The Global Search and Commercialization of Alternatives and Substitutes for Ozone-Depleting Substances

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#### Dedicated to Ozone Champions Who Would Have Loved to Celebrate With Us

- Anil Agarwal, John Chafee, Ralph J. Cicerone, Nandan Chirmulay, David Chittick, Derek Cunnold, Anil Madhav Dave, Gordon MB Dobson, David J. Erickson, Joseph C. Farman, Pierre Foucan, Yuichi Fujimoto, Boris Gidaspov, David Hofmann, John Hoffman, Don Hunt, Ivar S.A. Isaksen, Harold Johnston, Samuel C. Johnson, William Kenyon, Heinrich Kraus, Julius London, James A. Mertens, Mohinder Malik, Gérard Mégie, Simon Oulouhojian, David Pearce, F. Sherwood Rowland, K. Madhava Sarma, Dunstan Sorhaindo, John Stemniski, Mustafa Tolba, Dao Duc Tuan, Jan Cornelis van der Leun, Henry Waxman, John Wilkinson,... and a dozen others without whom the Montreal Protocol might never have succeeded
- With apologies for omissions, who else should we be honoring?

#### Viewer Discretion is Advised

- This conference contains strong science that may challenge policy makers and frighten the adults and children
- All the characters and incidents in this presentation are real, resemblance to any person is purely intentional
- Warning: Stratospheric Ozone Depletion causes skin cancer, cataracts, suppression of the human immune system, and damages agricultural crops and natural ecosystems
- Warning: Climate Change causes violent storms, flooding, drought, forest fires, epidemics, mass migration and war; insurance will not pay for damage and there is nowhere to run and nowhere to hide
- Parental guidance is advised in explaining why the ozone is protected and the climate is not

# MONTREAL PROTOCOL Most Successful Environmental Treaty!

#### Diplomatically!

• Full participation: all States are Parties, full cooperation and compliance. A model of flexibility with control measures that can be strengthened, accelerated, decelerated or exempted. Nationally- and company-determined technology; a collaborative of shared technology: "Unique in the annals of international diplomacy" (US Ambassador to 1987 MP Richard Benedick)

#### Scientifically!

• Science foundation meticulously built by international organizations and scientists, beginning with WMO/UNEP/ICSU report in 1984, confident scientists unafraid of sceptics, integrated assessment without political distortion and censorship, clearly translated for policy makers with "20 Questions and Answers"

#### Institutionally!

- Proactive Ozone Secretariat supporting deliberation of Parties and implementation
- MLF Executive Committee and Implementing Agencies satisfying Parties,
- Regional Ozone Networks inform and guide technical choice
- National Ozone Units (NOUs) are the 'boots on the ground' accountable to their Parties and companies Andersen Carvalho Gonzalez September 2017 Paris

# Successful Technically and Environmentally!

#### 99+% ODS Phaseout

More climate mitigation than Kyoto; comparable or lower toxicity than CFCs and HCFCs; flammability
mitigated with engineered solutions and training; 85% of ozone-depleting substance (ODS) phaseout is
non-fluorocarbon; technical and economic feasibility continuously updated by TEAP

#### HFC Phasedown

 At least half of the 15% that use hydrofluorocarbon (HFC) transition substances will be phased down with on-fluorocarbon or hydrofluoroolefin (HFO) substitutes delivering higher efficiency, lower global warming potentials (GWPs) and lower overall carbon footprints (LCCP). Each next generation of solutions is more sustainable

#### • Superior Replacement Technology

Replacement technologies with few exceptions are technically superior to ODSs – less toxic, higher energy
efficiency and more leak-tight for lower life-cycle costs. Recovery & recycle reduces materials extraction,
waste disposal

#### User Satisfaction

- Companies and customers are satisfied with the new technology and proud of doing their part for future generations
- Military organizations consider stratospheric ozone protection an environmental security issue with success that can inspire global collaboration on climate protection
- Cost-effective -- few consumers even noticed the transitions

# The Importance of Science and Scientific Assessment Panel (SAP)

- Trusted findings on what needs doing and when
- Extraordinary graphics reducing complex physics and chemistry to images that inspire action
- Agreed metrics for 'chlorine-equivalent' and 'carbon-equivalent' actions when substances have unique atmospheric lifetimes and chemical composition
- Thermometer, compass and gyroscope giving confidence to investment in transitional and sustainable technology
- Perhaps the most elegant integration of dozens of disciplines previously not appreciating how the puzzle comes together

## The Importance of Environmental Effects Assessment Panel (EEAP)

- Confident and unimpeached findings that ozone depletion causes skin cancer and cataracts, suppresses the human immune system and damages agricultural crops and natural ecosystems
- Global persuasion to protect skin from sun and to demand stratospheric ozone protection for future generations
- Conservative estimates that ODSs are the most damaging of all human inventions; only rivalled in consequense by war and pending climate change
- Guiding society to 'green chemistry' and sustainable alternatives to ozonedepleting greenhouse gases

#### The Importance of Technology and the Technology and Economic Assessment Panel (TEAP)

- Founded by ambitious environmental authorities and dominated by confident engineering experts from organizations pledged to phase out ODSs
- Often the first source of information on emerging technology
- Findings led to improvements in regulations and technical standards
- Identified and promoted superior technologies
- Responded objectively and honestly to government, corporate and environmental NGO claims and lobbying
- Mindful of the full range of selection criteria (ODP, GWP, atmospheric fate, toxicity, flammability, affordability, and availability...)

