of Energy Efficiency/ International Energy Agency/ Superefficient Equipment and Appliance Deployment Initiative

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Introduction to Lawrence Berkeley National Laboratory

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

Lawrence Berkeley National Laboratory

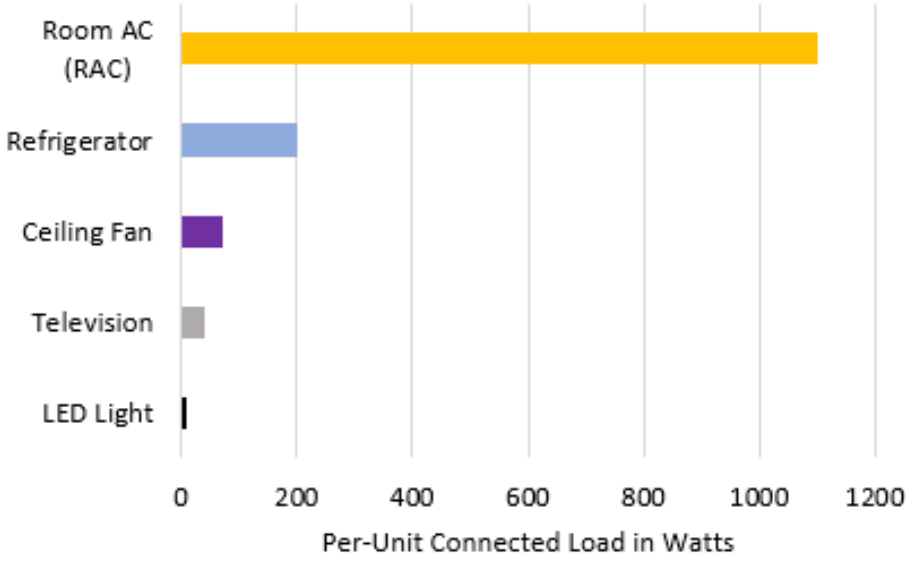
13 — Nobel Prizes
13 — National Medal of Science recipients
4,200 — Employees
200 — Site acreage

- Dedicated to solving the most pressing scientific problems facing humanity.
- More than two decades of work internationally on clean energy and climate policy, appliances, buildings, transport, industry, air quality.
- Significant focus on energy efficiency, including technical Support to US DOE Appliance Standards Rulemakings.
- Technical support for Kigali Amendment negotiations.
- Technical support for revision of India's 2016 Energy Efficiency standard and India's EESL bulk procurement program for ACs
- Technical support for market transformation programs for efficient ACs and refrigerators in various countries including China, Brazil, Mexico, Egypt, Indonesia and United for Efficiency (U4E) "model regulations".



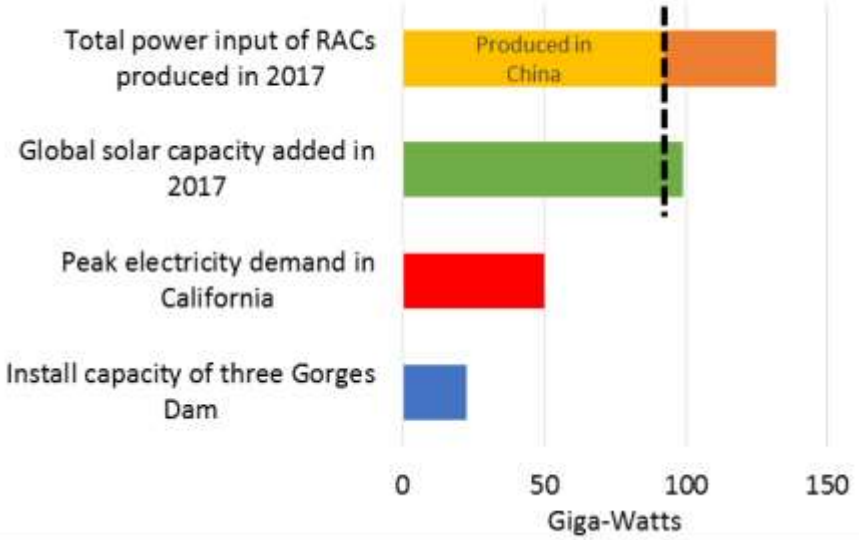
Size of cooling efficiency opportunity: room ACs

- Total RAC production worldwide is of the order of ~120-130 million units annually.
- Total load added by ACs produced in China in 2017 is comparable to total solar capacity added in 2017 (100GW).



Source: Shah et al 2019 (forthcoming)

