International Scenario on Emerging Refrigerants and Energy Efficiency

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1989-2013: Co-Chair & Senior Expert Member,

Montreal Protocol Technology & Economic Assessment Panel (TEAP)

1986-2009: Director of Strategic Climate Projects

United States Environmental Protection Agency

Global Refrigerant Challenge

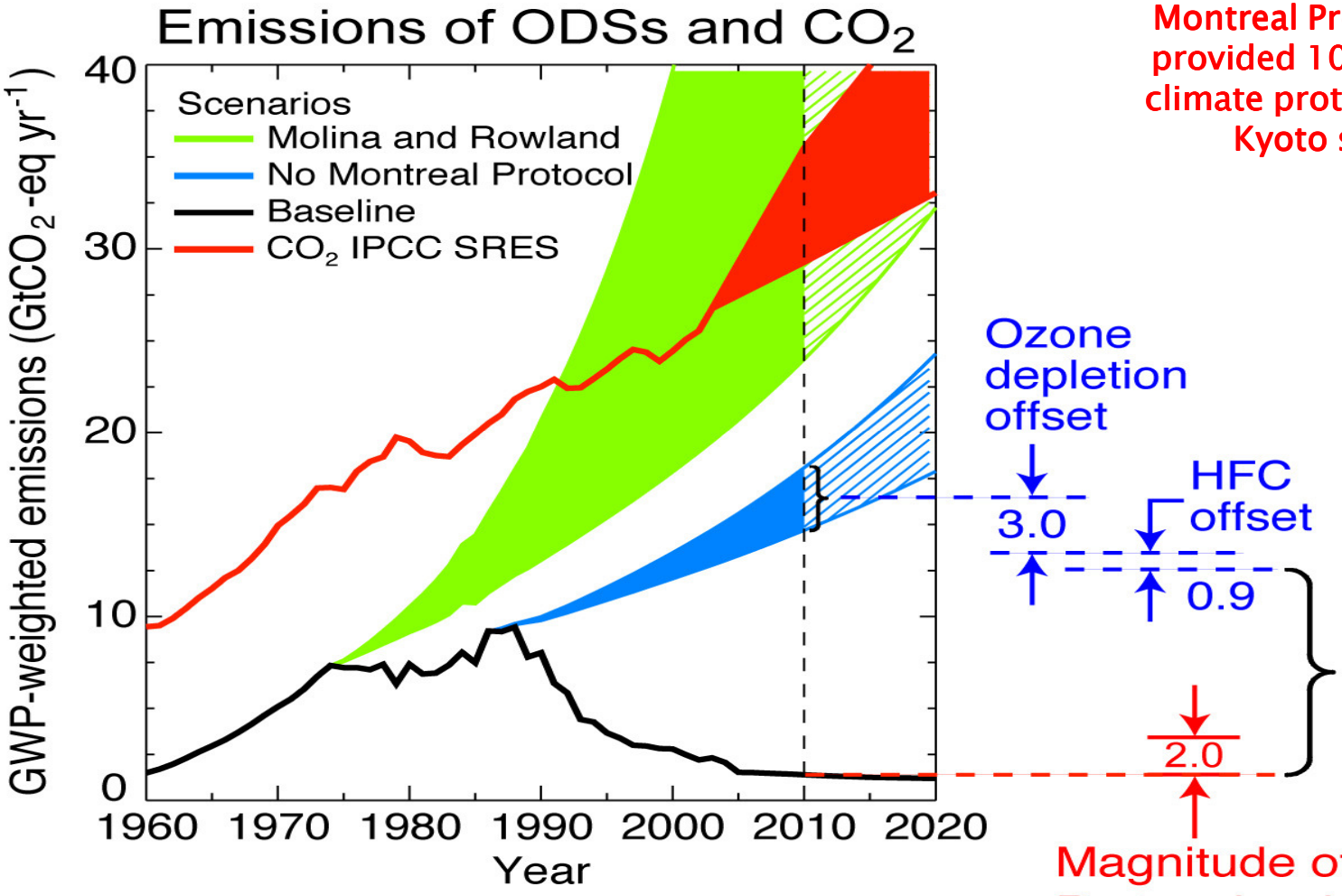
- Climate Change Coming Faster than Expected
- Climate Change Can Only Make Life Worse
- Long, Hot, and Sometimes Humid Cooling Seasons
- “Brown-outs” and Electricity Reliability Problems
- High Energy Cost; Low Equipment Durability
- Chemical Nomenclature is an Unreliable Indicator of Environmental Performance
- How Can Cooperation and Innovation Responsibly Serve Indian and Export Markets with Sustainable Technology?

Montreal Phaseout Just-in-Time

- ✓ 1974: Molina/Rowland sounded the Ozone Alarm; Consumer boycotts of CFC aerosol cosmetics stalls CFC growth
- ✓ 1987: Montreal Protocol agreed; people & technology saves the ozone layer!
- ✓ 2007: Scientists document extraordinary climate benefits of ODS phaseout; HCFC phaseout accelerated
- ✓ 2009: Scientists document extraordinary opportunity to phase-down HFCs
- ✓ Today: Montreal Protocol HFC Amendment

  Just in Time, or Just a Little Too Late

Montreal Protocol Protects Climate!



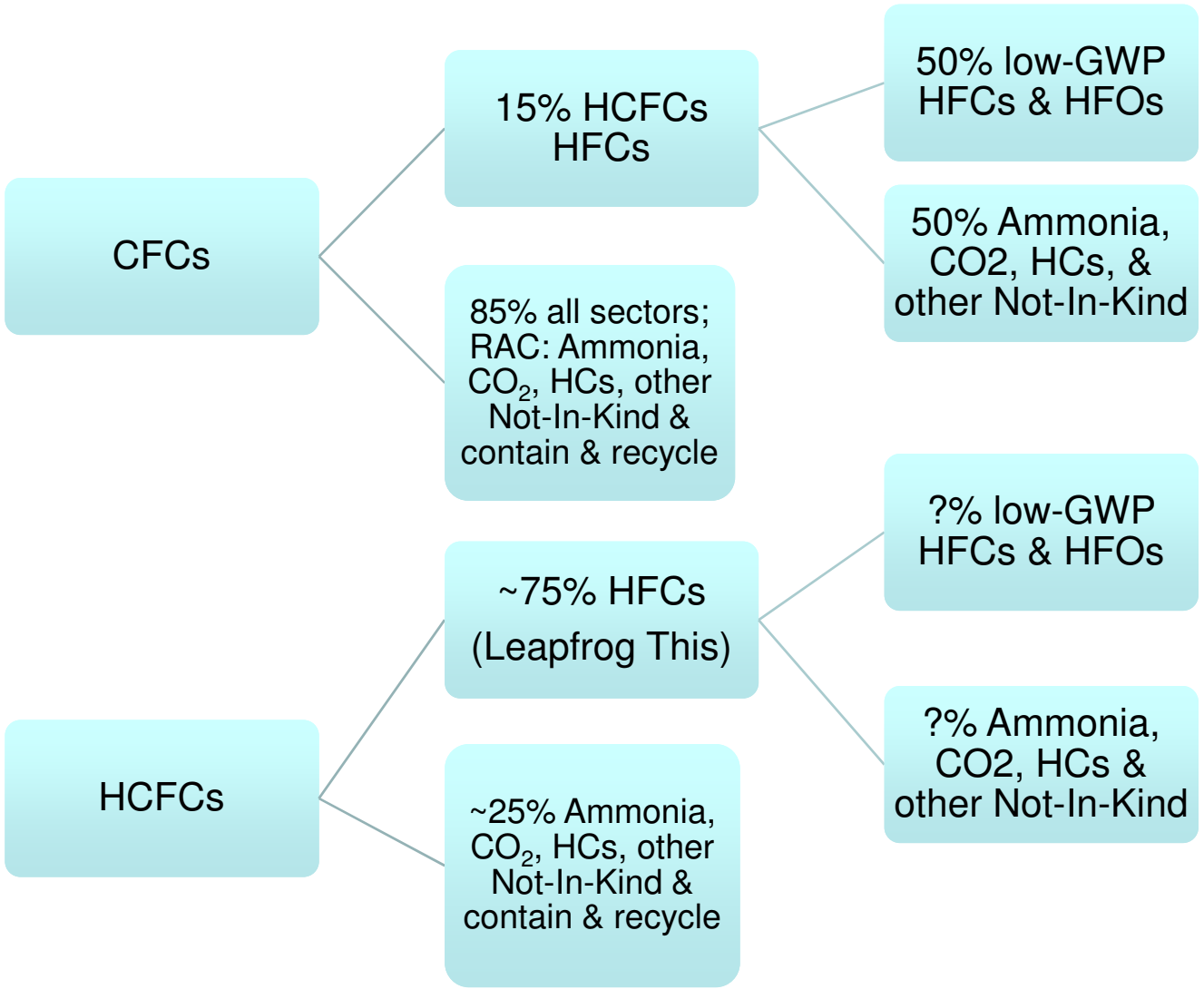
Montreal Protocol has provided 10-11 times climate protection that Kyoto seeks

From: Velders Guus J. M., Stephen O. Andersen, John S. Daniel, David W. Fahey, and Mack McFarland, *The importance of the Montreal Protocol in protecting climate;* Proceedings of the National Academy of Sciences, published online Mar 8, 2007.

HCFC and HFC Transition Substances Saved the Planet!

- The rush to protect the ozone layer required transitional use of unsustainable chemicals
- The world owes the refrigeration and AC industry a debt of gratitude and is asking you to carry on with innovation until the world is safe for future generations
- Indian industry is vital for success because so many people are gaining first access to refrigeration and AC
- Now is the time: Leapfrog high-GWP HFCs!

