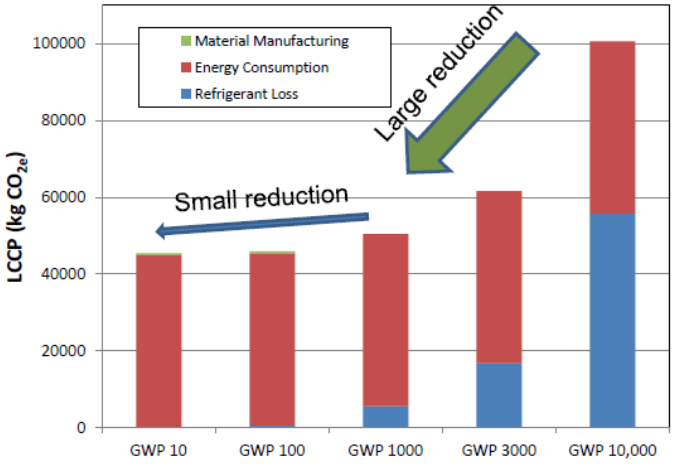
Legal text for Annex 54

Heat Pump Systems with Low GWP Refrigerants

1. Background

In 2016, 197 countries adopted an amendment to phase down HFCs under the Montreal Protocol in Kigali, Rwanda [1]. Under the amendment, countries committed to cut the production and consumption of HFCs by more than 80 percent over the next 30 years. Goal is to avoid more than 80 Billion Tons of CO_2eq emissions by 2050 and avoid up to 0.5°C warming by 2100. Refrigerant used in refrigeration and air conditioning systems is responsible about 2% of global greenhouse gas emissions [2]. In 2000, stationary air conditioning systems account for 37% of global refrigerant emission and 21% of CO_2 equivalent emissions of refrigerants [3]. However, more than 80% market growth of air conditioning systems are projected especially in developing countries due to their economic growth and climate changes [4]. The CO_2 equivalent emissions of the air conditioning systems can be evaluated by the life cycle climate performance (LCCP) evaluation method by summing their direct and indirect emissions generated over the lifetime of the system. Figure 1 illustrates the effect of GWP value on the LCCP for same efficient air conditioning systems. When the current high GWP refrigerant R-410A is replaced with ultra-low GWP alternative refrigerant with GWP value of 3, the LCCP can be reduced by 17-19%.



Assumptions

Annual Refrigerant Leakage Rate (%)	4
End of Life Leakage (%)	0/15
Unit Lifetime (years)	15
Total Amount of Refrigerant Charge (kg)	2.3
Average Power Plant Emission Rate (kg CO_{2e}/kWh)	0.91
T&D loss (%)	18
ISEER (-)	5.2

Figure 1: Effect of GWP on LCCP

In order to investigate promising alternative refrigerants used for major air conditioning and refrigeration systems responding to this global regulation, the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) started an industry-wide cooperative research program in the US called “Low Global Warming Potential Alternative Refrigerants Evaluation Program” (Low GWP AREP) in 2011 [5]. Since then, handful of low GWP alternative refrigerants listed in Table 1 were evaluated for air conditioning and heat pump systems under this program. As can be observed, most of alterative refrigerants investigated are either R-32 or its mixtures in A2L safety class with GWP values ranging 272 to 713. In addition to alternative refrigerants investigated under AREP, natural refrigerants like R-290 (propane) and R-744 (CO_2) are also studied elsewhere.

Table 1: Low GWP Alternative Refrigerants for R410A under AREP [6]