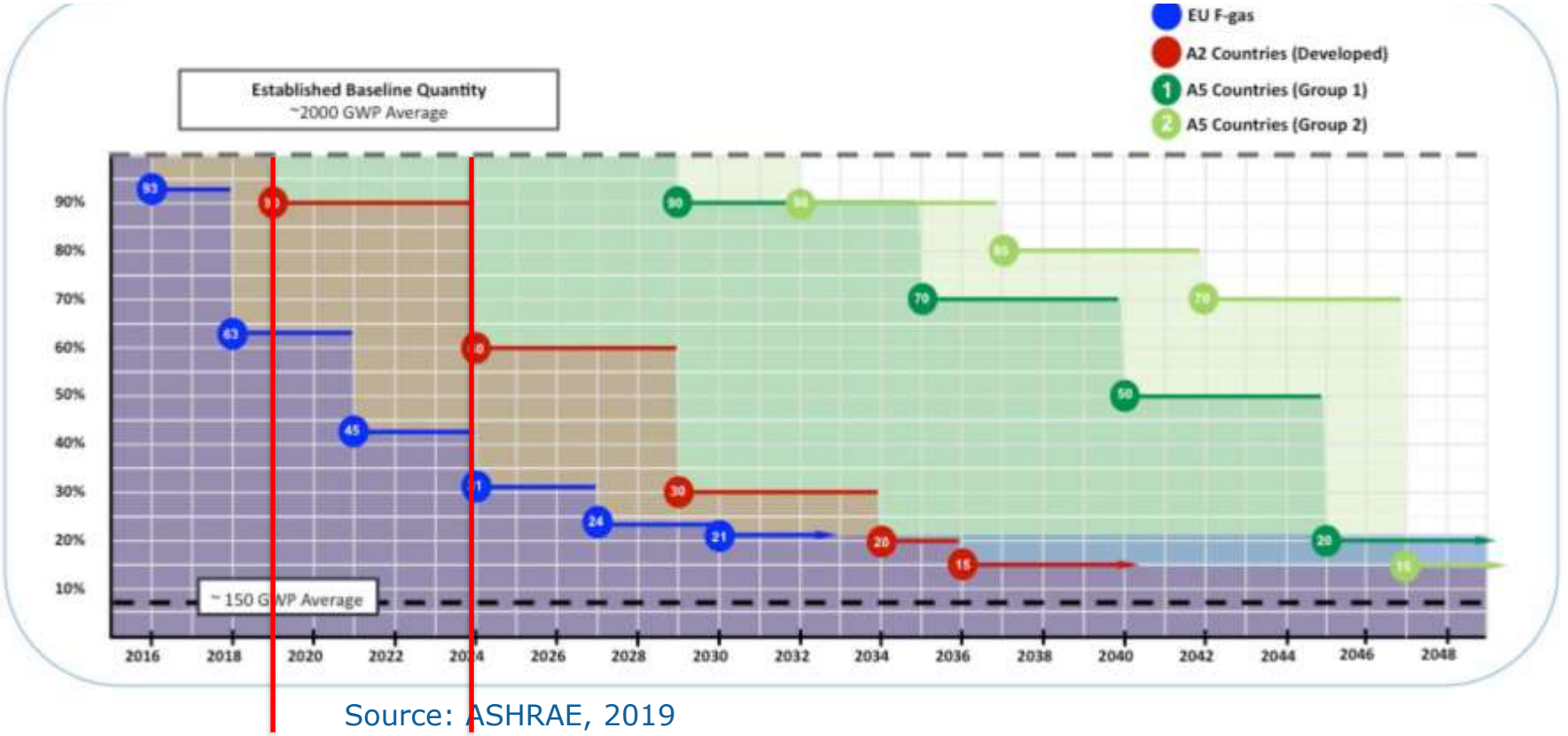
Per-unit connected load of an RAC and other end-uses



Source: Shah et al 2019 (forthcoming)

Total power input from RACs produced in 2017 and selected comparable electricity demand and generation capacity 2017