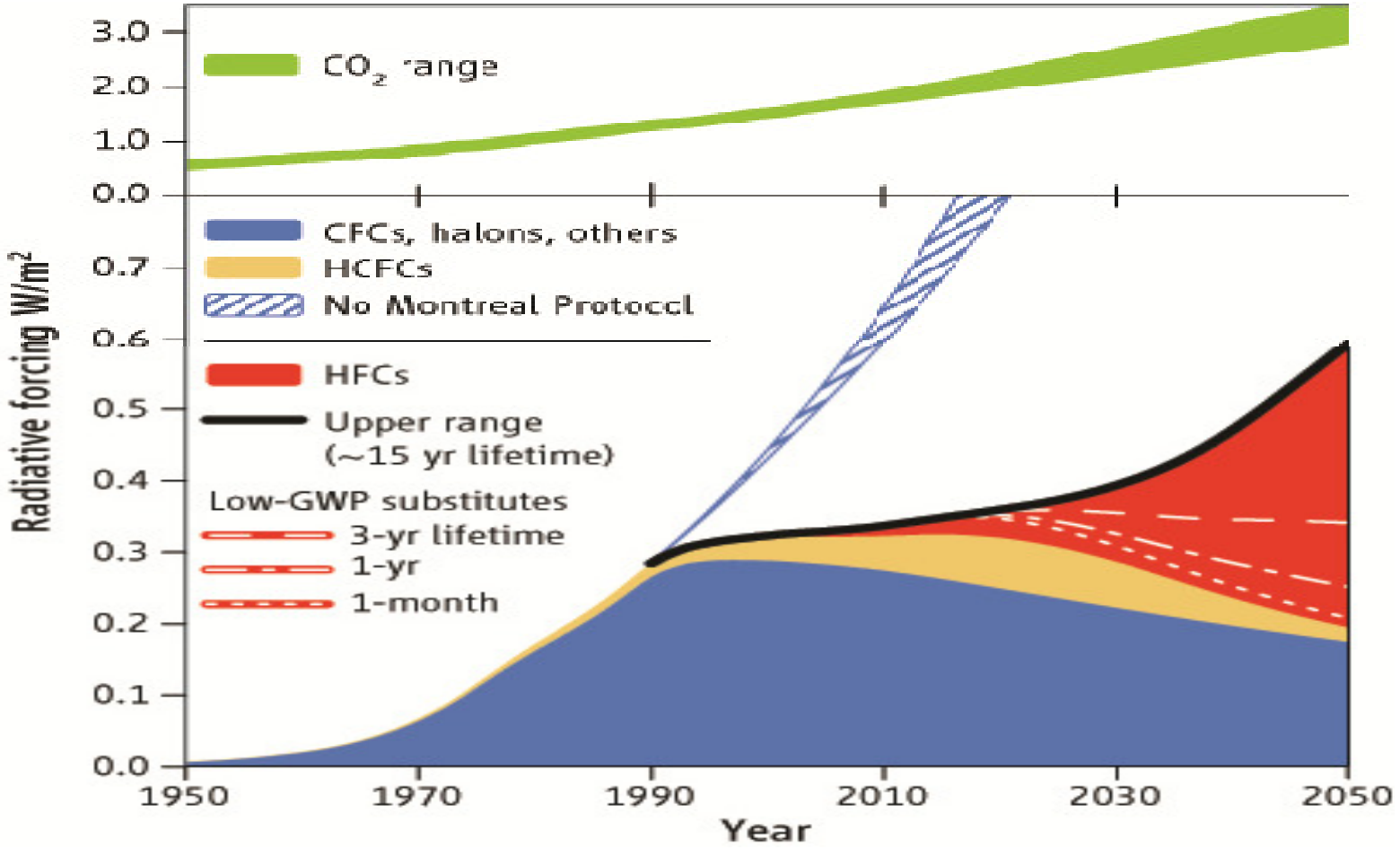
First, Second, & Third Transition



The Importance of Refrigeration & Air Conditioning Engineers

- Ozone protection achieved with familiar chemistry and mild product redesign
- Climate protection requires break-through chemistry, radical redesign, and load reduction
- Innovation is rewarded with profits and satisfaction from helping make the world safe for future generations
- India is prepared with education, centers of engineering excellence, global networks and innovative companies already with head-start

Low-GWP Substitutes Delay Irreversible Climate Change



Guus J. M. Velders, A. R. Ravishankara, Melanie K. Miller, Mario J. Molina, Joseph Alcamo, John S. Daniel, David W. Fahey, Stephen A. Montzka, & Stefan Reimann, Preserving Montreal Protocol: Climate Benefits by Limiting HFCs, Science, 24 February, 2012, Vol. 335, pp 922-23.

Advantages of HFC Controls Under The Montreal Protocol

- ✓ Every country is a Party to Montreal Protocol
- ✓ Ozone Units in 145+ developing parties
- ✓ Regional Networks worldwide
- ✓ Experience, confidence, trust & community
- ✓ TEAP assessments by industry experts
- ✓ Non-A5 phase-down motivates technology
- ✓ Grace Period for confident technology choice
- ✓ Multilateral Fund (MLF) finances A5 controls
- ✓ Essential Use Exemptions, if needed

BAU Scenario: Waiting for Kyoto

- Developed countries and China phase-down HFCs and prohibit manufacture and import
- Daikin, Godrej and other leadership companies increase market shares with superior energy efficiency
- Overseas joint venture partners dump obsolete HFC technology then switch quickly to next-generation technology
- India left with orphan technology / unreliable infrastructure / mismatched chemical supply

Industry-Friendly Amendment Scenario

- New funding to merge HCFC phaseout and HFC phase-down management plans and to align energy efficiency labeling upgrades
- Adjust the HCFC phaseout to allow time to leapfrog HFCs (yes, longer on HCFC-22)
- Include a long HFC grace period, but with ample financing immediately available to companies ready to leapfrog HFCs with maximum energy efficiency

An Industry-Friendly Amendment Can be Climate & Ozone Friendly

- The delay in an A5 HCFC-22 RAC phaseout can be be followed by a more rapid transition
- The climate benefits grow considerably because low-GWP refrigerants avoid HFC-410a
- Developed countries could offset any net ozone depletion by accelerating their own HCFC phaseout or by destruction of ODSs

“We must be the change
we wish to see in the world”

~ Mahatma Gandhi ~

Engineers, Environmental Authorities, and Montreal Protocol Agents Can be Pathfinders in Making the World Safe For Future Generations!

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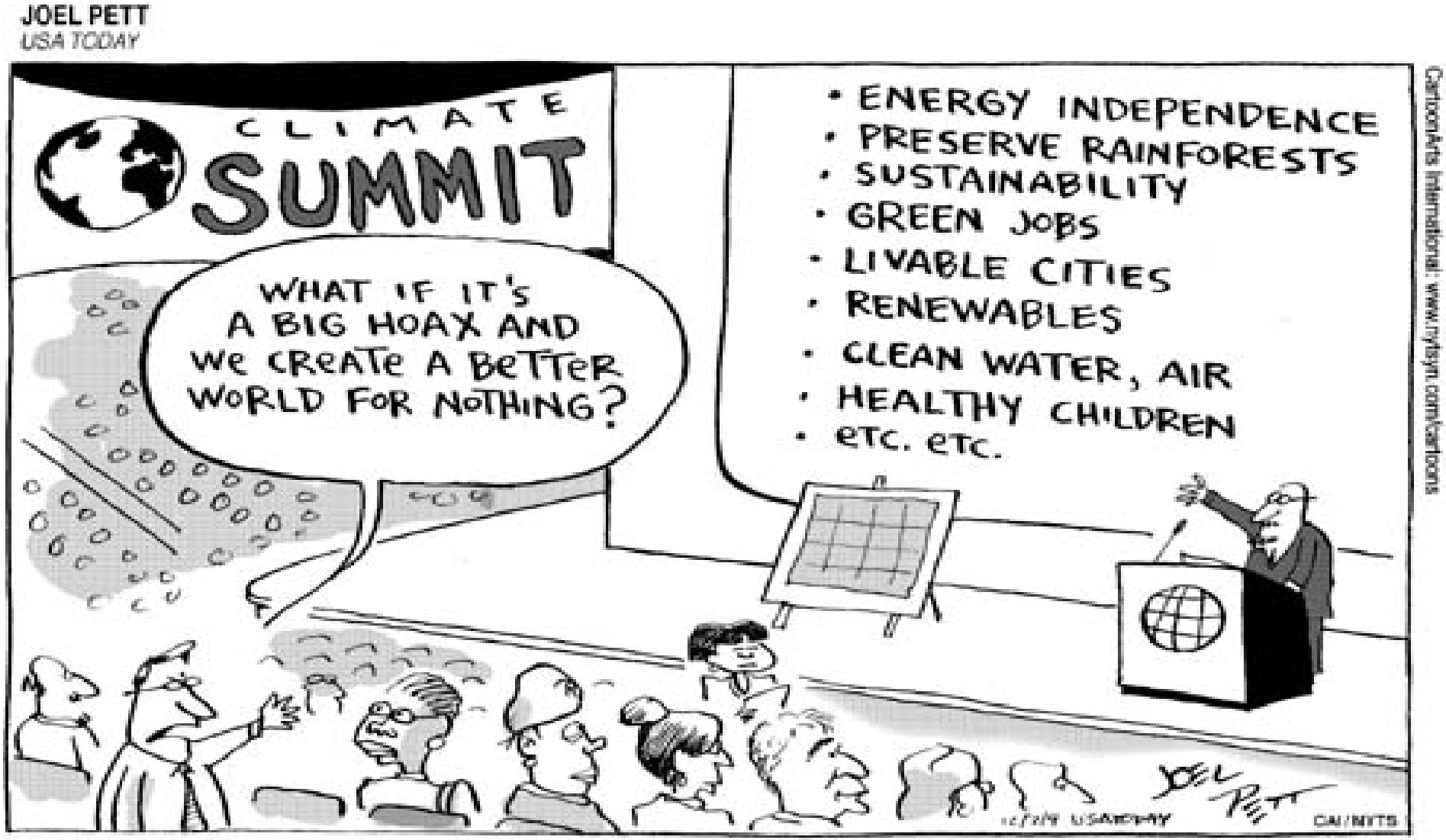
Any Questions for Dr. Andersen?



Backup Slides

New Thinking on Refrigerants

- Select the Safe Refrigerant with Superior LCCP
- Manage Refrigerant Emissions to the Lowest Practical Life-Cycle Level
- Offset ODP of HCFC Refrigerants to be “Chlorine Neutral”
- Offset GWP of all Refrigerants to be “Carbon Neutral”
- Design and Operate Equipment to Maximize LCCP

The EC Defines “Low-GWP”

- GWP <150
  - Household Refrigerators and Freezers by 2015
  - MACs by 2017
  - Technical Aerosol Products by 2018
  - Extruded Polystyrene by 2020
  - Commercial Refrigeration by 2022 (<2500 from 2020 to 2022)
  - Other Foams by from 2023
- GWP <750
  - Room AC with <3kg charge by 2025
- Foam/Aerosol Product Safety Exemptions

Indicative Low-GWP Refrigerants

Substance	ODP	<1-Month Lifetime	~1-Year Lifetime	3-5 Years Lifetime
HFO-1234yf	0	GWP ~ 0		
HC-290		GWP ~ 3		
HCFC-123	0.02		GWP = 79	
HFC-152a	0		GWP =138	
HFC-32	0			GWP = 677
HFC-32 (new blends)	0			GWP < 350

ODP Source: 2010 Montreal Protocol Scientific Assessment Panel (SAP will be updated in 2014)

GWP Source: 2014 Intergovernmental Panel on Climate Change (AR-5)

Unpatented Room A/C Choices

Substance	GWP	Component(s)	AC Product Cost relative to HCFC-22	Efficiency
HCFC-22	1760	Single	Status Quo	High
HFC-410a	1654 Adjusted to ~ 1604	HFC-125/-32 Azeotrope	Higher	Lower
HC-290	~3	Single	Lower	High
HFC-32	~677 Adjusted to ~ 474	Single	Lower	High

GWP from IPCC AR-5; HFC-32 adjusted for smaller charge size (HFC-410a is 97% and HFC-32 is 70% of the HCFC-22 charge size, respectively)

Proprietary Room A/C Choices

Manufacturer	Name	Component(s)	GWP/Flammability
DuPont	DR-91	?	~940 / not flammable (A1)
DuPont	DR-5a	?	460 / mildly flammable (A-2L)
Honeywell	N-20	HFO	1000/not flammable (A1)
Honeywell	L-20	?	<300/mildly flammable (A-2L)
Honeywell	L-41	HFO	<600/mildly flammable (A-2L)
Arkema	ARM-32c	HFO	<1400/mildly flammable (A-2L)
Coming Soon	Various	HFO/HFC	<350/mildly flammable (A-2L)