#### The Importance of the Multilateral Fund, MLF

- Democratic management of multilateral financial assistance (Executive Committee with 7 members from developing countries (A5 Parties) and 7 from developed countries (non-A5 Parties))
- Financing based on "the agreed incremental costs" efficient and fair basis for facilitating the transition, rather than the higher price typically found under trading schemes
- Since 1991, investing over US \$3.6 billion in industrial conversion, technical assistance, training and capacity
- Operating in a business-like manner that satisfied donors and recipients

#### **IMPACTED SECTORS**



# **The Global Search and Commercialization:** Medical Applications

- Metered Dose Inhalers (Asthma and Chronic Obstructive Pulmonary Disease (COPD)
  - Significantly improved the precision of drug dose and delivery
  - Facilitated superior asthma treatment
  - Raised awareness of pollution contributing to the asthma epidemic
- Sterilization
  - Increased the efficiency of sterilization
    - Ability to kill previously resistant pathogens
    - Ability to kill common pathogens faster than ever before
    - Ability to sterilize with lower doses of toxic ethylene oxide (EO) sterilant gas

#### **The Global Search and Commercialization:** Electronics & Metal Cleaning Applications

- Paradigm shift to aqueous, semi-aqueous, hydrocarbon and not-in-kind
- Collaboration of commercial & military aircraft maintenance
  - Literally thousands of specifications simplified and consolidated for technical performance and hundreds of millions of dollars of savings with replacement technology
- No-clean soldering revolutionized error-free electronics manufacture
  - Cheaper; faster, less toxic chemicals and lead dross waste; elegant chemistry, physics, and industrial art; billions in potential royalties donated by the ICOLP team for free global use in the interest of stratospheric ozone protection
- Innovative metal forming, no-clean stamping lubricant (compatible with paint) and multiple additional technical spin-offs

# **The Global Search and Commercialization:** Methyl Bromide Phaseout: Genius

- Before 1992, Netherlands prohibited MB due to toxicity; many alternatives were thus immediately available worldwide
  - Low permeability tarps and longer exposure allowed significantly lower doses in soil fumigation
  - More sustainable soil disinfestation alternatives, solarization, bio fumigation, and adapted farming practices reduced many soil fumigation uses
  - Sanitation with integrated heat, CO<sub>2</sub> and less harmful pesticides eliminated food facility use

# The Global Search and Commercialization: Refrigeration and Air Conditioning

- Continual improvements in energy efficiency and reductions in GWP
- Natural refrigerants (GWP=0 to ~6) penetrating expanding markets
- Lower-GWP HFCs (e.g. HFC-32 and HFC-152a) as transition substances
- HFOs with GWPs three to five times lower than most natural refrigerants
- Next-generation refrigerants, except HFO-1234yf, have no trifluoroacetic (TFA) atmospheric by-products
- Commercialization of new direct and hybrid expansion refrigerant cycles (super-critical CO<sub>2</sub> and secondary-loop motor vehicle air conditioners (MACs)

# **The Global Search and Commercialization:** Case Study: HFC-32 Residential ACs

- Indonesian, Japanese, UNDP and IGSD leadership in shifting from HFC-410A to HFC-32; other Parties, including India and Thailand followed
- Daikin granted global free access to its 93 patents and Daihatsu granted global free access to its 14 patents
- Lower flammability allows high energy efficiency in ACs up to 4.0+ tonnes
- Only refrigerant in room ACs sold in Japan, achieves highest documented 'Top Runner' energy efficiency
- So far, 30 million HFC-32 ACs sold in ~50 countries with manufacturing in China, European Union, India, Indonesia, Japan, Korea, Philippines, and United States

# 'Buyers Clubs' for Affordable Super-Efficient Room Air Conditioners

- Market Transformation Brainchild of India's Energy Efficiency Services Limited (EESL)
- Leadership by Daikin in offering 5-Star ACs at 3-Star price
- Support by The Energy and Resources Institute (TERI), IGSD and the Technology, Education, Research and Rehabilitation for the Environment (TERRE) Centre, the Natural Resources Defense Council (NRDC) advisor
- First 2017 tender of 100,000 super-efficient units with a ~30% price reduction
- Lessons learned and communicated for replication worldwide
- Applicable to all refrigeration and air conditioner products produced in standard configurations and high volume
- Lowering the cost and speeding the phasedown of hydrofluorocarbons (HFCs)

# **Energy & Refrigerant GWP Solutions**

- The new metric: Life Cycle Climate Performance (LCCP) accounting for *direct* refrigerant, *indirect* energy, and *embodied* GHG emissions
- Comprehensive LCCP calculations
  - Local: climate, lifestyle, and time-of-day carbon-intensity of electricity; accounts for cooling lost in duct work/wasted when the cooling of occupied spaces unnecessarily cools unoccupied spaces
- The big (long-term) strategy: re-discover how to live comfortably in hot places
  - Reduce AC requirements through building orientation and design, district cooling and natural cold sources, landscaping, cross ventilation and thermo-syphoning, sun shading, ground-coupling, and wearing clothing comfortable at higher temperatures

#### Ozone Champions, Please Take a Bow, But Don't Walk Off Stage!

#### **THANK YOU!**

The authors welcome edits and additions to the detailed history of environmental leadership and technical innovation presented in the presentation and backup slides.