Refrigerant	Constituent	Mass fraction [wt.%]	GWP	ASHRAE safety class
R32	-	-	675	A2L
R32/152a	R32/152a	95/5	647	A2L
R32/134a	R32/134a	95/5	713	A2L
ARM-70a	R32/134a/1234yf	50/10/40	482	A2L
ARM-71a	R32/1234yf/1234ze(E)	68/26/6	460	A2L
D2Y60	R32/1234yf	40/60	272	A2L
DR5	R32/1234yf	72.5/27.5	490	A2L
DR5A (R454B)	R32/1234yf	68.9/31.1	466	A2L
DR55	R32/125/1234yf	67/7/26	698	A2L
L41a	R32/1234yf/1234ze(E)	73/15/12	494	A2L
L41b	R32/1234ze(E)	73/27	494	A2L
L41-1 (R446A)	R32/600/1234ze(E)	68/3/29	461	A2L
L41-2 (R447A)	R32/125/1234ze(E)	68/3.5/28.5	583	A2L
HPR1D	R32/744/1234ze(E)	60/6/34	407	A2L
HPR2A	R32/134a/1234ze(E)	76/6/18	600	A2L

Future heat pump systems will use low-GWP refrigerants and energy efficient technologies to meet latest international regulations and reduce overall environmental impacts. As summarized above, low-GWP refrigerants candidates are R-32, R-32 mixtures and natural refrigerants (HC and CO_2) and their GWP values will be lower than 700. Since candidate refrigerants have wide range of thermophysical properties and thermodynamic characteristics, which are different from current refrigerants, customized and optimized component and system designs for new low-GWP refrigerants are very important.

The proposed Annex will explore this new opportunity and contribute to expanding the optimized low-GWP air conditioning and heat pump systems, advancing their technology readiness levels (TRL) by developing design guidelines for low-GWP technologies, assisting to reduce their market barriers and promoting international collaboration. Therefore, the proposed annex aligns with IEA's vision and mission by targeting clean, low-carbon energy systems' design and applications. This annex will assist IEA to achieve its strategic goals by promoting new, alternative or natural refrigerants with lower GWP for heat pumps. By engaging experts worldwide, this annex will promote environmental awareness to policy makers. Overall, this new annex has close relationship with past and current IEA annexes focused on component and system aspects of heat pumps by introducing more refrigerants that have not been considered before. Related past and current annexes are as follows:

- Annex 18 – Thermophysical Properties of Environmentally Acceptable Refrigerants
- Annex 20 - Working Fluid Safety
- Annex 22 - Compression Systems with Natural Working Fluids
- Annex 23 - Heat Pump Systems for Single-Room Applications
- Annex 33 - Compact Heat Exchangers in Heat Pumping Equipment
- Annex 46 - Heat Pumps for Domestic Hot Water
- Annex 47 - Heat Pumps in District Heating and Cooling Systems
- Annex 50 - HPs in MF buildings

2. Description of Technical Sector

Buildings account for 20-40% of final worldwide energy consumption [7], and half of that is used for HVAC systems [8]. For cooling and heating of buildings, the vapor compression

technology has been used widely due to their superior efficiency and cost-effectiveness to other technologies. However, their conventional working fluid, HCFC-22, and its first-generation replacement, R-410A has high GWP value near 2,000. Replacing current working fluid of vapor compression technology to low-GWP ones while keeping and/or improving its efficiency will assist to minimize the environmental impacts by the building's cooling and heating systems.

3. Objectives and Scope

This annex aims at promoting low-GWP refrigerant application to accelerate phase down of high-GWP HFCs by developing design guidelines of optimized heat pump components and system for low-GWP refrigerants through the review of available low-GWP refrigerants, their properties and applicable standards, safety and flammability of refrigerants, and safe use of flammable refrigerants; optimization of heat pump components and system for low-GWP refrigerants; analysis of the LCCP impact by the current design and optimized design with low-GWP refrigerants; and market opportunity study for heat pumps with low-GWP refrigerants and low-GWP refrigerants availability for 2030. Target applications are air-conditioning and heat pump systems for residential and commercial buildings.