GWP Source: IPCC AR4; blends not easily updated to AR5 due to confidentiality

Common Sense

- HFC-410a is Obsolete & Unwanted
- Factory Cost is Paid by Multilateral Fund
  - Insist on investment suitable for any likely refrigerant (high pressure and high flammability)
- Consider Flexible Manufacture
  - Design your product and manufacturing plant to welcome technical progress on refrigerants
- Communicate to Policy Makers the Importance of Transition from HCFC-22 to an Energy Efficient Low-GWP Refrigerant

2014: Clear & Sustainable LCCP Technical Choices

- HCs for household refrigerators/freezers, stand-alone retail refrigerators/freezers, and small room air conditioners
- HCs, CO_2 and ammonia for supermarket refrigeration (driven by Consumer Goods Forum Pledge and supermarket industry leadership)
- HFC-32 for larger room air conditioners where HC-290 is unsafe or not yet allowed; HFOs and HFC/HFO blends are promising
- HFC-1234yf or HFC-152a for automobile AC and other HFC-134a applications where natural refrigerants have inferior LCCP
- HCFC-123 for building air conditioning chillers until a better safe and energy efficient refrigerant is available

2014 Clear Room A/C Choice: HFC-32

- Daikin Sales in Japan: 2.2 to 8.0 kW
  - 1+ million sold
- Daikin Sales in India: 2.2 to 7.1 kW
  - 30+ million sold
- Mitsubishi, Hitachi, Panasonic, Fujitsu & Sharp have announced 2014 HFC-32 Room AC launches in Japan
- Projects underway in China, Indonesia, Thailand, and elsewhere

2014 Clear Room A/C Choice: HC-290

- Godrej sales in India: 3.3 & 5.0 kW (40K+ sold)
- Gree sales in Australia and Maldives
- UNIDO reports 18 RAC production lines and 5 compressor lines in China converting to R-290 with capacity for >6 million units/year

2014 Clear Automobile A/C Choice: HFO-1234yf

- Global choice in MACs (except Daimler et al.)
- Honeywell claims an application patent, challenged by competitors
- At least five companies with production process patents
- GWP <1; comparable to HC's GWP If produced without HCFC-22 feedstock or if all HFC-23 is destroyed
- Kyoto will control emissions HFC; but GWP <1 avoids regulatory impact
- Low toxicity and nearly non-flammable in practice
- Secondary-Loop design would reduce refrigerant charge, cost and leakage and increase energy efficiency and reliability

Emerging Automobile A/C Choice: HFC-152a

- Global automakers second choice in MACs
- No manufacturing or application patents and competitively priced at less than half the price of HFC-134a,
- GWP=138; No TFA atmospheric decomposition
- Kyoto will control emissions HFC, but low GWP avoids regulatory impact
- Low toxicity and easy leak detection
- Secondary-Loop design required for fire safety reduces refrigerant charge, cost and leakage and increase energy efficiency and reliability

2014: Clear Building A/C Chiller Choice: HCFC-123

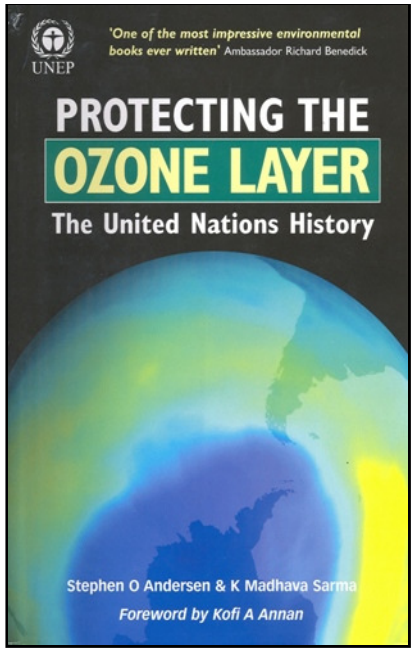
- Fully commercialized and competitive price
- Low-ODP, low-GWP, low toxicity and non-flammable
- Highest available energy efficiency
- Kyoto Protocol does not control HCFCs
- Montreal Protocol controls production & consumption
  - Prolonged phaseout for service until at least 2040
  - Indefinite use of ODSs produced prior to phaseout
  - New production allowed if offset by destruction
  - Essential Use Exemption typically authorized in anticipation of phaseout
- HFO-1234ze and HF)1233zd(E) are promising

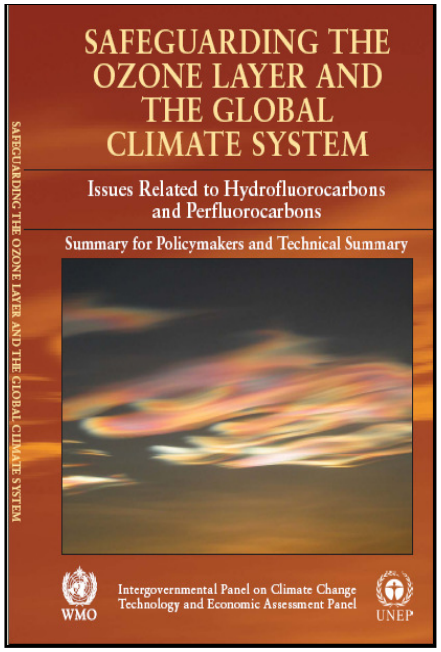
Important UNEDO News

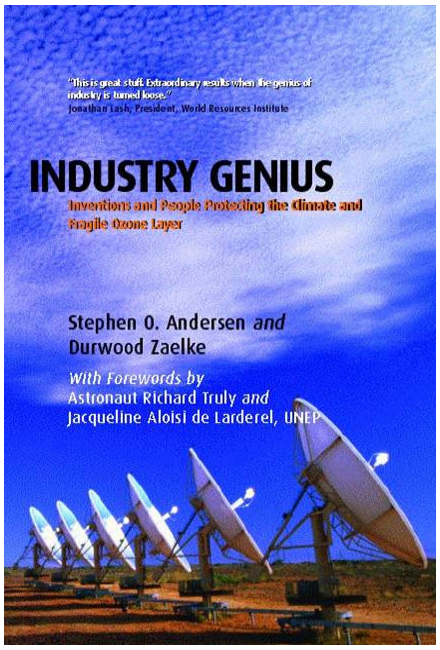
- UNIDO/UNEP will 3rd party test the energy efficiency of HC, HFC-32 and HFO Room A/Cs optimized by advocates for high-ambient temperatures
  - Promoting Low-GWP Refrigerants for the Air Conditioning Sector in High Ambient Countries (PRAHA) – sponsored by MLF
  - Ole Reinholdt Nielsen: O.Nielsen@unido.org

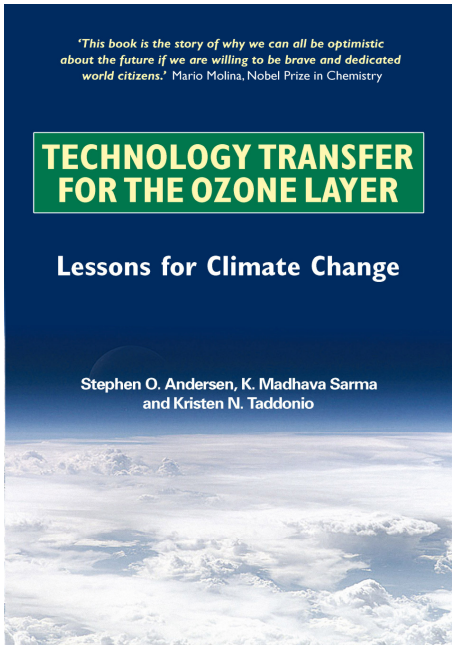
Important AHRI News

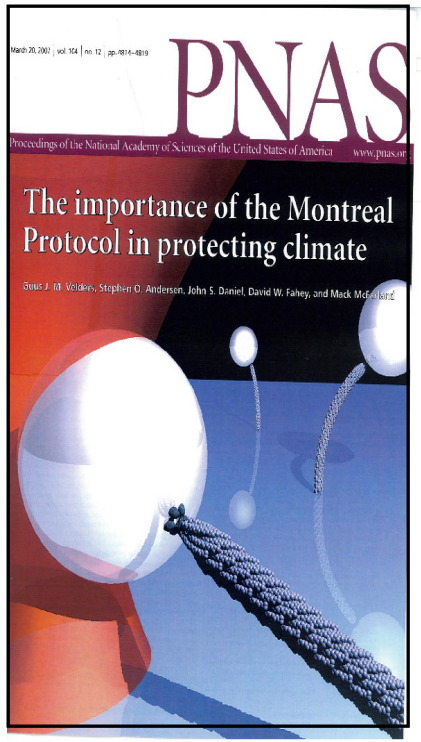
- Very low risk of HFC-32, HFO-1234yf or HFO-1234ze in ducted residential heat pumps
  - www.ahrinet.org/technical+results.aspx
- Design of AC/HP systems using ammonia, carbon dioxide, hydrocarbons, and HFO-1234yf to satisfy previously defined safety requirements
  - http://www.ahrinet.org/App_Content/ahri/files/RESEARCH/Technical %20Results/AHRI-8006%20Final%20Report.pdf

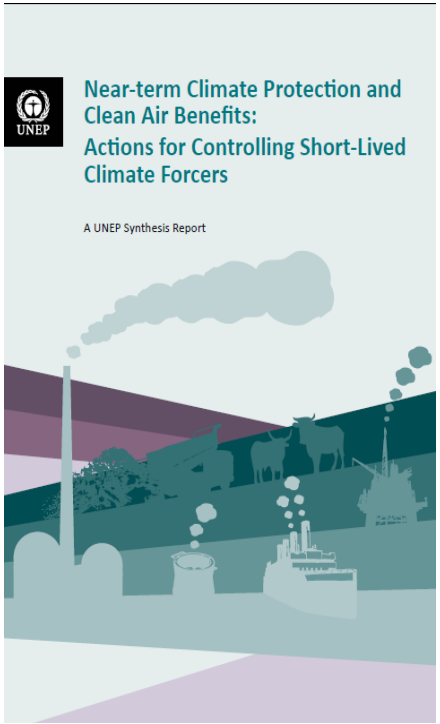

UNEP
'One of the most impressive environmental books ever written' Ambassador Richard Benedick
PROTECTING THE
OZONE LAYER
The United Nations History
Stephen O Andersen & K Madhava Sarma
Foreword by Kofi A Annan


SAFEGUARDING THE OZONE LAYER AND THE GLOBAL CLIMATE SYSTEM
Issues Related to Hydrofluorocarbons and Perfluorocarbons
Summary for Policymakers and Technical Summary
SAFEGUARDING THE OZONE LAYER AND THE GLOBAL CLIMATE SYSTEM
WMO
Intergovernmental Panel on Climate Change
Technology and Economic Assessment Panel
UNEP