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#### 85+ Backup & Elaboration Slides Follow

- More details of Global Search
- Montreal Protocol environmental achievement
- Market and award measures of success
- Government and non-government synergy
- Virtuous cycle of strengthened controls and technical innovation
- Spotlighting company, non-governmental organization (NGO) and Party leadership
- Lessons Learned
- What's Next?
- Montreal Protocol Core Reading/Bibliography

#### **The Global Search and Commercialization:** Solvent Military & Space Applications

- Solvent phaseout from rockets nearly catastrophic, but high payoff
  - First US/USSR space cooperation
  - First collaboration of previously isolated rocket manufacturers
- International military leadership and cooperation had side-benefits
  - Initially with USSR, then Russia and Former Soviet States, China, Australia, Canada, Germany, India, Netherlands, Norway, Saudi Arabia, Singapore, Sweden, Turkey, United Kingdom...and NATO

#### The Global Search and Commercialization: Halon Military & Space Applications

- Early 1994 halon production phaseout advocated with industry and military support
- 90+% of halon emissions was for testing and training
- A majority of use based on **aggressive marketing**
- Search for solutions taught improved fire protection
- Aggressive military and industry leadership in revisions to sector-specific policies, standards and regulations: Military Specifications (MilSpecs), National Fire Protection Association (NFPA), International Standards Organization (ISO), International Maritime Organization (IMO), International Civil Aviation Organization (ICAO)
- Halon banking by military organizations more successful than by others

# **The Global Search and Commercialization:** Methyl Bromide

- Until 1991-92, atmospheric scientists believed that all MB was from natural sources and did not appreciate the large manufactured sources for use as a biocide (kills every life form in every life stage)
- An emergency 1992 integrated Scientific Assessment Panel (SAP)/Technology and Economic Assessment Panel (TEAP) assessment identified risk of methyl bromide to stratospheric ozone and documented available alternatives
- As a result of the assessment, the Protocol was Amended in Copenhagen in 1992 to control methyl bromide
- The ultimate methyl bromide phase out, despite powerful agricultural interests and some governments, is a tribute to the integrity of the TEAP assessment process

#### Methyl Bromide Privilege

- MB 'Critical Use Exemptions--CUE' were granted for uses that may not have qualified under the more stringent 'Essential Use Exemption—EUE' criteria applied to all other ODSs
- Parties did not enforce the criteria that stockpiles be utilized before new MB production for critical uses
- There were instances when TEAP Methyl Bromide Technical Options Committee (TOC) members supporting a CUE worked for the Party requesting the use -- appearance of a conflict of interest and an unacceptable or ethical bias
- Parties have been granted CUEs for applications already phased out by other Parties
- One Party requested a CUE that was not granted by the Meeting of the Parties, and later classified its use as quarantine, which does not require approval by other Parties.

# Case Study: HC-600 (Isobutane) Refrigerators

- Greenpeace advocacy and German leadership (with USA, China & India)
- Aggressive unfounded opposition by fluorocarbon manufacturers claiming flammability safety risk
- Technically superior with patent-free refrigerant at lower cost, higher potential energy efficiency, and less noise and vibration
- Adopted quickly worldwide, with the exception of Japan and North America (Canada, Mexico, USA)
- Now penetrating stand-alone refrigerated display cases worldwide
- Finding traction in North America and Japan

# Case Study: Motor Vehicle Air Conditioners (MACs)

- 1987: MAC service caused the largest intentional service emissions of ODSs
- 1989: Global agreement to recover & recycle CFC-12 (ODP=1; GWP=10,200)
- 1990: Agree on transition from CFC-12 to HFC-134a
- 1995: Transition to HFC-134s (ozone safe; GWP=1300) complete in non-A5 Parties (developed countries); complete in A5 Parties 10 years later
- 2006: EC MAC Directive GWP<150 by 2017
  - 6 companies announce unique pathways to HFO-1234yf (ozone safe; GWP<1)
  - Flammable HFC-152a (GWP=138) and toxic CO<sub>2</sub> (GWP=1) are also options
- 2009: All transitioning non-A5 automakers selected HFO-1234yf for nonflammability
- Future: Automakers will have the option of HFC-152a with its lower price, higher energy efficiency, and superior life-cycle carbon footprint

#### Case Study: HC-290 (propane) in Residential ACs

- German leadership with demonstrations at Gree China and Godrej India
- Successfully marketed by Godrej in India, but Gree insisted on approval by German safety authorities prior to widespread marketing, so to date not commercialized in Germany.
- Most safety authorities restrict highly-flammable HC-290 refrigerant charge
  - Limits cooling capacity to ~2 tonnes for the highest energy efficiency offered in India and ~1.0 to ~1.5 tonnes for the higher efficiency achieved in Japan
- Patent-free refrigerant at lower cost and higher potential energy efficiency than HFC-410A

#### **The Global Search and Commercialization:** Foam Applications

- Cost-effective and technically superior
- Energy efficient and more durable
- Continuous improvement with technical knowledge shared worldwide
- Reinventing foam matrix science for next-generation technology
- Commercialization and market penetration of existing and new not-inkind solutions (plant fibre, fiberglass, mineral wool, and more)
- Some technology developed in A5 Parties and penetrating non-A5 markets with South-North technology transfer (e.g. methyl formate)

#### **ODS Phaseout Not Risk-Free**: Space Shuttle Rocket Case in Point

- The ODS-free space shuttle rocket motors experienced 'anomalies' on the O-rings connecting rocket motor segments that had failed on Space Shuttle Challenger, which required return to ODS solvents until the Shuttle was retired
- The Space Shuttle Columbia disintegrated in flight because foam from the struts holding the Shuttle to the oxygen tank broke off during launch and damaged heat-shield tiles on the wings
  - The foam on the struts was made with CFC-11 (unlike all the other insulating foam used on the Shuttle that transitioned to HCFC-141b), so the accident was not attributable to efforts under the Montreal Protocol