4. Means

The participants shall share the coordinated work necessary to carry out the work required for this Annex. While considering the development stage of this important topic and the effects of earlier tasks to later tasks, each earlier task will be revisited in following years, and updated information from previous years will be included in annual task report. Annual report shall be made to the ExCo, and the ExCo shall take a decision on how to proceed for the following year. The objectives shall be achieved by the following task-sharing activities:

Task 1: Review of state-of-the-art technologies

Since the Montreal Protocol started in 1987, there have been a lot of researches and engineering works conducted to search for alternative refrigerants. Especially during the last decade, these activities are more focused on low-GWP refrigerants including natural refrigerants and newly introduced HFOs. This task aims at reviewing latest information on low-GWP refrigerants being investigated, current components and system designs, current standards and policies, thermophysical properties and heat transfer characteristics, safety and flammability of refrigerants, and safe use of flammable refrigerants of identified low-GWP refrigerants.

Each participant will be asked to propose one or more technical areas to contribute and submit country reports summarizing current development of low-GWP refrigerants and related project plans to OA/Task leader. OA/Task leader will compile country reports into Annex Task 1 summary report.

Milestone/deliverable – Task 1 report by December 2019.

Task 2: Case studies and design guidelines for optimization of components and systems

Low-GWP refrigerants have different thermophysical properties from those of currently used refrigerants so that their thermodynamic cycle behaviors, heat transfer and hydraulic performances in heat exchangers, compression behavior through the gas compressor and expansion behavior though throttling device are different. This task aims at conducting case

studies and developing design guidelines for optimizing components and systems for identified low-GWP refrigerants from Task 1. Both modeling tools and experimental approach can be used for optimizing components and systems for identified low-GWP refrigerants in selected applications. Moreover, additional information for Task 1 will be collected, analyzed, reported and applied to Task 2.

Each participant will be asked to propose one or more target components and/or systems to investigate and submit country reports summarizing their optimization results of components and systems, and design guidelines to the OA/Task leader.

OA/Task leader will compile country reports into Annex Task 2 summary report.

Milestone/deliverable – Task 2 report by December 2020.

Task 3: Review of design optimization and advancement impacts on LCCP reduction

This task aims at evaluating design optimization and advancement on the LCCP reduction. For this purpose, the LCCP impact of using optimized designs and various technical options as compared to the baseline system will be investigated such as advanced cycles, new components, and integrated options. Moreover, additional information for Task 1 will be collected and analyzed. Task 2 will be repeated for new important refrigerant candidates identified from additional Task 1. Results of revised Task 2 will be applied to Task 3.

A short report shall be submitted to the OA/Task leader for compilation into an Annex Task 3 report. OA/Task leader will compile country reports into Annex Task 3 summary report.

Milestone/deliverable – Task 3 report by June 2021.

Task 4: Outlook for 2030

This task aims at studying market opportunities of heat pumps with low-GWP refrigerants and low-GWP refrigerants availability in different levels for 2030 while considering possible bottlenecks on availability of low-GWP refrigerants. Furthermore, similar work will be conducted for projecting beyond 2030.

Milestone/deliverable – Task 4 report by September 2021.

Task 5: Report and information dissemination

This task aims at reporting works conducted and disseminating information developed in Annex.

Each participant will be asked to provide country report summarizing all tasks conducted with any update to the OA/Task leader for compilation into an Annex report. OA/Task leader will compile country reports into draft Annex report and submit to ExCo for their review and approval. After approval with any revision, Annex will publish final report.

Milestone/deliverable – draft final country reports summarizing all Annex activities by November 2021.

Milestone/deliverable – final Annex report submitted to ExCo for review/approval by December 2021.

5. Target Audience and Benefits

The sectors targeted for this Annex include:

- Component and/or system providers who manufacture refrigerants, HVAC components and/or systems.
- Building architectures who select HVAC systems and designing buildings
- Safety experts for flammability and toxicity
- Policy makers (i.e., government energy agencies, legislative bodies, etc.) in varied geographic conditions, particularly hot and cold climates.
- NGOs involved in programs to minimize energy utilization (i.e., utilities, utility commissions, etc.).

6. Deliverables

The essential deliverables of the Annex are:

- Progress Annual Reports to ExCo meetings per template:
  - once a year oral presentation (focusing on results, achievements and/or success stories), and
  - twice a year management reports.
- Final report of the Annex per template.
- A public Annex Website as a subsite to the HPC website.
- Short status report to the HPC two to four times annually for publication in the Newsletter/Magazine, focusing on results, achievements and/or success stories.
- One article per year, topical or non-topical, to the HPC Newsletter/Magazine
- Report to the HPT Annual report.
- Text and pictures to a 2-page popular scientific summary of Annex results to be freely disseminated.