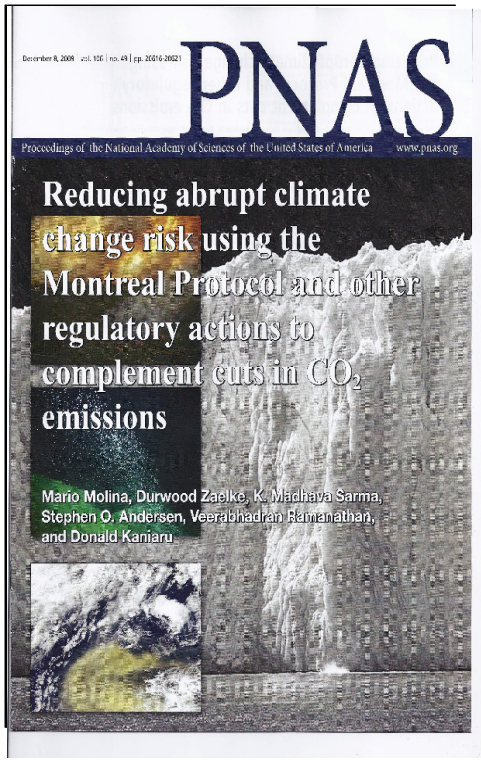

"This is great stuff. Extraordinary results when the genius of industry is turned loose."
Jonathan Lash, President, World Resources Institute
INDUSTRY GENIUS
Inventions and People Protecting the Climate and Fragile Ozone Layer
Stephen O. Andersen and
Durwood Zaelke
With Forewords by
Astronaut Richard Truly and
Jacqueline Aloisi de Larderel, UNEP

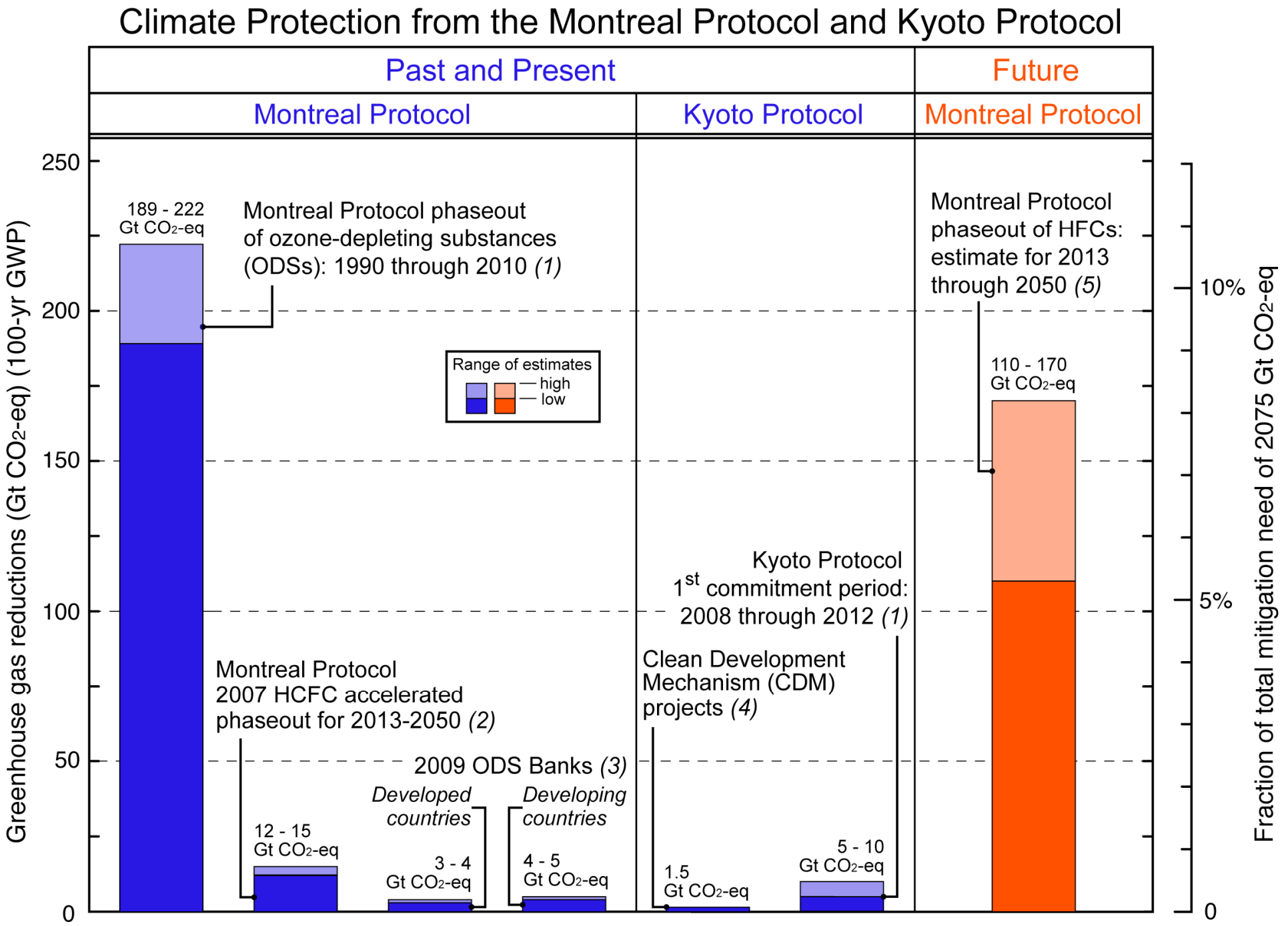

'This book is the story of why we can all be optimistic about the future if we are willing to be brave and dedicated world citizens.' Mario Molina, Nobel Prize in Chemistry
TECHNOLOGY TRANSFER FOR THE OZONE LAYER
Lessons for Climate Change
Stephen O. Andersen, K. Madhava Sarma
and Kristen N. Taddonio


PNAS
Proceedings of the National Academy of Sciences of the United States of America
The importance of the Montreal Protocol in protecting climate


UNEP
Near-term Climate Protection and Clean Air Benefits:
Actions for Controlling Short-Lived Climate Forcers
A UNEP Synthesis Report

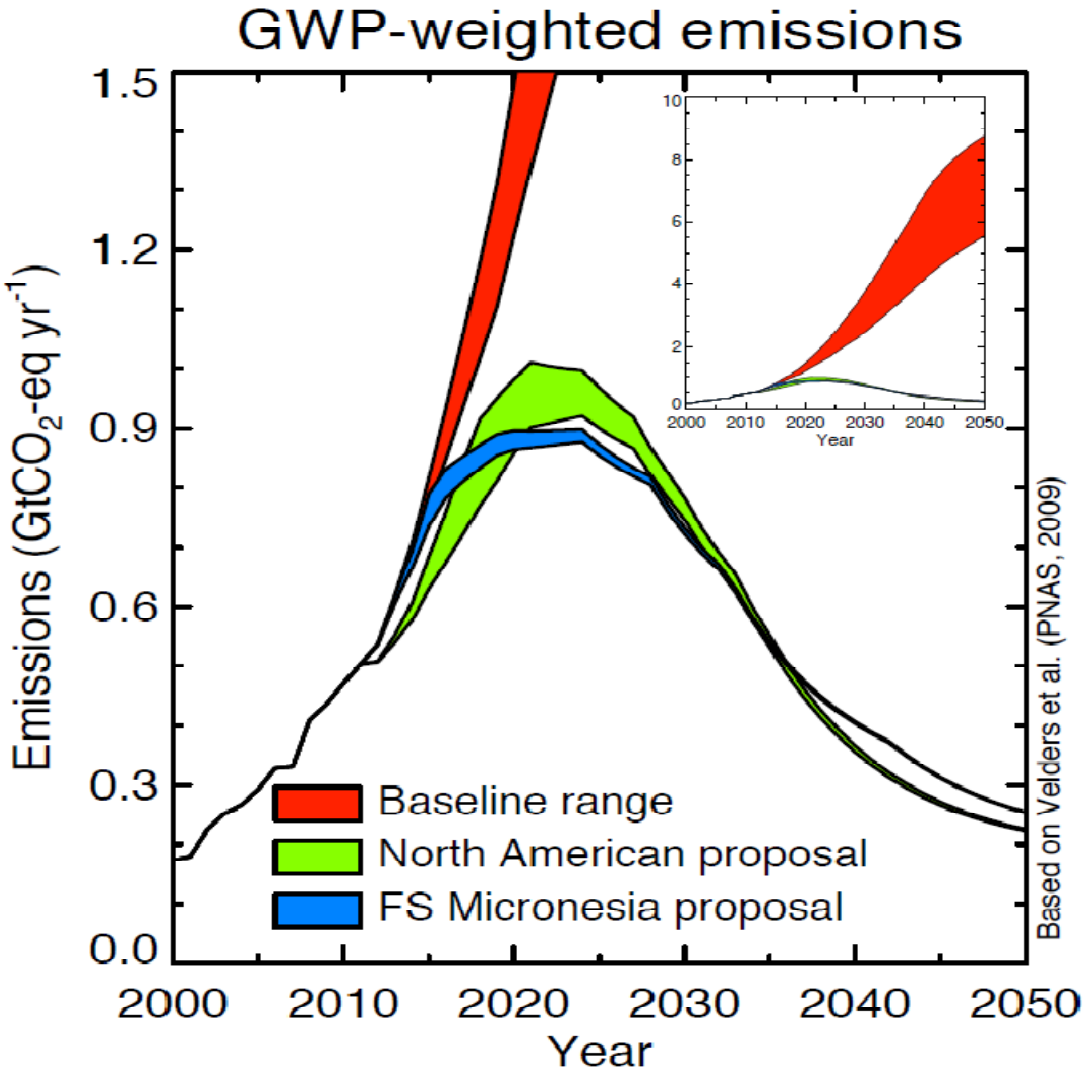

PNAS
Proceedings of the National Academy of Sciences of the United States of America
The large contribution of projected HFC emissions to future climate forcing


PNAS
Proceedings of the National Academy of Sciences of the United States of America
Reducing abrupt climate change risk using the Montreal Protocol and other regulatory actions to complement cuts in CO_2 emissions
Mario Molina, Durwood Zaelke, K. Madhava Sarma, Stephen O. Andersen, Veerabhadran Ramanathan, and Donald Kaniaru


Climate Protection from the Montreal Protocol and Kyoto Protocol
Past and Present
Future
Montreal Protocol
Kyoto Protocol
Montreal Protocol
Greenhouse gas reductions (Gt CO2-eq) (100-yr GWP)
Fraction of total mitigation need of 2075 Gt CO2-eq
250
200
150
100
50
0
10%
5%
0
189 - 222 Gt CO2-eq
Montreal Protocol phaseout of ozone-depleting substances (ODSs): 1990 through 2010 (1)
Range of estimates
high
low
Montreal Protocol phaseout of HFCs: estimate for 2013 through 2050 (5)
110 - 170 Gt CO2-eq
Kyoto Protocol 1st commitment period: 2008 through 2012 (1)
Clean Development Mechanism (CDM) projects (4)
Montreal Protocol 2007 HCFC accelerated phaseout for 2013-2050 (2)
2009 ODS Banks (3)
Developed countries
Developing countries
12 - 15 Gt CO2-eq
3 - 4 Gt CO2-eq
4 - 5 Gt CO2-eq
1.5 Gt CO2-eq
5 - 10 Gt CO2-eq