# Happy 30<sup>th</sup> Anniversary Montreal Protocol!

- Science sounded the ozone alarm
- Citizens motivated governments to act
- Some governments acted locally in the 1970s
- 24 nations & EC signed 1987 Montreal Protocol
- All governments acted globally by the 1990s
- The Montreal Protocol crafted the way forward
- Technical innovation transformed markets
- Ozone awards and publications tell the history of corporate, military, government, environmental NGO, and individual leadership

## Ozone & Climate Recovery

- So close...
  - Alternatives are available for all ODS uses
  - ODS production is 99% halted from ~250 sectors
  - Atmospheric ODS chemical levels are declining
  - First signs of ozone recovery to 1990 benchmark
  - HFC Amendment delivers 0.5° C less global warming
  - Energy efficiency can be another 0.5°C benefit
  - Emerging technology will soon allow accelerated HFC phasedown
- Yet so far...
  - Ozone recovery to 1990 level much later than hoped
  - Ozone protection jeopardized by climate change with risk of over-recovery
  - Procrastination on climate protection pushing earth toward tipping points with recovery only in timescales beyond human comprehension

#### Prosperity Measures of Success

- Avoided:
  - At least 1 billion skin cancer cases and saved at least 20 million lives
  - At least 500 million cataracts
  - Suppression of the human immune system
- Protected crops & ecosystems
- Improved energy efficiency
- Reduced net GWP-weighted ODS emissions in 2010 by about 11 Gt  $CO_2$ -eq/yr-1

#### Market Measures of Success

- Wide choice of alternatives & substitutes
  - Improved energy efficiency, mitigated safety & toxicity, reduced ownership cost, and increased employment in engineering, service and recycling
  - Low-GWP options available and emerging to immediately phase down HFCs – markets are moving faster than the Montreal Protocol
- Phaseout inconspicuous to customers & citizens
  - Same products, continuously available
- Industry & military pride in a job well done
  - No other treaty has so many satisfied stakeholders

#### Award Measures of Success

- About 500 individuals and organizations have earned UNEP, US EPA, Best-ofthe-Best, and national stratospheric ozone awards
- These individuals and organizations went beyond the call of duty and accomplished extraordinary results that inspire others to become ozone and climate champions
- Please see slides spotlighting landmark achievements

#### Montreal Protocol Overcame Denial & Obstruction

- Unscrupulous doubt on science & technology
- Marketing ODS technology in foreign markets after phaseout in home market
- Exaggerating essential, critical, feedstock & process agent uses
- Trading illegally & abusing trade loopholes
- Claiming unearned patents
- Withholding technology & licensing
- Harming future generations

#### Policies to Protect: Montreal Protocol Synergy

- Start, motivate, strengthen, fine-tune, & finance
  - The Montreal Protocol *started* with 24 Parties agreed on just CFCs and halons; *motivated* leadership companies and military organizations delivering spectacular technical innovation; strengthened by amendments, adjustments & decisions in response to scientific evidence and public support; *fine-tuned* by HCFC & HFC 'transition substances' and 'essential/critical' use exemptions; and *financed* for A5 Parties choosing best available technology
- In a *virtuous cycle* of technical evolution

#### Policies to Protect: Government Synergy

- Prohibit, promote, pick, penalize, & praise
  - National governments *prohibited* aerosol products, methyl bromide, halons and more; *promoted* new technology with certification, trade shows, and publications; *picked* technology for its own military and civilian operations; *penalized* ODSs and HFCs with taxes, labeling and emissions disclosure; and *praised* with awards, joint ventures, and product launches
- Orchestrated and fine tuned regulations and enforcement to phase out faster than required by Montreal Protocol control measures
#### Policies to Protect: NGO Synergy

- Appreciate, alert, energize, & demand
  - NGOs are often first to *appreciate* new science, to *alert* public and policymakers, to *energize* debate and action, and to *demand* justice for human and ecosystem victims
  - NGOs think outside the corporate comfort box with emission disclosure, naming names, undercover investigations, litigation, and more
  - NGOs think inside the corporate comfort box with product endorsements and praise for companies doing what's right for this and future generations

#### Policies to Protect: Corporate Synergy

- Pledge, cooperate, motivate, guide & phase out
  - Leadership companies *pledged* fast phaseout; *cooperated* with ICOLP, JICOLP, HARC, SAE, UNEP and others; *motivated* research centers of excellence and suppliers; *guided* standards and regulations; and phased out faster than required
- Invent, commercialize, advertise, & profit
  - Inspired companies *invented* and *commercialized* new technology, advertised the new against the ODS, and often *profited* handsomely by product sales and consumer loyalty and respect

#### Policies to Protect: Military & Space Strategy

- Grasp, embrace, motivate, & command
  - When the Montreal Protocol was signed, every modern weapon and space system depended on ODSs
  - Military and space organizations quickly grasped that ozone protection was a national security issue, embraced the priority, motivated suppliers and their own engineering centers of excellence and commanded phaseout in no uncertain terms
  - Technology was shared worldwide, even with adversaries