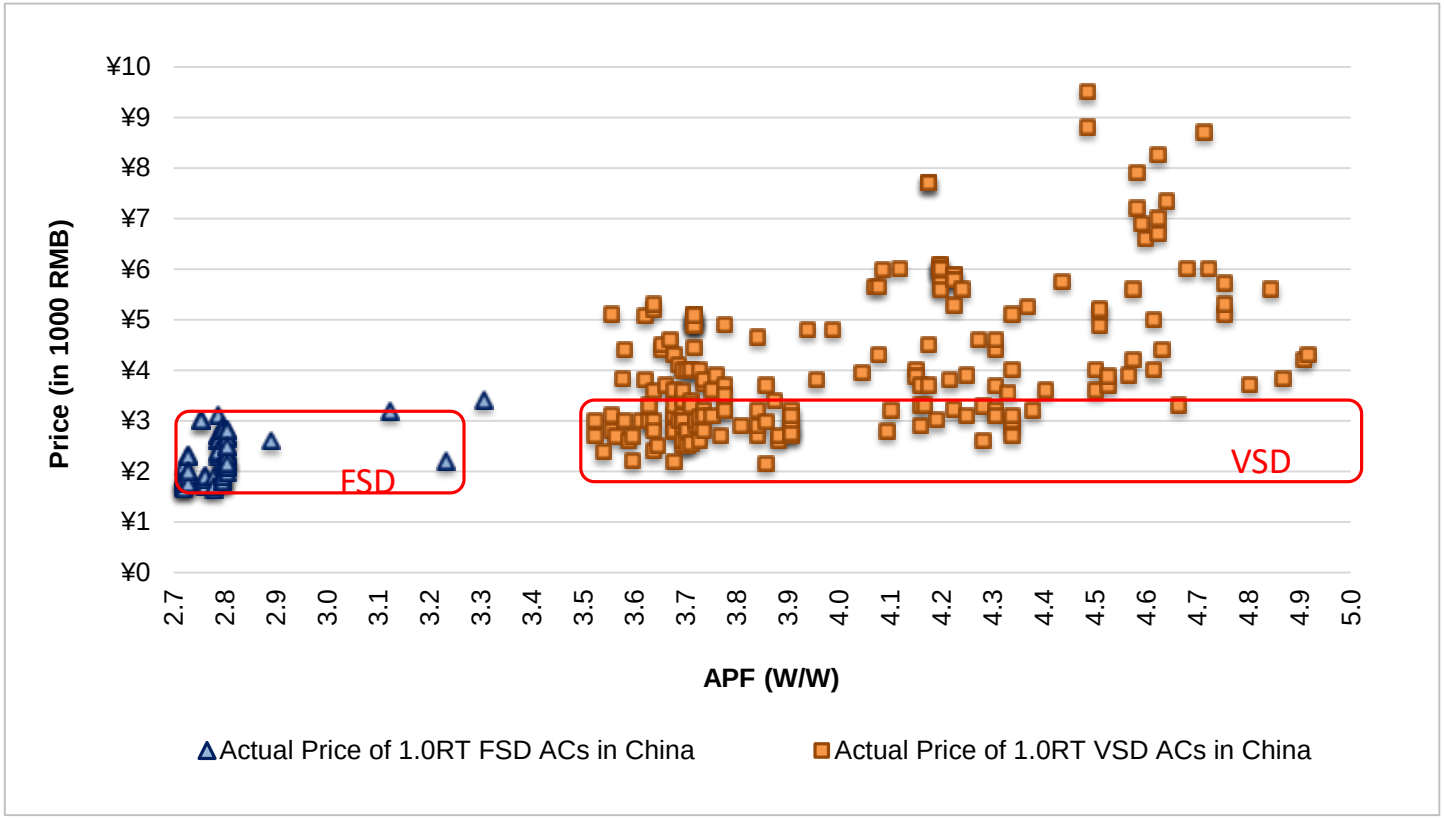
Global Cooling Industry in Transition



Source: ASHRAE, 2019

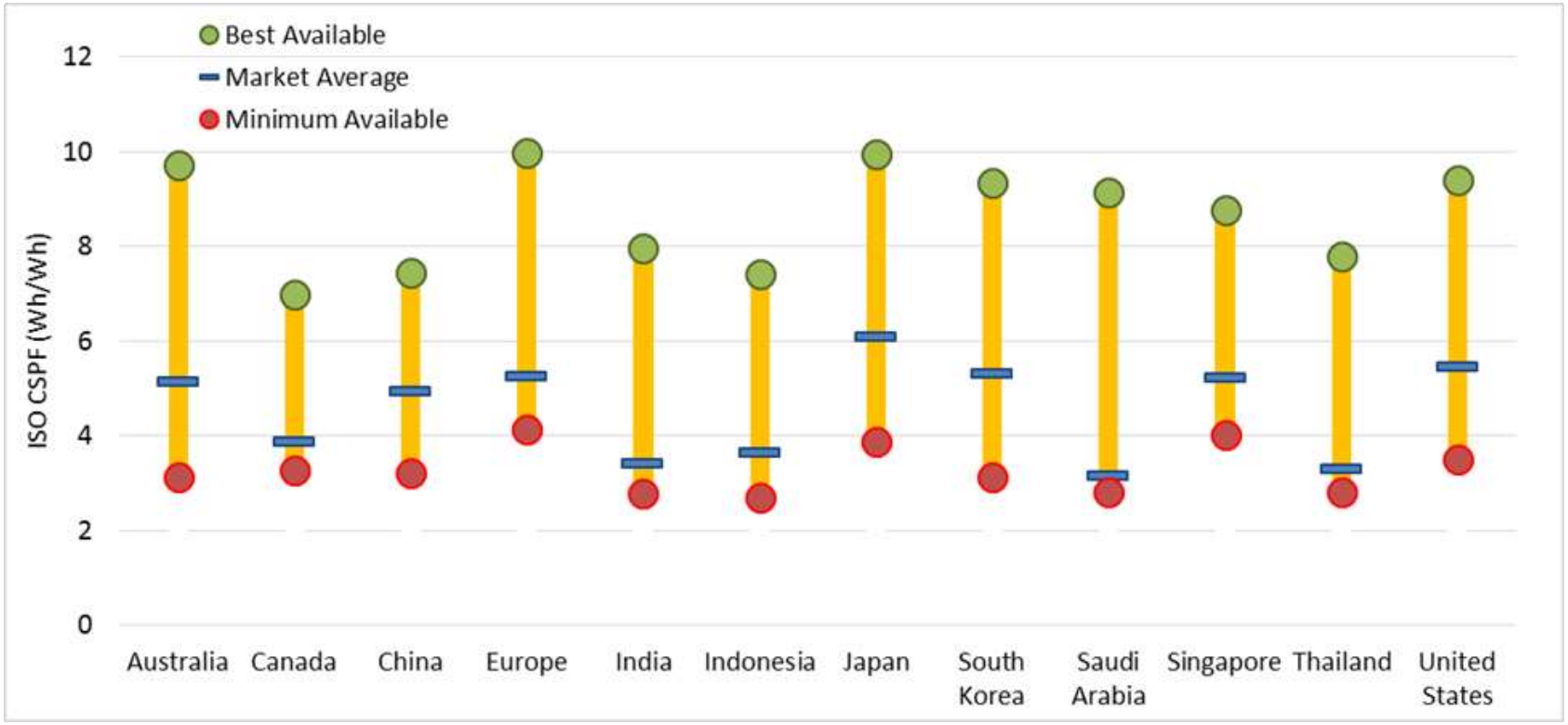
- Kigali Amendment estimated to save ~0.5 deg of global average temperature rise.
- Global cooling industry is at a "disruptive moment" due to refrigerant transitions.
- The world has 3-4 years to put in place the "right" cooling technologies.

Efficient ACs are available



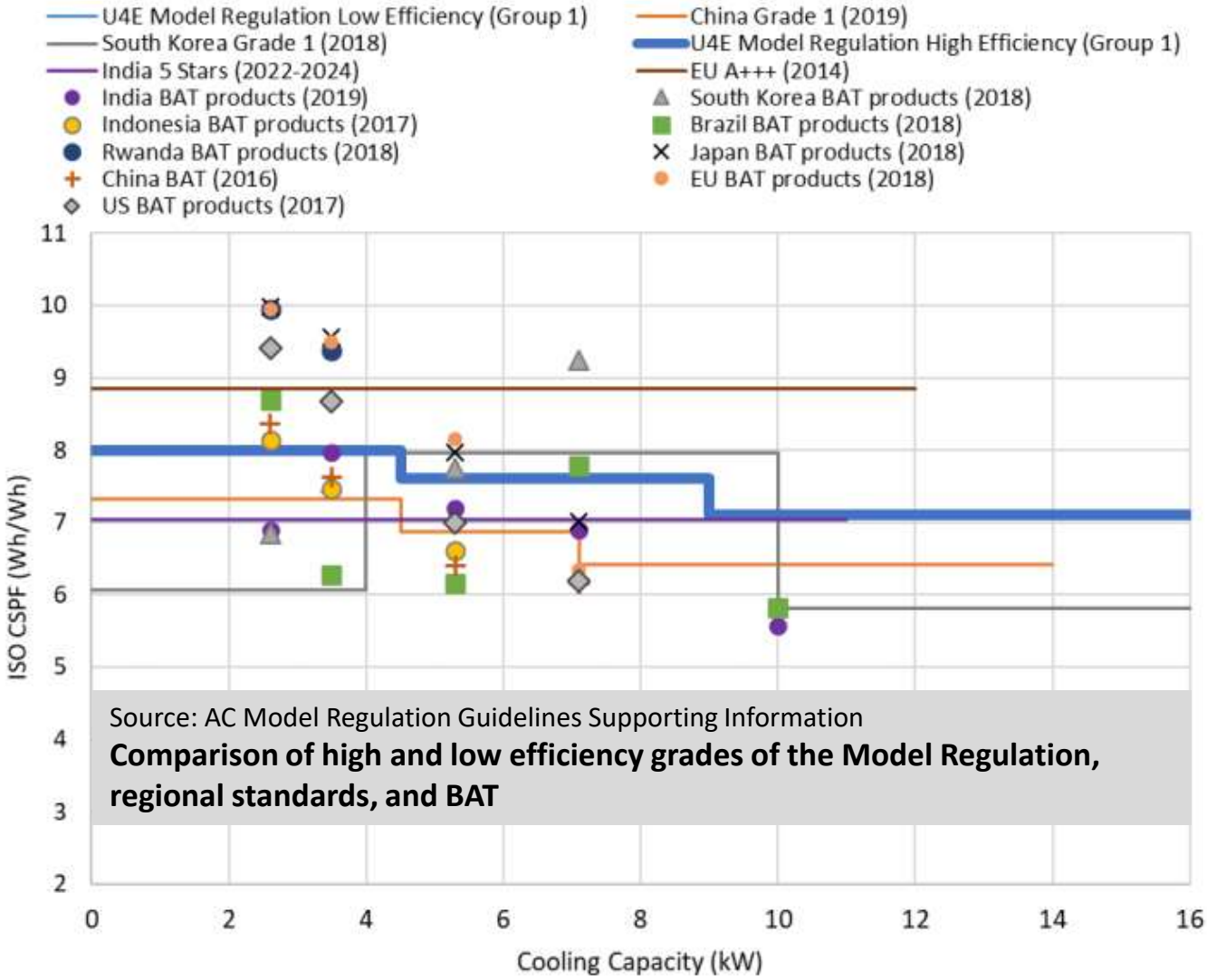
- Both efficient FSD and VSD ACs are available at reasonable cost
- Market prices appear to reflect the bundling of AC features other than efficiency, because prices at the same efficiency level vary by over 200%.