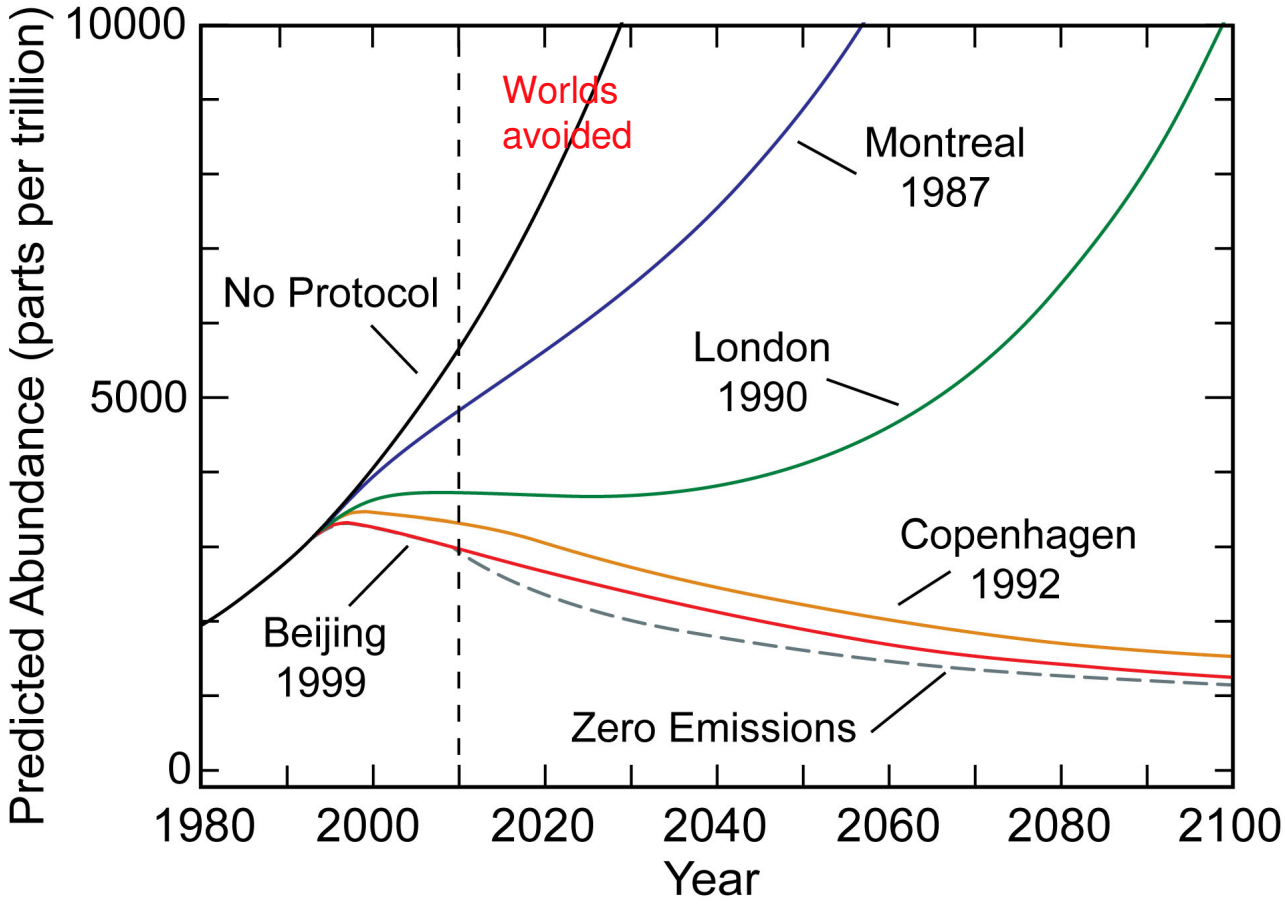
North American & Micronesian

Proposals for Montreal Protocol to Control HFCs



The Montreal Protocol and its Amendments & Adjustments Saved the Ozone Layer

Total ODS abundance

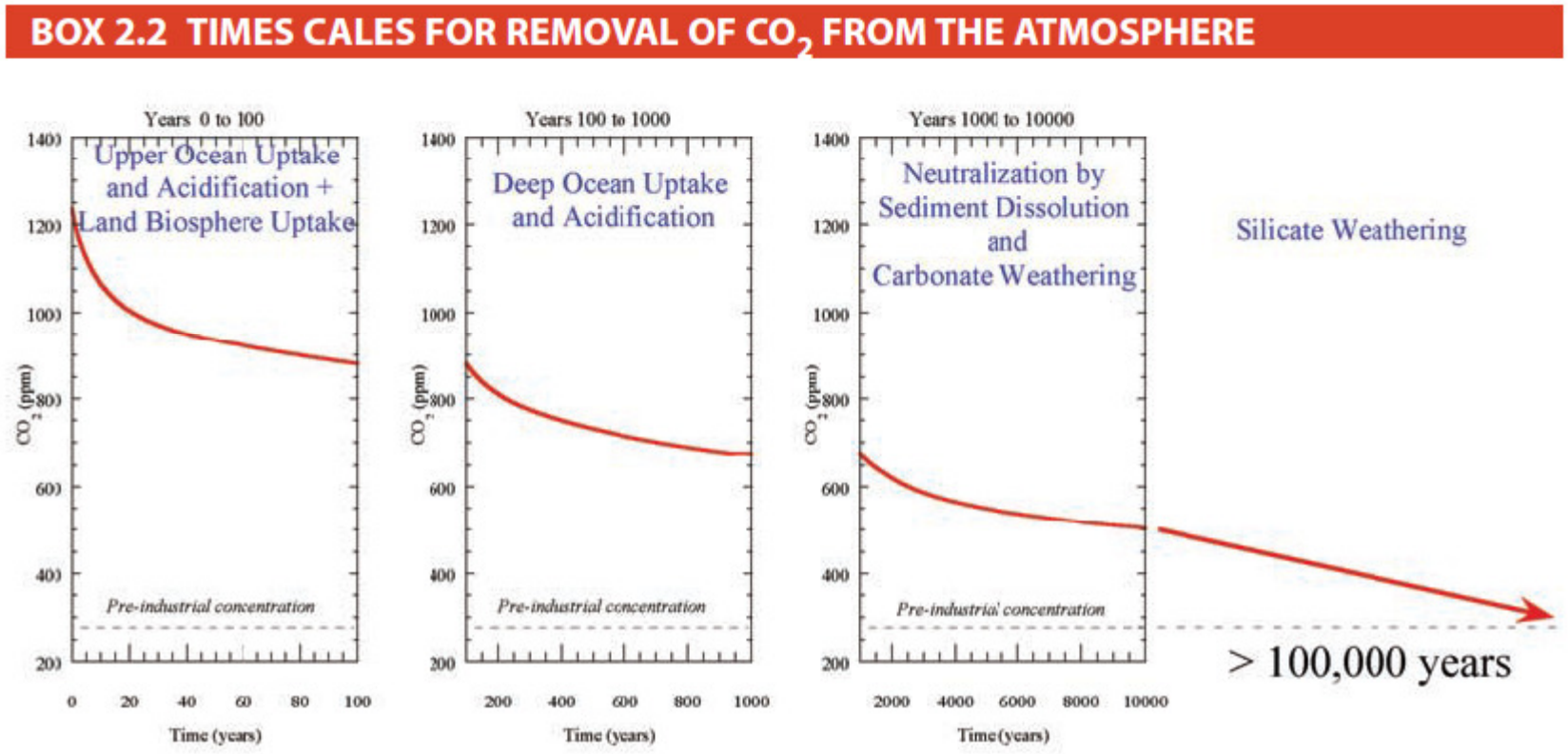


> The Montreal Protocol reduced global ODS production and consumption in developed and developing nations

(*Vienna Convention for the Protection of the Ozone Layer* signed 22 March 1985, *Montreal Protocol on Substances that Deplete the Ozone Layer* signed 16 September 1987; Vienna Convention and Montreal Protocol entered into force 1 January 1989)

UNEP/WMO Ozone Assessment, 2006

Timeline for Removal CO2



CO_2 Controls Are Not Enough

IPCC (AR4 2007):

While more than half of the CO_2 emitted is currently removed from the atmosphere within a century, some fraction (about 20%) of emitted CO2 remains in the atmosphere for many millennia.

Solomon, et al. (PNAS 2009):

"Climate change that takes place due to increases in carbon dioxide concentrations is largely irreversible for 1,000 years after emissions stop."

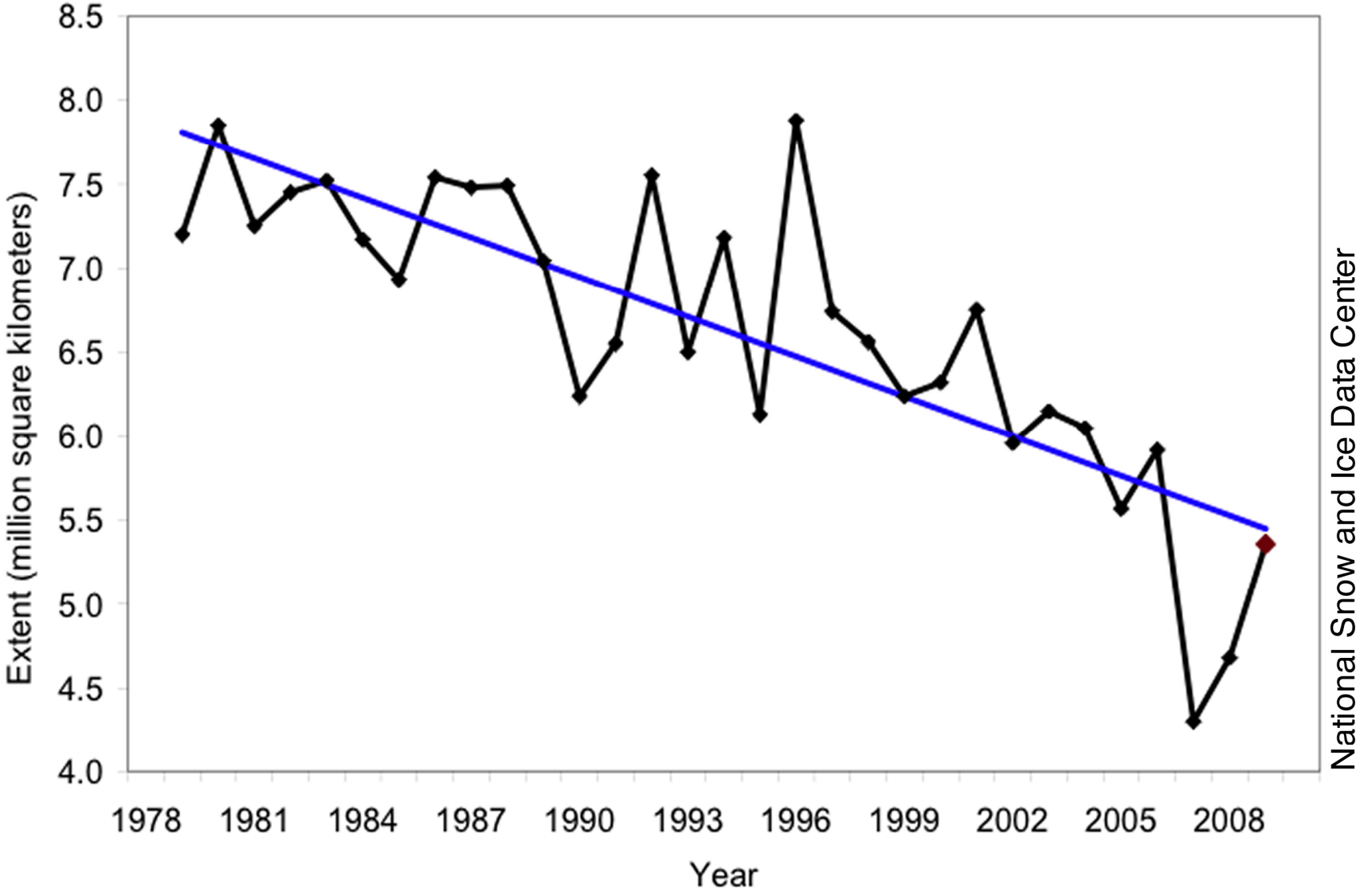
Ramanathan & Feng (PNAS 2008):