## Spotlight: Chemours (DuPont)

- 1972: Manufacturers Summit on the ecology of fluorocarbon impacts
- 1988: First ODS manufacturer to advocate CFC and halon phaseout
- 1990: First ODS manufacturer to warn of methyl bromide threat
- 1999: Summit on reducing HFC use and emissions (torpedoed and sunk by other HFC manufacturers)
- 2007/09: Sponsored co-author of Velders I & II scientific papers
- 2010+: Among the strongest and most articulate voices advocating early action on climate, including the 2016 Kigali Amendment

## Spotlight: First to Pledge Phaseout

- Dow Chemical
- General Dynamics
- Nissan
- Nortel and AT&T
- Penn. Engineering
- S.C. Johnson
- Seiko Epson
- US Dept. of Defense

Thermal insulating foam Aircraft Motor vehicles Electronics **Sterilants** Aerosol convenience and cosmetic products **Precision manufacturing** Weapons

## Spotlight: First ODS-Free Manufacturing

- 1991: GM/Nissan/Mercedes/Volvo -- Mobile AC
- 1991: Nortel Telecommunication products
- 1992: Seiko Epson Precision products
- 1992: General Dynamics -- Military/Civilian aircraft
- 1993: Matsushita -- Kitchen/Entertainment products
- 1995: 3M -- Metered Dose Inhalers (MDIs)
- 2012: Godrej/Gree -- HFC-Free room AC
- 2012: All Japanese manufacturers Replace HFC-410a with HFC-32 in room ACs

#### Spotlight: First Use Phaseouts

- 1988: Toys-R-Us -- Toys
- 1989: General Motors -- Recycling at all dealerships
- 1992: Coca Cola Refrigerated equipment
- 1992: General Dynamics Aircraft manufacture
- 1992: Lufthansa Aircraft maintenance
- 1992: Alaska Petroleum Halon fire suppression
- 1993: DoD -- Weapons and commercial vehicles
- 1993: Cadbury/Sainsbury's/Woolworths -- Retailing
- 1995: Wal-Mart -- CFC-free supermarket
- 2012: Coca Cola -- New HFC-free beverage coolers

## Spotlight: Donation of Patented Technology

- AT&T: precision flux spray for no-clean soldering
- Daihatsu: HFC-32 room air conditioners
- Daikin: HFC-32 room air conditioners
- Digital Equipment Corporation: advanced aqueous cleaning
- ICOLP: no-clean soldering
- Ingersoll Rand: R-452B room air conditioners
- Minebea: de-oxidized H<sub>2</sub>O & vacuum degreasing
- Nortel: rosin testing for no-clean soldering
- Seiko Epson: aqueous and alcohol cleaning
- Thiokol/NASA/DoD: solvent selection criteria

## Spotlight: Technology Announcements (1)

- 1975: S.C. Johnson pledges CFC aerosol product phaseout; Bristol Meyers, Gillette, Mennen, & Sherwin-Williams join S.C. Johnson pledge and advertise "CFC-free"
- 1987: US EPA Tiger Team
  - "Chemical substitutes at only 3-5 times the cost of ODSs"
- 1988: AT&T & Petroferm:
  - "Semi-aqueous natural solvent cleans electronics as well as CFC-113"
- 1991: Asahi Glass
  - "Successful manufacture and commercialization of first Low-ODP fluorocarbon solvent -- HCFC-225"
- 1995: Thailand is the first A5 Party to phase out manufacture of CFC refrigerators and first A5 with ODS environmental trade barrier

## Spotlight: Technology Announcements (2)

- 2006: EC, Asahi/Arkema/DuPont/Honeywell/Ineos/Sinochem
  - Phaseout of refrigerants with >150 GWP in new vehicles sold in the EC by 2017," EC F-Gas Directive."
  - "Low GWP replacements announced for motor vehicle AC" within days of announcement of EC MAC F-gas Directive
- 2010: General Motors
  - "HFO-1234yf (GWP<1) selected to replace HFC-134a (GWP=1300)"</li>
- 2011: Government of Indonesia, MITI, Daikin, UNDP and IGSD
  - "HFC-32 as super-efficient transition substance to eliminate HFC-410A"
- 2017: Every Japanese residential AC manufacturer
  - "Complete transition from HFC-410A to HFC-32 with Top Runner Efficiency"

## Spotlight Institutional Champions (1)

- 1972: DuPont holds CFC manufacturers' summit to investigate fluorocarbon environmental impacts
- 1974: Manufacturing Chemists Association announces financing of research into the ozone-depletion theory
- 1987: The Foodservice and Packaging Institute (FPI), US EPA and ENGOs agree to phase out CFCs in food packaging within one year, HCFCs when feasible, and to share technology worldwide
- 1987: US Air Force supports halon control at Montreal Protocol negotiation
- 1988: US Air Forces restricts new applications of halons
- 1988: DuPont, and later the same day Pennwalt, endorses phaseout of fully halogenated fluorocarbons

## Spotlight Institutional Champions (2)

- 1988: Programme for Alternative Fluorocarbon Toxicity Testing (PAFT)
- 1989: The Mobile Air Conditioning Society, Underwriters Laboratories and US EPA announce CFC recycling technology satisfying stakeholders
- 1989: Founding of the:
  - Alternative Fluorocarbon Environmental Acceptability Study (AFEAS)
  - Halons Alternatives Research Corporation (HARC)
  - Industry Cooperative for Ozone Layer Protection (ICOLP)
  - Japan Industrial Conference for Ozone Layer Protection (JICOP)
- 1992: Alliance for Responsible CFC Policy petitions US EPA to phase out CFCs and HCFCs 22, 141b and 142b faster than the Montreal Protocol and Clean Air Act require