Global best available technology(BAT) is more than twice as efficient as the market average



CSPF: cooling seasonal performance factor
LBNL's adjustment from the IEA study

Global Best Available Technology(BAT) surpasses the highest efficiency levels recognized by labeling programs



Source: AC Model Regulation Guidelines Supporting Information

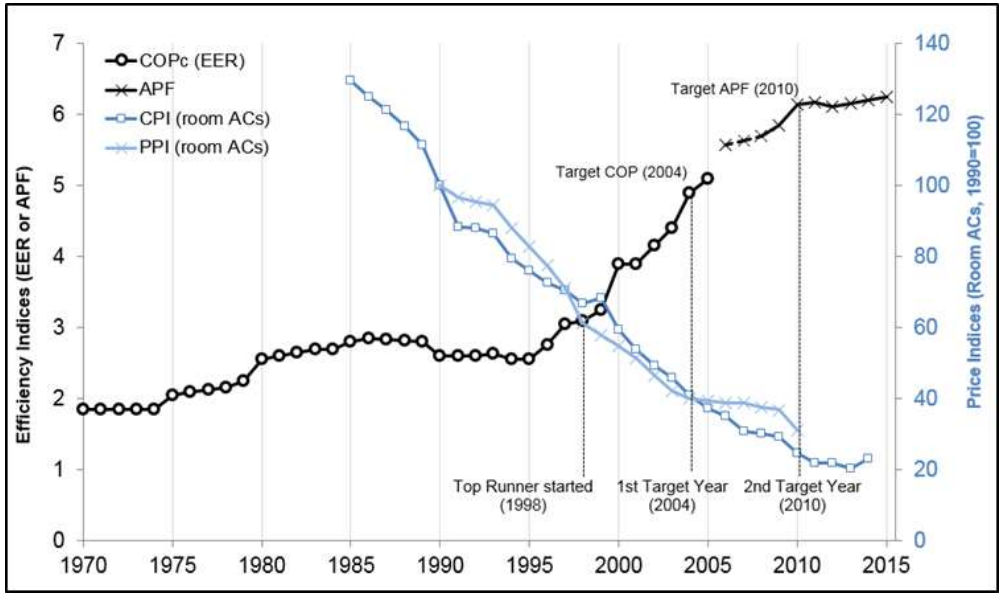
Comparison of high and low efficiency grades of the Model Regulation, regional standards, and BAT

Trends in best-in-class energy-efficient cooling technologies

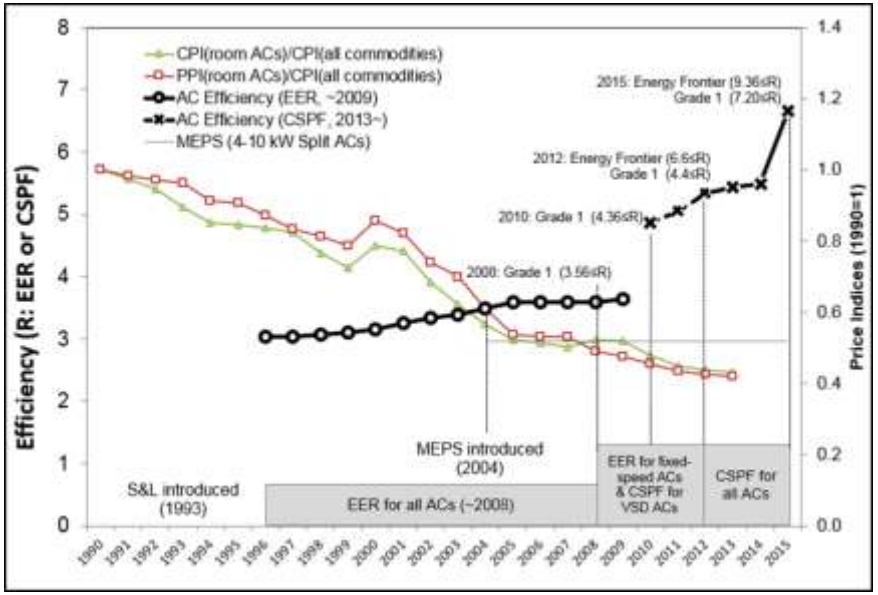
- **Key efficiency features**: The highest-efficiency RAC models use advanced compressor and inverter technologies whose efficiency optimized at a low frequency, large heat exchangers with evolved fin patterns and diameter-reduced tubes, highly-efficient direct current fan motors, and smart sensors for temperature and humidity control.
- **Part-load efficiency**: Although significant improvement in RAC efficiency was historically made in full-load operation, manufacturers are recently improving seasonal efficiency which reflects full- and part-load performances, rather than focusing on full-load efficiency only.
- **Refrigerant**: The highest-efficiency RAC models use low global warming potential (GWP) refrigerants, as well as conventional high-GWP refrigerant, varying by manufacturer and region.
- **Innovative technologies in development**: moving toward smart hybrid designs, evaporative cooling, separate sensible and latent cooling and solid-state materials beyond conventional vapor compression technology.