Additional deliverable of the Annex is:

- An Executive Summary of the final report which shall be made available for general distribution to all IEA HPT countries immediately after the approval of the final report by the Executive Committee.

7. Funding

(a) Working Meetings. The working meetings shall be hosted in turn by the several participants. The costs of organizing and hosting meetings shall be borne by the host participant.

(b) Publications. The cost of publishing the Final Report and summary assessments described in paragraph 6 above shall be equally shared by all the participants.

(c) Individual Financial Obligations. Each participant shall bear all the costs incurring in carrying out the Task activities, including reporting, workshop(s) participation, and travel expenses. Additionally, each participant shall make a direct financial contribution to the Operating Agent to cover co-ordination and report preparation expenses and other Annex-related (e.g. Workshop) costs.

Number of Participants	Participant Fee (USD)		
	2019	2020	2021
2	8,720	9,156	9,614
3	6,248	6,561	6,889
4	5,013	5,263	5,526
5	4,271	4,485	4,709
6	3,777	3,966	4,164
7 and greater	3,424	3,595	3,774

The table above shows the OA fees per participating country, based upon varying numbers of participating countries. Each Participant's fee shall be paid in two (2) annual installments.

8. Time Schedule

It is proposed that this Annex be conducted over a period of 36 months to begin in early 2019. While considering the development stage of this important topic, annual report shall be made to the ExCo, and the ExCo shall take a decision on how to proceed for the following year. Prior to Annex start date, participants to this new Annex will be identified. Within the limits of the terms of the Agreement, this Annex may be extended by two or more of the participating countries (Participants), acting in the Executive Committee and taking into account any recommendation of the IEA's Committee on Energy Research and Technology concerning the terms of this Annex. Such extensions shall thereafter apply only to those ongoing Participants.

The following is a tentative work schedule for the different tasks.

Start Date	End Date	Activity
Jan., 2019	Jun., 2019	Initial Kick-off meeting. Participants to identify scope of effort that they will be undertaking. Venue TBD (could be in conjunction with the ASHRAE Winter Meeting in Jan. 12–16, 2019 – Atlanta, GA)
Jul., 2019	Dec., 2019	**Task 1** started and completed (Task 1 Report)
Jan., 2020	Dec., 2020	**Task 2** started and completed (Task 2 Report)
Jan., 2021	Jun., 2021	**Task 3** started and completed (Task 3 Report)
Jul, 2021	Sep., 2021	**Task 4** started and completed (Task 4 Report)
Oct., 2021	Nov., 2021	**Task 5** started and completed (Draft Final report completed and shared with Annex Participants for review.)
Dec., 2021	Dec., 2021	**Final Report** delivered to ExCo.

9. Specific Obligations and Responsibilities of the Participants

a) Each Participant shall nominate a representative to participate in the work under this Annex and act as the point of contact (POC) with the Operating Agent. At his/her discretion the POC may appoint other individuals to lead the Participant's work in each of the Annex Tasks as defined in Section 4.
b) Each Participant shall carry out the equivalent of total two- to six-person months of task-sharing work during the programme period unless otherwise agreed by the Participants.
c) Each Participant shall contribute to the working meetings and to one or more workshops on the results achieved through the activities conducted under this Annex, including the identification of speakers and participants.

d) Each Participant shall make a direct financial contribution to the Operating Agent to cover co-ordination and report preparation expenses and other Annex related (e.g. Workshops) costs.
e) Each Participant shall provide a Country Report as identified in Section 4 (Task 5) and shall contribute to the deliverables identified in Section 6 ("Deliverables").