## Spotlight Institutional Champions (3)

- 1994: A US Interagency Task Force code-named "Operation Cool Breeze" in Florida and "Fri Tejas" along the Mexican border by 1999 accomplished about 100 convictions and collected nearly \$64 million in fines and restitution
- 1995: 40 multinational companies from 7 countries agree to help Vietnam avoid dependence on ODSs, including HCFCs
- 1997: 23 multinational companies pledge to not transfer CFC technology to Article 5 Parties and countries with economies in transition (CEIT)
- 1999: Mobile Air Conditioning Society, SAE International, and EPA form the "Mobile Air Conditioning Climate Protection Partnership"

## Spotlight Institutional Champions (4)

- 2004: Green Customs initiative to stop environmental crime (e.g. illegal ODS trade)
  - Basel, CITES, Montreal, Rotterdam and Stockholm Agreements; Interpol, Organisation for the Prohibition of Chemical Weapons (OPCW), UNEP, United Nations Office on Drug and Crime and the World Customs Organization plus other organizations
- 2004: "Refrigerants Naturally" launched by The Coca Cola Company, Unilever, and McDonalds
- 2006: K. Madhava Sarma and Stephen O. Andersen publish "Some preliminary thoughts on strengthening the Montreal Protocol," that is the impetus for the Stockholm Group
- 2006 Operation "Skyhole Patching," carried out by RILO Asia-Pacific, targeted illegal ODS and waste flows, the first ever coordinated action against environmental crime by customs authorities in Asia.

## Spotlight Institutional Champions (5)

- 2009: SAE International publish J-2766 standard for life-cycle energy performance (LCCP) in MACs
- 2010: The Consumer Goods Forum's 400 member companies pledge HFC phaseout in 2015 with replacement by natural refrigerants, where allowed
- 2011+: NRDC, IGSD, and EIA successfully petition US EPA to remove HFC-134a from SNAP list of acceptable technology for motor vehicle AC
- 2014: The Alliance for Responsible Atmospheric Policy (ARAP), the Air-Conditioning, Heating and Refrigeration Institute (AHRI), and the Brazilian Association for HVAC-R (ABRAVA) announce the Global Refrigerant Management Initiative at the United Nations Secretary-General's Climate Summit

## Spotlight Institutional Champions (6)

 2016: EIA and Greenpeace work with the Consumer Goods Forum (CGF) to craft a new Refrigeration Resolution committing CGF members to use natural or ultra-low GWP refrigerants in all new equipment wherever viable

#### NGO Synergy Appreciate, Alert, Energize, & Demand

- NGOs are often first to appreciate new science, to alert the public and policymakers, to energize debate and action, and to demand justice for human and ecosystem victims
- NGOs think outside the corporate comfort box with emissions disclosure, naming names, undercover investigations, litigation, and more
- NGOs think inside the corporate comfort box with product endorsements and praise for companies doing what's right for this and future generations

## Spotlight Environmental NGO Champions (1970s)

- 1970: Union of Concerned Scientists organizes NGO opposition to supersonic transport (SST) feared to deplete stratospheric ozone and change climate
- 1974: NRDC joins Mario Molina & Sherry Rowland in organizing the American Chemical Society presentation warning of ozone depletion and later that year petitions the US Consumer Product Safety Commission to ban US sales of CFC aerosol products
- 1975: NRDC asks UNEP to take the lead on the ozone issue
- 1978: NRDC publishes study showing leadership of Canada, Netherlands, Sweden and USA in banning CFC cosmetic and convenience aerosol products, and that other countries had done little or nothing

# Spotlight Environmental NGO Champions (1980-1986)

- 1982: International Institute of Refrigeration (IIR) Congress focuses on ozone depletion and climate change
- 1983: NRDC files intent to sue notice charging US EPA with failure to protect the ozone layer as required by the Clean Air Act
- 1986: Court accepts US EPA Ozone Protection Plan in settlement of law suit by NRDC
- 1986: 79 European and North American ENGOs urge the total phaseout of CFCs within 10 years
- 1987: 59 ENGOs from 22 countries issue joint policy statement
- 1987: Environmental Action (EA) urges ODS product boycotts and letter writing campaigns

## Spotlight Environmental NGO Champions (1987-88)

- 1987: NRDC report published in USA Today lists AT&T, GE, IBM, US Air Force, and United Technology as biggest US ODS emitters
- 1988: Asia-Pacific People's Environmental Network campaign calls for stronger ODS controls
- 1988: Friends of the Earth (FoE) Netherlands reaches agreement of 4 largest foam packaging companies to phase out ODS by 1989; FoE UK reaches agreement on phaseout of CFC foam packaging in most restaurants, egg packers and supermarkets
- 1988: FoE, Environmental Defense Fund (EDF), NRDC, and US EPA sign agreement with the Foodservice and Packaging Institute (FPI) to phase out CFC from foam food packaging within one year and HCFCs as soon as feasible

# Spotlight Environmental NGO Champions (1989-90)

- 1989+: Greenpeace activists post banners on corporate and government buildings worldwide
- 1989: Australian NGOs, labor organizations, fluorocarbon manufacturers and government agree on a voluntary halon phaseout by December 1995
- 1989: Mobile Air Conditioning Society, global vehicle manufacturers, EPA and a dozen NGOs agree to voluntarily recover and recycle CFC-12 from MACs
- 1989: 93 ENGOs demand a 'crash program' to protect the ozone layer
- 1990: Paul McCartney 'Rescue the Future' world tour promoting FoE ozone protection campaign
- 1990: NRDC publishes *Who' Who of America's Ozone Depleters* listing the 3014 companies