Efficient cooling at scale: Examples from Japan and South Korea

- If efficient ACs are made "at scale", the cost of efficient technology falls due to "economies of scale"
- Similar examples from US, Korea, India, EU for different appliances e.g. refrigerators and washing machines. (Abhyankar et al 2017 and Spurlock, 2013)
- **How to encourage manufacture and deployment of efficient ACs at scale?**



Room AC efficiency and price trends in Japan



Room AC efficiency and price trends in South Korea

Source: Amol Phadke, Won Young Park, Nikit Abhyankar, Nihar Shah. 2017. Relationship between Appliance Prices and Energy-Efficiency Standards and Labeling Policies: Empirical Evidence from Residential Air Conditioners. Presented at the 9th INTERNATIONAL CONFERENCE ON ENERGY EFFICIENCY IN DOMESTIC APPLIANCES AND LIGHTING (EEDAL).

Opportunity: Simultaneous Efficiency Improvement and Refrigerant Transition

- Air Conditioners and refrigeration appliances are often first products regulated for energy efficiency and will also undergo refrigerant transition under Kigali Amendment or current Montreal Protocol obligations.

- refrigerant transition and efficiency improvement both typically *require* redesign of appliances and retooling of manufacturing lines.

- Coordinated efficiency improvement with refrigerant transition can *keep costs low* for consumers, manufacturers, utilities and funders.

Takeaways

- Growth in cooling demand is a huge opportunity and challenge (~$billions and GW)
- The global cooling industry is in transition
- There are 3-4 years to put in place the “right” cooling technology at scale
- Efficient cooling technologies are increasingly available
- Encouraging deployment of efficient cooling “at scale” can reduce costs
- Co-ordinating finance of efficiency improvement with refrigerant change may further reduce costs

Thank you

Questions, Suggestions?

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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

Global AC Market and refrigerant alternatives

Table ES-1: Status of A/C Equipment Categories with Low-GWP Refrigerant Options Showing Comparable or Improved Performance and Efficiency[10]

Residential	Status	2012 Global Annual Sales (US$B)	Commercial	Status	2012 Global Annual Sales (US$B)
Room & portable	●	$3.4	Packaged terminal	◔	$0.2
Ducted split & single-package	◔	$3.3	Packaged rooftop unit	◔	$4.6
Ductless split system	●	$48.5	Ductless (VRF/VRV)	◔	$10.7
			Scroll / recip. chiller	◔	
			Screw chiller	●	$8.3 (All chillers)
			Centrifugal chiller	●	

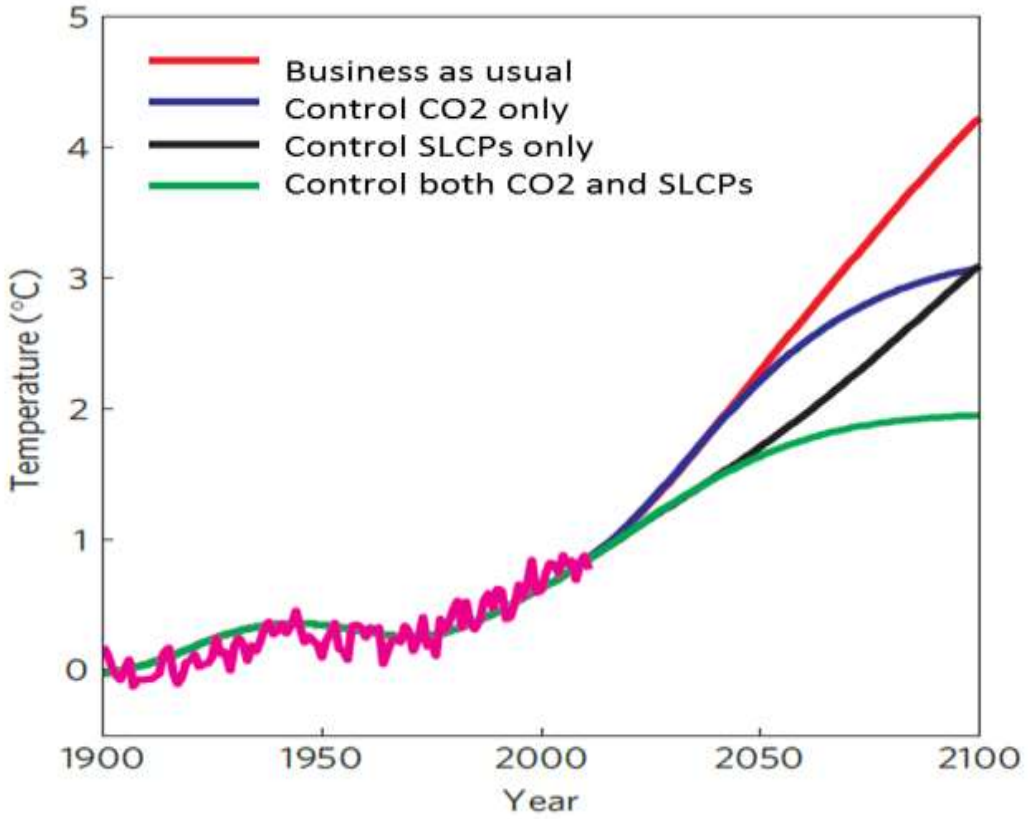
Green signifies that equipment operates using refrigerants with GWP as low as 10 or less
Blue signifies that equipment operates using refrigerants with GWP as low as 700 or less

● Commercially available in some global markets; ◕ Product under development; ◔ Tested in Lab

Source: DOE,"Future of Airconditioning for Buildings" , 2016

- The industry has developed alternative technologies for many categories and is in the process of developing further alternatives.