"*Even the most aggressive CO_2 mitigation steps … can only limit further additions to the committed warming, but not reduce the already committed GHGs warming of 2.4° C.*"

IPCC (AR5 2014)

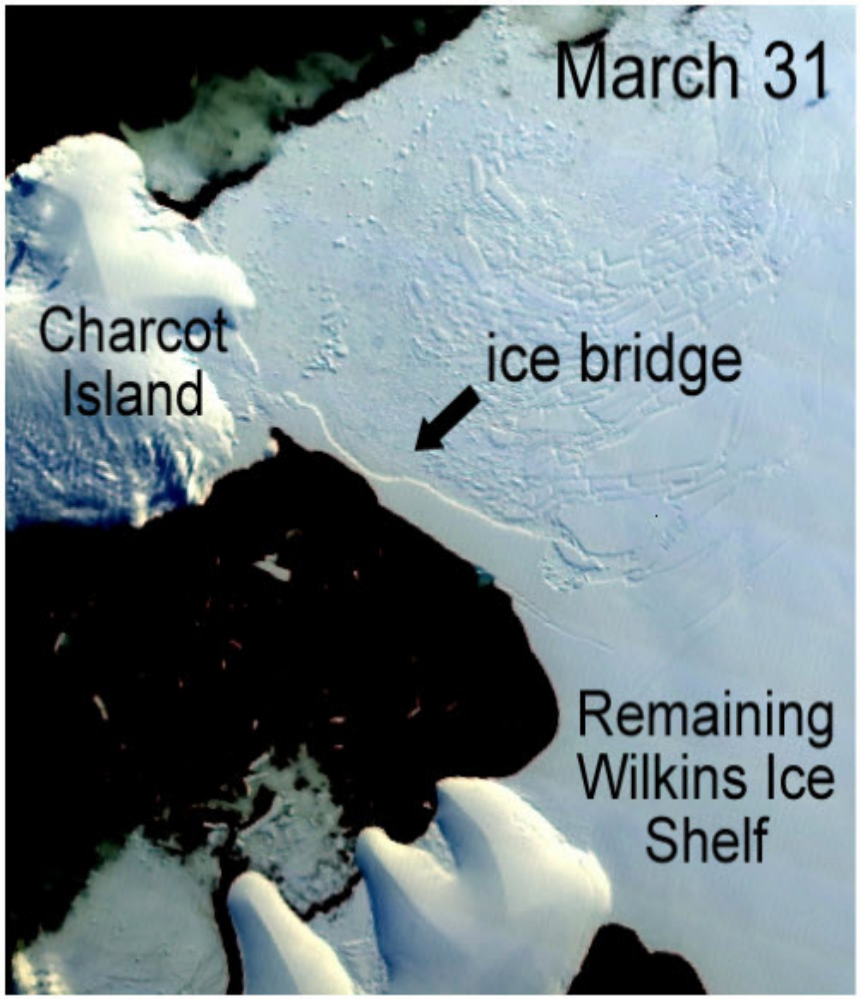
Unequivocal that human activities have substantially increased climate change, action now or suffer consequences

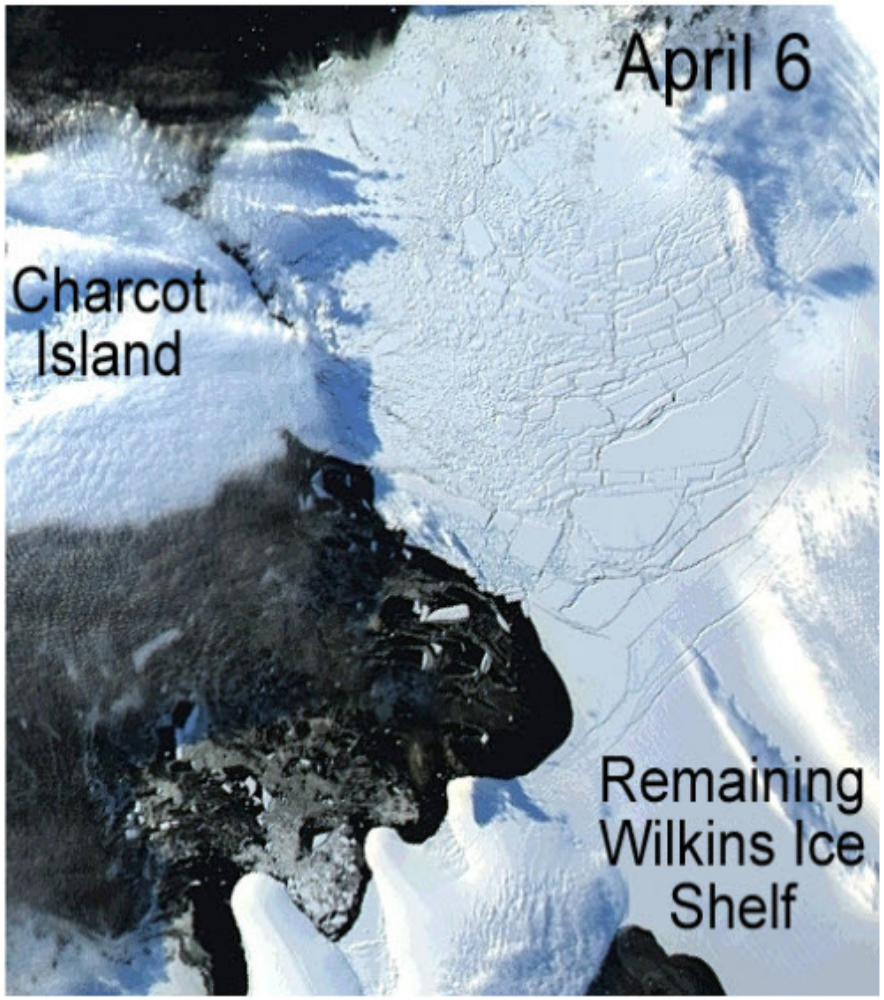
Average Monthly Arctic Sea Ice Extent
September 1979 to 2009