## Spotlight Environmental NGO Champions (1991-92)

- 1991: ENGOs from Indonesia, Malaysia, Thailand, Philippines and Papua New Guinea organize regional action network
- 1991: Greenpeace ads feature photographs of Hoechst and Kali Chemie CEOs; 8-year judicial process concludes that German CEOs are public figures and subject to such scrutiny & ridicule
- 1991: The Center for International Environmental Law (CIEL) and ICOLP organized the 'pathfinder' meetings where NATO countries agree to cooperate with the USSR on ODS-free technology
- 1992: US Securities & Exchange Commission finds that DuPont was wrong to prevent a FoE shareholder from offering a phaseout resolution

## Spotlight Environmental NGO Champions (1993-97)

- 1993: FoE, Earth Action, Pesticide Action Network (PAN), and the Methyl Bromide Alternatives Network launch campaigns against methyl bromide
- 1993: UK Advertising Standards Authority rules for Greenpeace in 4 of 5 complaints that ICI advertising of HFC environmental acceptability is misleading
- 1994: CIEL publishes "ICOLP: A New Spirit at Work" praising the aerospace and electronics industry for global collaboration in the ODS solvent phaseout
- 1996: Amana, GE, & Whirlpool pay US\$ 100,000 settlement in litigation with Ozone Action and the Environmental Law Foundation for implying that CFCfree HCFC foam is ozone-safe
- 1997: EIA published their report on illegal ODS trade "Chilling Facts about a Burning Issue;" Montreal Protocol agreement on licensing systems was agreed later that year.

## Spotlight Environmental NGO Champions (1998-2000)

- 1998: Labor & ENGOs launch the "Sustainable Tomato" campaign against methyl bromide
- 1998: ENGOs in Mexico, Chile, Senegal and Malaysia organize to monitor methyl bromide use
- 1999/00: Centre for Environmental Education in India launches workshops & teaching toolkits on ozone depletion
- 1999: Pesticide Action Now (PAN) and UNEP publish inventory of resources for methyl bromide phaseout
- 1999: The US Superior Court, in response to litigation by The Environmental Working Group, FoE, PAN, and Pesticide Watch, orders California to protect the public against methyl bromide exposure

## Spotlight Environmental NGO Champions (2010s)

- 2000: Greenpeace campaigns against use of HFCs at the Olympics by Coca Cola & McDonalds; Coca Cola pledges to phase out HFCs as soon as suitable technology is available
- 2001: Nestle pledges to accelerate its HFC phaseout using natural refrigerants
- 2005: EIA report "Under the Counter" exposed the role of China in illegal ODS trade, leading to training for enforcement officers and improved enforcement.
- 2006: Institute for Governance & Sustainable Development (IGSD) helps form the 'Stockholm Group' of like-minded Parties seeking to accelerate the HCFC phaseout
- 2006: EIA report "Turning up the Heat" exposed skyrocketing HCFC-22 production caused by perverse incentives from the destruction of HFC-23 byproduct under the UNFCCC Clean Development Mechanism
- 2007+: IGSD organizes a comprehensive campaign of like-minded governments and NGOs, leading to agreement on the Kigali Amendment

# Spotlight Environmental NGO Champions (2000s)

- 2011: EIA and NGO partners expose the HFC-23 carbon credit scandal and successfully lobbied the European Union to ban HFC-23 carbon credits from the European Union's Emissions Trading Scheme
- 2012: Governments and NGOs form the Climate and Clean Air Coalition to Reduce Short-Lived Climate Pollutants (CCAC)

## Spotlight Environmental NGO Champions (2010s)

- 2013: NRDC, CEEW, TERI, and IGSD, in cooperation with the Confederation of Indian Industry (CII), publish "Cooling India with Less Warming: The Business Case for Phasing Down HFCs in Room and Vehicle Air Conditioners"
- July 2014: Chatham House and IGSD publish "A Global Response to HFCs through Fair and effective Ozone and Climate Policies"
- 2015: NRDC, IGSD and CEEW publish "Amending the Montreal Protocol: Summary of Amendment Proposals and Discussion of Key Components to Phasing Down HFCs"
- 2017: TERI, IGSD, and TERRE with NRDC achieve alignment of Indian government policy necessary for EESL's bulk super-efficient AC procurement

## Spotlight Country Champions Australia

- In 1988, EPA Victoria proposed sector milestones for 95% phaseout by 1996
- In 1989, national agreement to phase out halons with "banking" for "critical use"
- Australian student's intervention at the 1992 MOP motivated action by pleading: "Our fate lies in your square brackets"
- Unequaled leadership by Refrigerant Reclaim Australia
- High Australian TEAP participation

## Spotlight Country Champions Costa Rica

- Costa Rica was first to extradite any fugitive for any environmental crime!
  - Bruce Burrell was extradited from Costa Rica to the United States and subsequently convicted for conspiracy to smuggle CFC-12
- Hosted the 8<sup>th</sup> Meeting of the Parties to the Montreal Protocol and spearheaded the \$540 million replenishment of the MLF
- Organized in 2003, the Ministry of Environment and Energy (MINAE), Ministry of Agriculture and Livestock (MAG), Phytosanitary Directorate (MAG), Cut Flowers Growers' Association (ACFLOR), Melon Growers' Association (CANAPEM), Agricultural Extension Organisation (BUN), and universities and research centers to accomplish successful methyl bromide phaseout