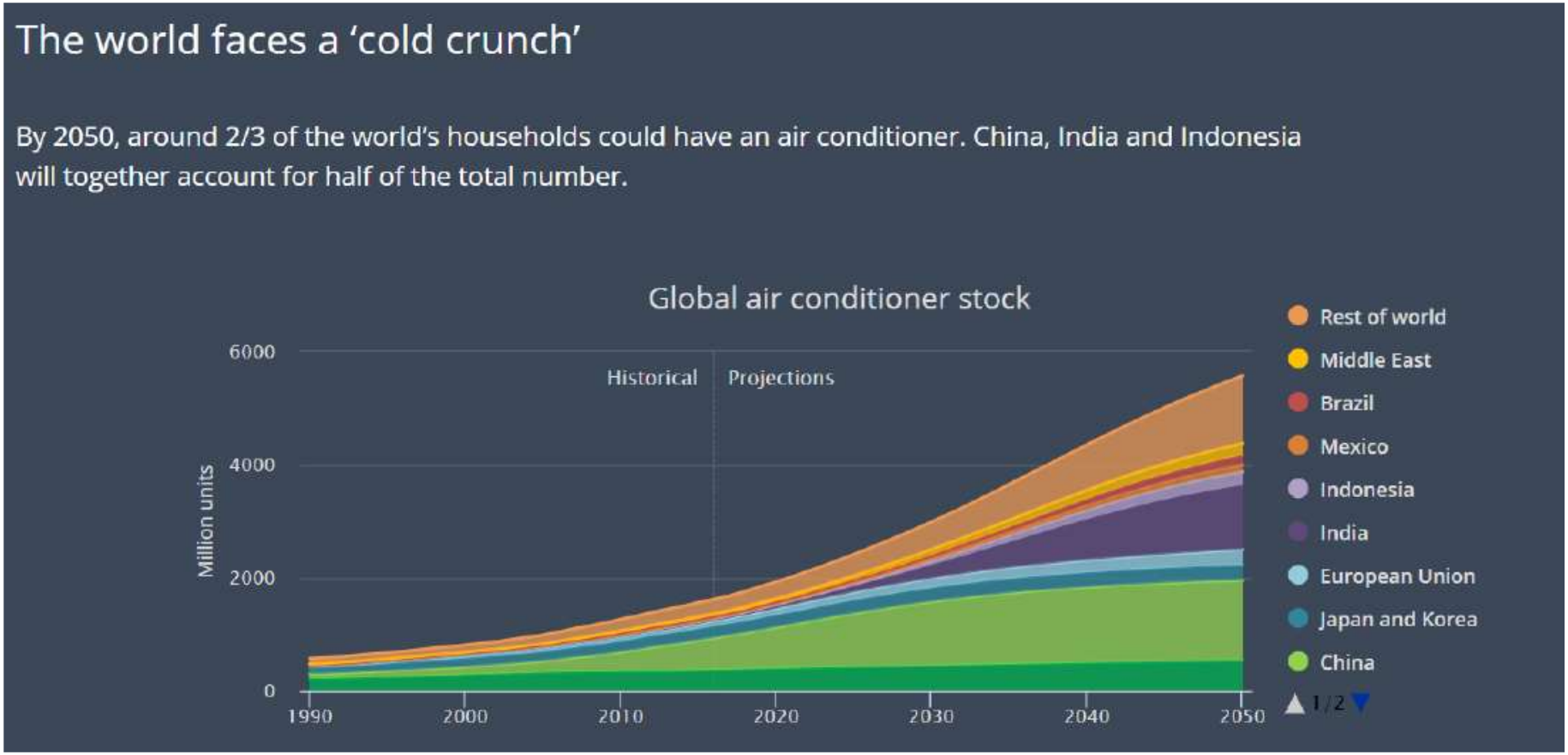
Control of CO_2 *and* HFC emissions needed to stay below 2 degree temperature rise



Source: Hu et al, 2013, Nature Climate Change

Is there a win-win opportunity to reduce *both CO_2 and HFC emissions* in cooling?

The Cooling Challenge and Opportunity



Source: IEA, 2018 "The future of cooling"

Global AC and Room AC stock is estimated to grow significantly from now till 2050 with much of the growth in major emerging economies such as China, India, SE Asia (Indonesia, Vietnam, Thailand).

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?

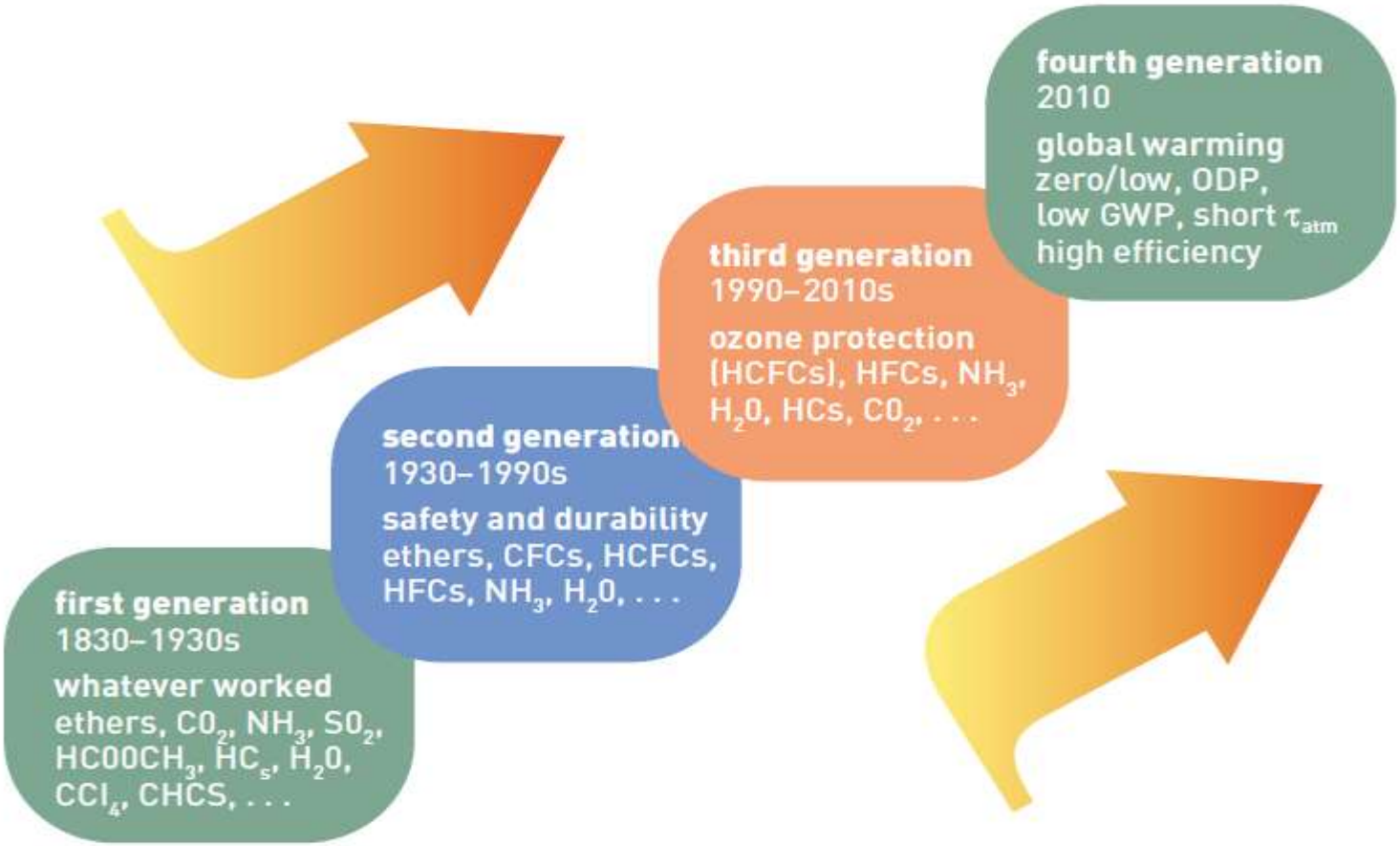
** This implies that just by changing refrigerant in the same equipment, there will be higher (or lower) efficiency. This needs to be accounted for when planning further EE investment, beyond this level.