BACK

Antarctic Ice Bridge Collapse

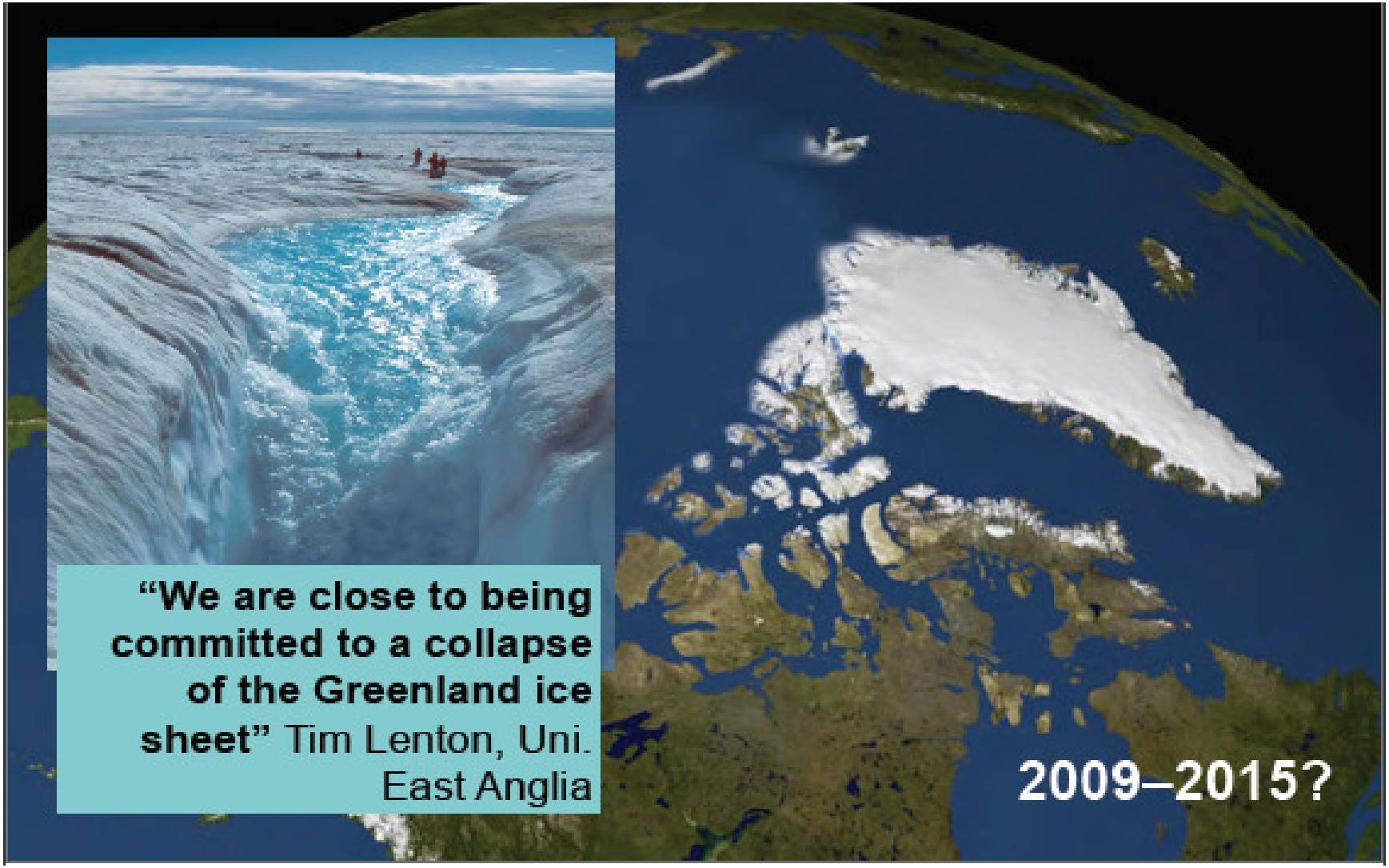




2009

BACK

Greenland Ice Sheet

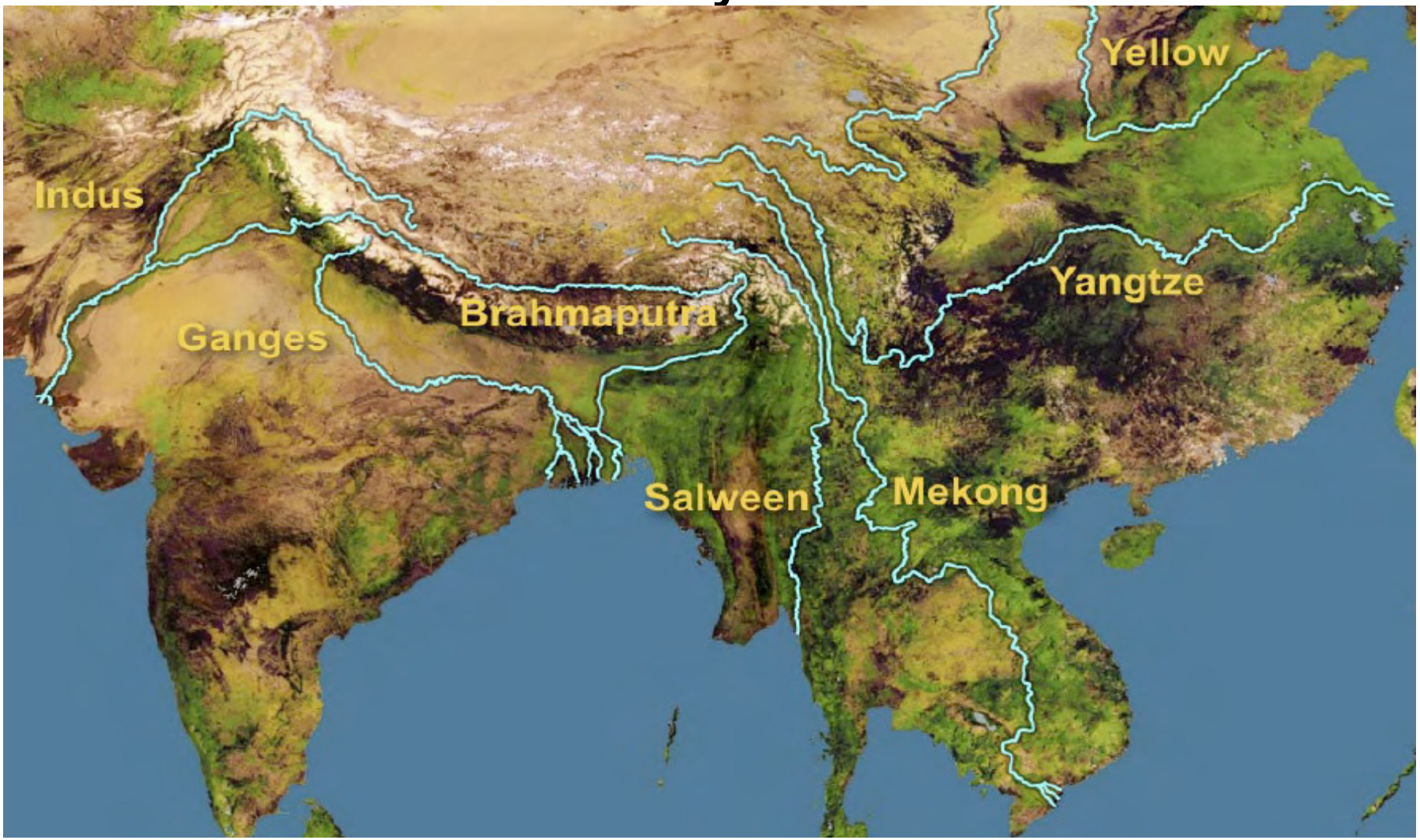


BACK

Hindu-Kush-Himalaya-Tibetan Glaciers

- Floods followed by drought
- Billions affected
- National security threat from water conflicts among 3 nuclear powers and a half dozen adjacent developing countries

Rivers Originating in Hindu-Kush-Himalaya-Tibetan Glaciers



NEXT

Environmental Common Sense

- The ultimate goal is green buildings designed and managed for zero net energy using low-carbon renewable energy
- Containment mitigates refrigerant toxicity, flammability, ODP, GWP, and unwanted atmospheric decomposition (Trifluoroacetic acid -- TFA)
- Once near-zero lifecycle refrigerant emissions are achieved, all the attention turns to energy efficiency

Arctic and Other Snow & Ice Regions Are Especially Vulnerable to Black Carbon Pollution

Without soot, rays reflected

BC is 50% of 1.9 C warming in Arctic since 1890 (Shindell & Faluvagi 2009)

With soot, rays (and heat) absorbed

BC and its organic co-pollutants are responsible for just under half of the total springtime melt in the Himalayas (Flanner et al. 2009)

NASA, Black Soot and Snow: A Warmer Combination, 2004

Fast Action:
Reduce Non-CO2 Radiative Forcing

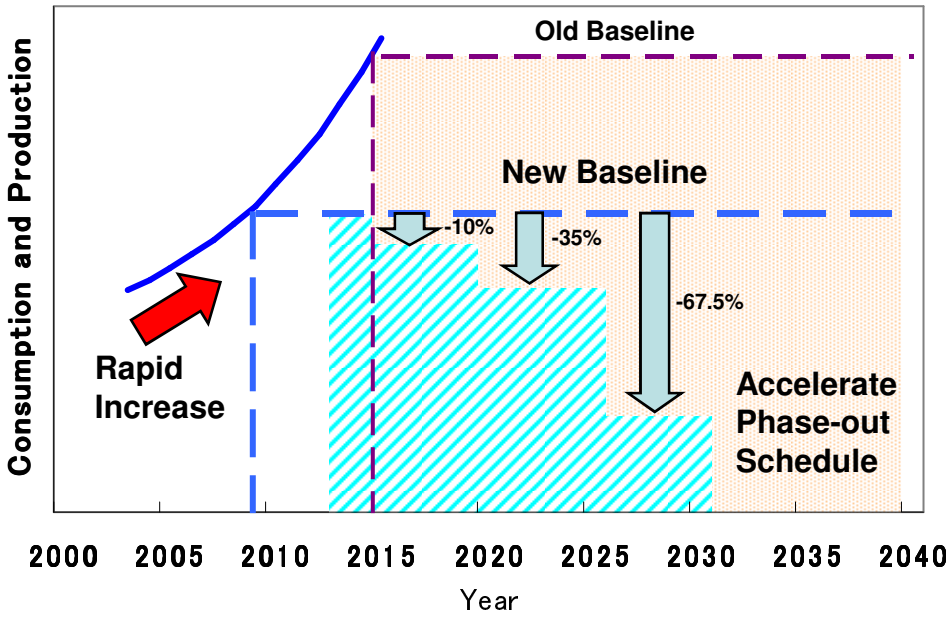
Emission	Percent CO_2 RF	Atmospheric Lifetime
HFCs	9-19% in 2050	Most < 15 Years
Methane	29%	10 to 12 Years
Black Carbon	26-54%	Days to Weeks
Tropospheric Ozone	21%	Hours to Days

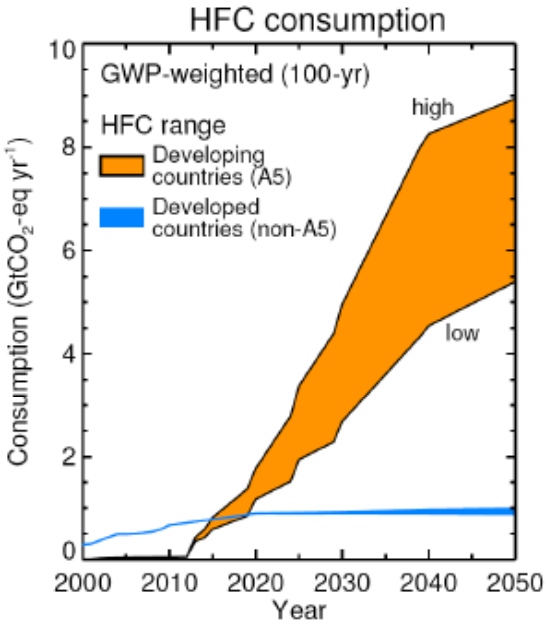
HCFC Phase-out Schedule for A5 Countries

◆**In 2007, Parties to the Montreal Protocol accelerated the HCFC phase-out schedule for both developed and developing countries.**

Baseline: Average of 2009 and 2010

Freeze by 2013 Phase-out by 2030





Source: "The Large Contribution of Projected HFC Emissions to Future Climate Forcing" by Velders, Fahey, Daniel, McFarland & Andersen, PNAS 2009

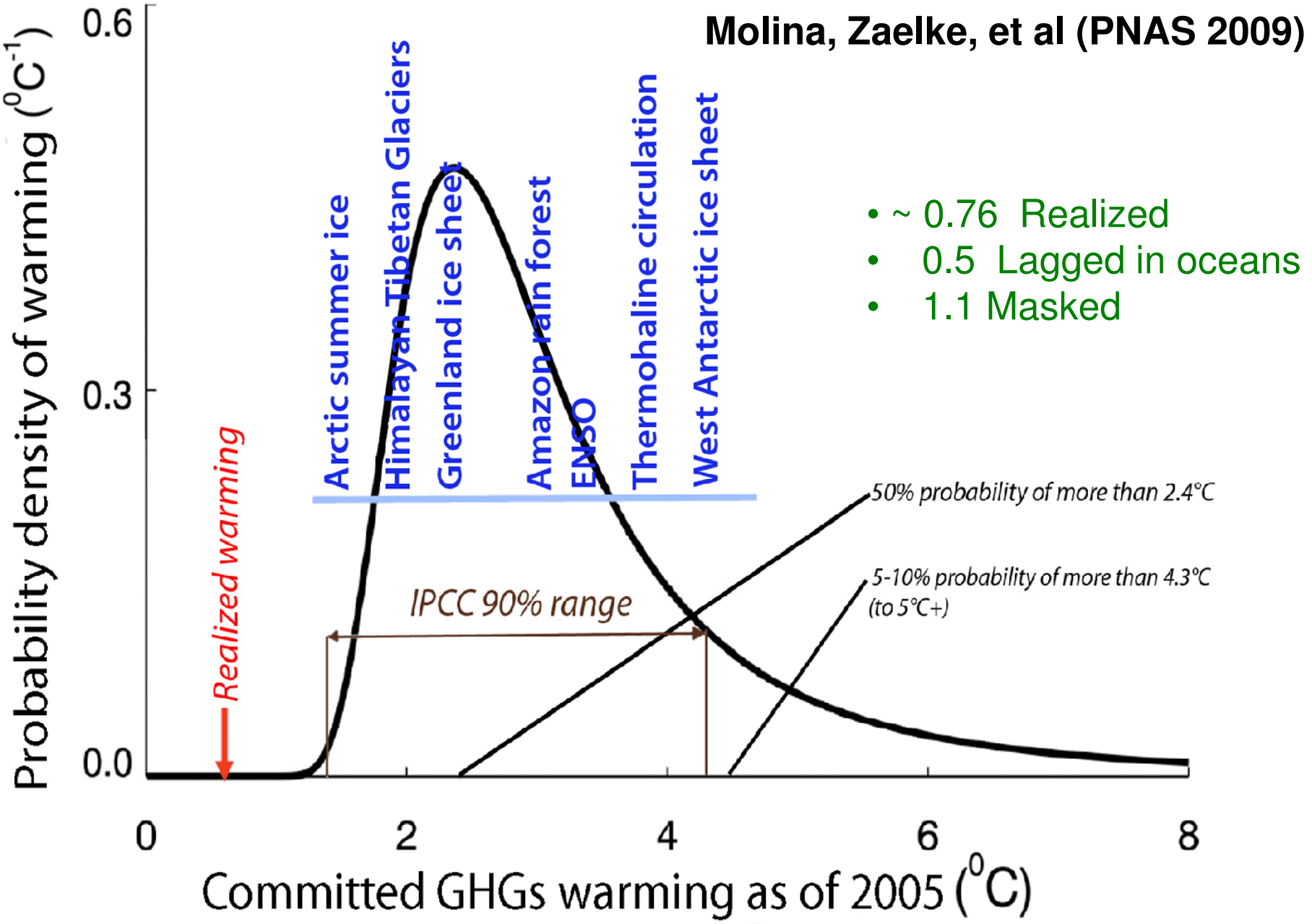
Developing countries will start changing to the alternative refrigerant in 2013

Choice of a high GWP refrigerant would increase Global Warming impact

Choosing the superior LCCP technology is very important.