## Spotlight Country Champions European Union

- Champion of methyl bromide phaseout
- Pioneer of HFC phaseout (particularly Denmark)
- 2006 MAC F-Gas Directive inspired California and US EPA action
- 2014 F-Gas regulation is first comprehensive HFC phaseout plan agreed by governments, industry, and NGOs

### Spotlight Country Champions India

- Early leadership in organizing A5 Parties
- Advocate of "common but differentiated responsibilities" with binding commitments
- Principal architect of 1990 MLF Agreement
- Central to 2007 HCFC accelerated phaseout
- Energy Efficiency Services Limited (EESL) designed and implemented the first bulk procurement of super-efficient air conditioners at affordable price
- National origin of K. Madhava Sarma, Rajendra Shende, Atul Bagai and a dozen other key ozone champions working for UN agencies

## Spotlight Country Champions Mexico

- First to sign & ratify Montreal Protocol!
- First voluntary A5 phaseout of cosmetic and convenience aerosol products
- First with Brazil and Egypt to complete country study of phaseout cost
- First ODS production phaseout by A5 companies
- First A5 HCFC sector phaseout (foams)
- First A5 National Ozone Unit (NOU)
- First North American A5 Party to propose HFC phasedown amendment

## Spotlight Country Champions Brazil

- 1988: First A5 Party to organize a technical group to investigate the use of alternatives to ODS (one year earlier than the formation of TEAP)
- 1990 Ford Motor Company's Arbor electronics plant in Brazil pioneers the ODS-free electronics assembly technology applied at Ford
- 2010: Commercialized ozone-safe, negligible-GWP, and energy efficient methyl formate as an alternative to HCFCs in a wide range of foam applications
- 2015: Embraco first with variable-speed ultra-low temperature cascade refrigeration using low-GWP R-290 and R-170 at twice the energy efficiency
- 2017: First to propose buyers clubs of room AC manufacturers to gain access to affordable inverter compressor technology

## Spotlight Country Champions Nepal

- Early warning of glacier melting with vulnerability to Asian river flows
- First A5 Party to cap HCFCs
- Among first A5 Parties to intercept illegal ODSs
- First A5 Party to destroy illegally traded ODSs
- First to organize hotels to avoid HFCs and demand super-efficiency

## Spotlight Country Champions Russian Federation/USSR

- USSR
  - Strong leadership in reaching agreement on the 1987 Montreal Protocol
  - Launched US Total Ozone Mapping Spectrometer (TOMS) as part of the Meteor-3 science payload on Soviet Tsyklon-3 rocket
- Russian Federation
  - Technology cooperation on global phaseout in rocket manufacture

## Spotlight Country Champions United States of America

- Diplomatic leadership in crafting Vienna Convention, Montreal Protocol, & MLF
- Assessment leadership EAP, EEAP, SAP & TEAP
- Technology leadership with ICOLP, HARC, MACs, SAE, and more
- Military leadership in electronics, aerospace, rockets, and procurement
- EPA Stratospheric Ozone & Climate Protection Awards
- First global conferences on the importance of military organizations in protecting stratospheric ozone and climate
### Lessons Learned for Engineers

- Erroneous or missing metrics for carbon footprint that underestimate climate impacts and clean air and economic co-benefits
- Status-quo, self-inflicted design limits that assume technology is irreplaceable
- Exaggerated ODS performance achieved with biased testing
- Historic safety focus on the risks that turned out to matter least
  - ODSs are "colourless, odourless, non-toxic, non-flammable, and energy efficient"
  - However, ODSs destroy the stratospheric ozone and climate that makes life on Earth prosperous and sustainable

# What's Next in Vision/Policy?

- Transition from stratospheric ozone Montreal Protocol with extraordinary climate benefits to climate oriented Montreal Protocol embracing low-GWP refrigerants, super energy efficiency, and not-inkind cooling—building design, ventilation, orientation, district cooling...
- Integrated policy and regulations to take into account energy efficiency and refrigerants
- Pursue alignment of public and private policies making superefficiency affordable and enabling high minimum energy efficiency standards
- New environmental trade barriers to avoid dumping of obsolete technology with high ownership and carbon cost.

# What's Next in Technical Solutions?

- Technology choice driven by Parties and leadership companies accounting for private ownership and public air quality and climate co-benefits
- HFC-152a (ozone safe; GWP=138; no TFA), as a patent-free, low cost, energy efficient, slightly flammable transition substance to replace HFC-134a (ozone safe; GWP=1300) in motor vehicles
- New lower-GWP refrigerants with a non-refrigerant ingredient to reduce flammability (Trane/Arkema research partnership)
- Active safety systems for flammable and/or toxic refrigerants (detect and isolate)

# What's Next in Enforcement & Compliance?

- Control ozone-depleting greenhouse gas nitrous oxide (N<sub>2</sub>O), and ozonedepleting climate-safe dichloromethane (DCM), and N-propyl bromide (NpB)?
- Control ozone-safe GHGs: sulfur hexafluoride (SF<sub>6</sub>), perfluorocarbons (PFCs), and perfluorotributylamine (PFTBA)?
- Track down atmospheric sources of CTC, CFC-112, CFC-112a, CFC 113a and HCFC-133a
- Adjust the Essential Use Exemption to require chlorine-equivalent offsets through ODS collection and destruction
- Plug loophole allowing Parties to claim quarantine or pre-shipment exemption for uses not qualifying for a critical use exemption

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