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

Why Joint Investment in EE and Refrigerant Transition?

- 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)

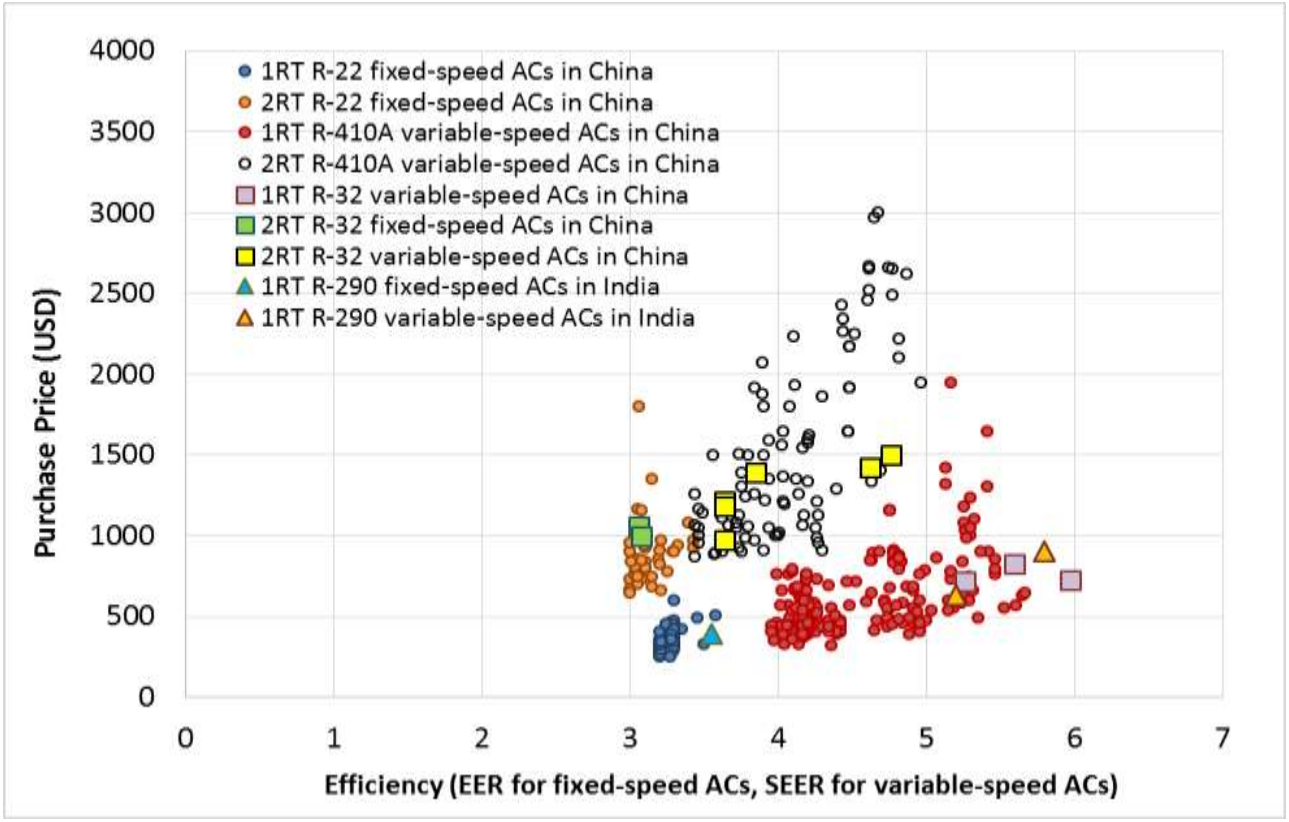
Evolution of Refrigerant Use



Source: Adapted from Calm, *International Journal of Refrigeration*, 2008, http://www.sciencedirect.com/science/article/pii/S0140700708000261

Deliberative draft—Not for distribution

Energy Efficiency vs. Market Price



Source: Park et al. (2017) based on data in the China Energy Label database and Indian market.

- High efficiency is typically a feature of high-end products due to bundling of efficiency with other features. However, highly efficient, cost-competitive RACs are also available.
- Best ACs are 2-3x more efficient than average (in SEER terms) or 50-75% lower energy consumption than average.