Committed Warming as of 2005

Molina, Zaelke, et al (PNAS 2009)



- ~ 0.76 Realized
- 0.5 Lagged in oceans
- 1.1 Masked

Refrigerant Reality

- Chemical nomenclature is an unreliable indicator of environmental acceptability
- LCCP analysis cuts through the rhetoric
- The realized GWP of a chemical substance includes all manufacturing emissions
- Short-term and long-term atmospheric impact are both important to climate protection: no one correct GWP time interval

The “Andersen 5-Step”

① Calculate the “safety-screened energy efficiency” of products satisfying reasonable health & safety standards;

② Compare the LCCP of the safety-screened systems for the climate, electricity carbon intensity, and owner preferences;

③ Select the superior LCCP technology in cases of clear advantage, but in cases of comparable LCCP, favor the lowest GWP;

④ Proceed with investment, unless an emerging technology is far superior and worth waiting for; and

⑤ Limit cumulative life-cycle emissions to acceptable levels by engineering, economic incentives, and training.

LCCP Analysis of R32 RAC in Indonesia

Calculation in Indonesia

■Unit: Panasonic CS-PC9 MKJ

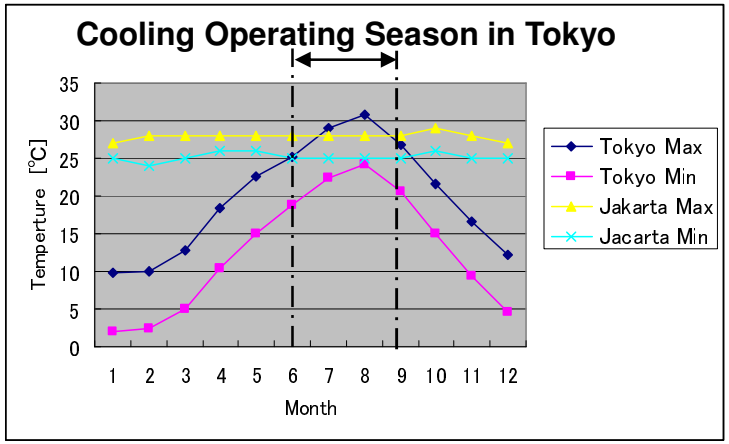
Refrigerant : R-22 490g
Cooling Capacity : 9000BTU (2640W)
Energy Consumption : 840W
COP : 3.14

■Running Time : 2920hrs/yr

365days × 8hrs/day (11PM-7AM)
12years

■Cooling Seasonal Performance Factor (CSPF) using temperature of Jakarta

Average Temperature



	R22	R410A	R32	R290*1
COP	3.14 (100)	3.14 (100)	3.27 (104)	3.00 (96)
CSPF	3.40	3.40	3.54	3.25

*1) Gree R290 RAC announced in Maldives 2011
Refrigerant amount : 200g

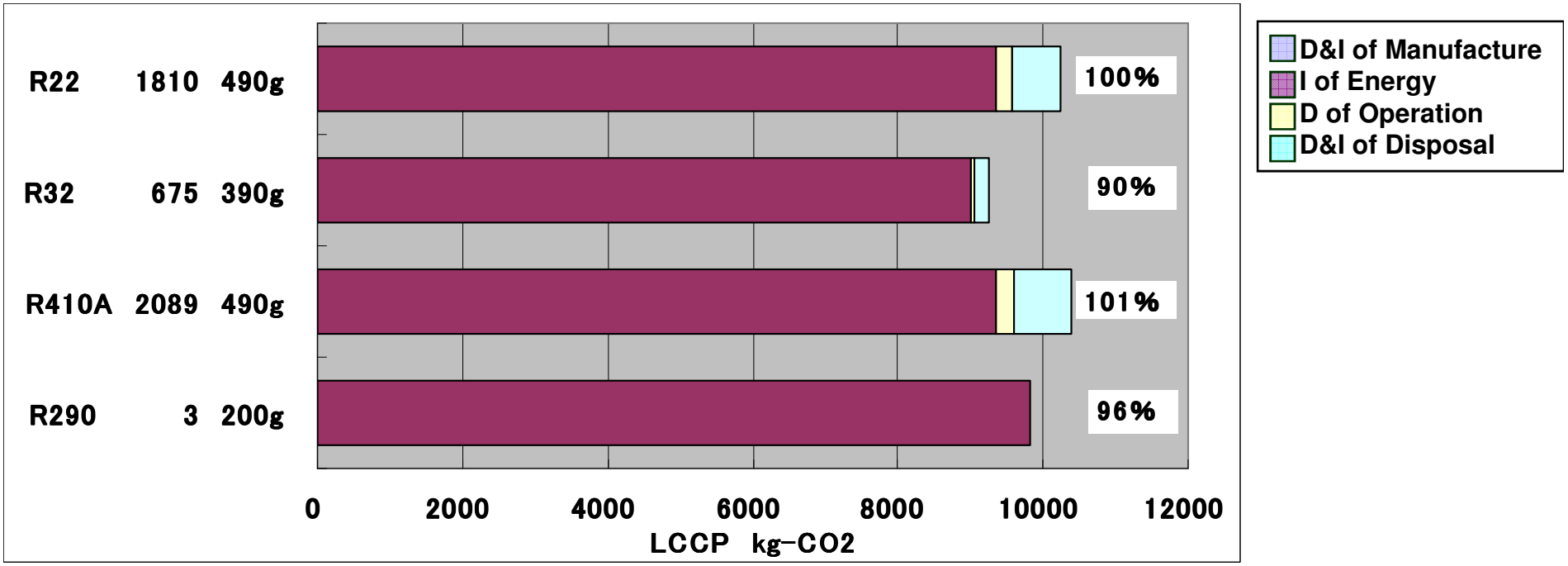
■Refrigerant Recovery rate = 0% Leakage rate during operation = 2%/yr

■CO2 Emission Factor : 0.997 kg-CO2/kWh

Source: Panasonic

LCCP Analysis of R32 AC in Indonesia

LCCP Calculation Result



R32 has the lowest carbon footprint in Indonesia.
Using the efficient refrigerant is very important to reduce the global warming impact in the developing countries.

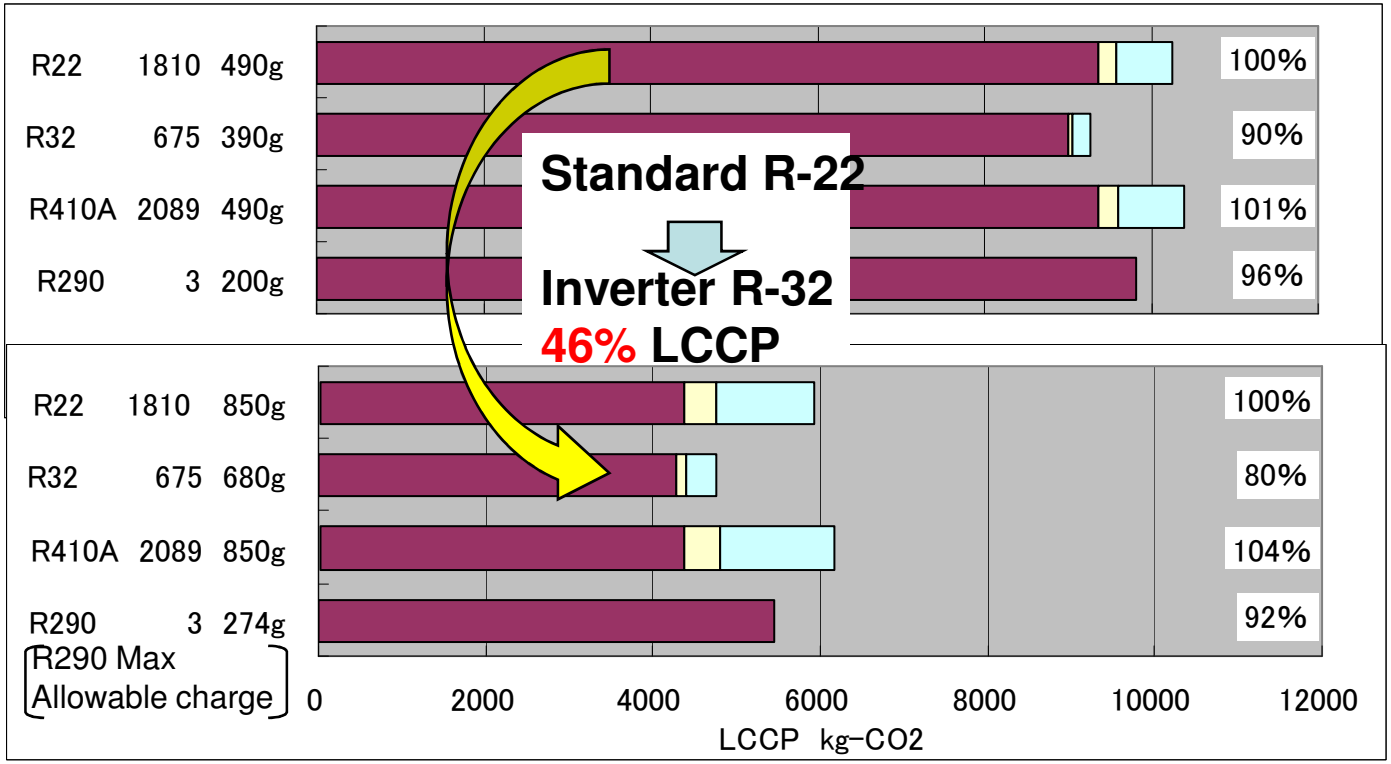
Source: Panasonic

LCCP Analysis of Inverter R32 AC in Indonesia

LCCP Result compared with Standard Model and Inverter Model

Standard Model In Indonesia CSPF=3.14

Inverter Model In Japan CSPF=7.29



Choice of the R-32 inverter model in Indonesia would reduce the carbon footprint by 46% of the R-22 standard model. Energy savings can repay the higher cost of the inverter model. Other features can further increase energy efficiency.

Source: Panasonic