Rocky Mountain Institute: Global Cooling Prize

The Prize criteria ensures that the winning RAC works for developing countries, in challenging conditions

Primary criteria used to determine final award

Supplementary criteria used to shortlist finalists

CLIMATE
One-fifth of the life-time climate impact (electricity and refrigerant) of the baseline unit[1]



AFFORDABILITY
At assessed industrial scale, will cost no more than 2x cost of the baseline unit to consumers



POWER
Consumes less than 700W from the grid at rated cooling capacity or during test period



EMISSIONS
Zero onsite emissions from any captive power or heat source



SCALABILITY
Usable in existing homes, no "designed in" solution; less than 2x volumetric size of the baseline unit



OPERATION
Delivers 1.5 TR cooling capacity at standard outdoor conditions and Maintains below 27°C DBT and 60% RH for the duration of the test period



WATER
Consumes less than 14 liters per day onsite for operation



REFRIGERANTS
Zero ODP, lower toxicity, and compliance with safety standards



MATERIALS
Minimal usage of high embodied carbon or rare earth materials



[1] The baseline unit represents the most common RAC product sold in India and is in accordance with the BEE defined ISEER rating for a 3 star AC in 2018. It is equivalent to EER 3.5 of a 5 star AC in 2016-17.

China is the world largest producer (~70%) of the world's room ACs.

U4E model regulations rate fixed speed and variable speed ACs on APF/CSPF adjusted for respective country climate.

U4E model regulations set S&L levels at the draft (see below) issued by China: improves MEPS for fixed-speed ACs by 32-54% and will drive down cost of efficient ACs

Draft China AC S&L for 2020-2022

2010/2013-Present

Variable-speed

GB 21455-2013

Split VSD, Cooling only		1	2	3
CC≤4500	SEER	5.40	5.00	4.30
4500 < CC≤7100	SEER	5.10	4.40	3.90
7100 < CC≤14000	SEER	4.70	4.00	3.50

Fixed-speed

GB12021.3-2010

Split FSD, Cooling only		1	2	3
CC≤4500	EER	3.60	3.40	3.20
4500 < CC≤7100	EER	3.50	3.30	3.10
7100 < CC≤14000	EER	3.40	3.20	3.00

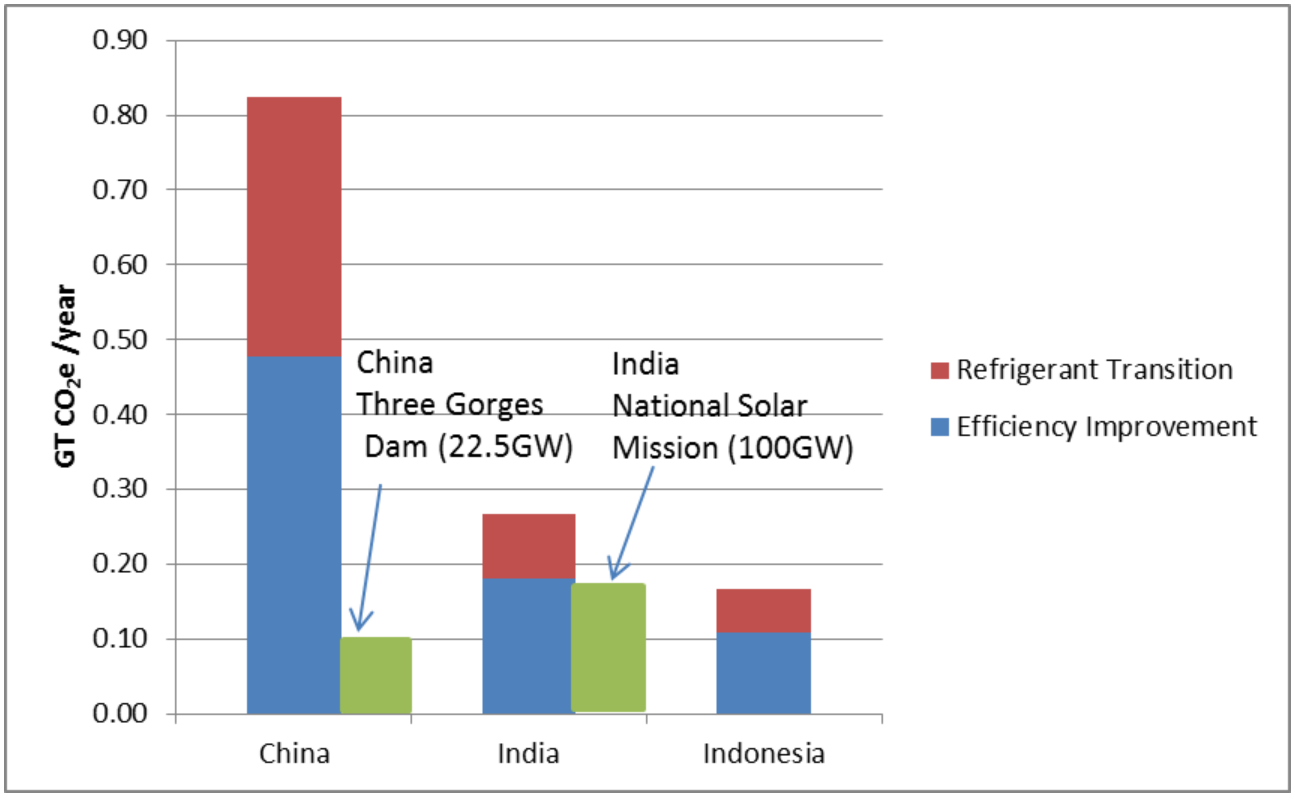
(2020) Proposed MEPS for VSD
13-16% improvement

(2022) 32-54% improvement

(2020) The proposed Grade 1 requirements are more stringent by 7-11% than the current VSD Grade 1 requirements.

	1	2	3
SEER	5.80	5.40	5.00
SEER	5.50	5.10	4.40
SEER	5.20	4.70	4.00

Annual GHG Impact of AC policies in 2030



Source: Shah et al, 2015

- Transformation of the AC industry to 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 0.32 GT/year annually in India, roughly **twice India's solar mission.**
- 30% efficiency improvement in parallel with refrigerant transition could save ~1000 -2500 peak load power plants in 2030.