10. Specific obligations and responsibilities of the Operating Agent

The Operating Agent shall:

a) Develop, in co-operation with the Participants, a detailed work programme, a framework for the Final Country Report and a budget for all the activities carried out under this Annex, including methodology, solicitation/identification of individual Task leaders and time schedule
b) Provide the Executive Committee with periodic reports describing the progress of the work being accomplished under the Annex, once a year oral (focusing on results, achievements and/or success stories) and twice a year a management report.
c) Deliver the results as described in Section 6 ("Deliverables").
d) Provide to the Executive Committee, within six months after completion of all work under the Task, a Final Report for its approval and transmittal to the Agency.
e) In co-ordination with the Participants, use its best efforts to avoid duplication with activities of other related programs and projects implemented by or under the auspices of the Agency or by other competent bodies.
f) Provide the Participants with necessary guidelines for the work they carry out, assuring minimum duplication of effort.
g) Co-ordinate the efforts of all Participants and ensure the flow of information within the Task.
h) Co-ordinate the work to ensure the compulsory deliverables to the HPC Newsletter/Magazine and to the website.
i) Provide general administration.

The IEA Heat Pump Centre will assist in the establishment of the Annex. Thereafter, the Heat Pump Centre will follow the Annex to check that the routines are followed, that the status and progress reports are delivered in due time and the quality of them. They will also assist the OA in the publication of the final reports and compilation of the summary in the end of the Annex. Therefore, it is the responsibility of the OA to follow the instructions of Heat Pump Centre.

11. Information and Intellectual property

(a) *Executive Committee's Powers.* The publication, distribution, handling, protection and ownership of information and intellectual property arising from this Annex shall be determined by the Executive Committee, acting by unanimity, in conformity with this Annex.
(b) *Right to Publish*. The Participants shall have the right to publish information provided to or arising from their Task, except for proprietary information, as defined in paragraph (c) below.
(c) *Proprietary Information.* For the purposes of this Annex, proprietary information shall mean information of a confidential nature such as trade secrets and know-how (for example, computer programmes, design procedures and techniques, chemical

compositions of materials, or manufacturing methods, processes or treatments) which is appropriately marked provided that such information:

(1) Is not generally known or publicly available from other sources;
(2) Has not previously been made available by its owner(s) to others without obligation concerning its confidentiality; and
(3) Is not already in the possession of the recipient Participant(s) without obligation concerning its confidentiality.

It shall be the responsibility of each Participant supplying proprietary information, and of the Operating Agent, to identify such information as proprietary and to ensure that it is appropriately marked. The Participants and the Operating Agent shall take all necessary measures in accordance with this paragraph, the laws of their respective countries and international law to protect the proprietary information provided to or arising from this Task.

(d) *Production of Relevant Information by Governments.* The Operating Agent should encourage the governments of all Agency Participating Countries to make available or identify to the Operating Agent all published, or otherwise freely available information known to them that is relevant to the Task.
(e) *Production of Relevant Information by Participants.* Each participant agrees to provide to the Operating Agent all previously existing information, and information developed independently of the Task, which can assist or is needed by the Operating Agent to carry out its functions in this Task, which is freely at the disposal of the Participants, and the transmission of which is not subject to any contractual and/or legal limitations, under the following conditions:
    (1) The Participant will make such information available, at its own costs, provided that such costs are not substantial.
    (2) If substantial costs are necessary for the Participant to make such information available, the Operating Agent and all Participants will determine the charge of the costs for each participant, upon approval of the Executive Committee.
(f) *Use of Confidential Information.* If a Participant has access to confidential information which would be useful to the Operating Agent in carrying out the studies, assessments, analysis or evaluations described in this Annex, such information may be communicated to the Operating Agent but shall not become part of any report or other form of documentation issued as part of this Task, nor shall it be communicated to the other Participants, except as may be agreed between the Operating Agent and the Participant who supplies such information. This information must be marked clearly as “confidential”.
(g) *Acquisition of Information for the Task*. Each Participant shall inform the Operating Agent of the existence of information that can be of value to the Task, but which is not freely available, and each Participant shall endeavour to make such information available to the Task under reasonable conditions, in which event the Executive Committee may, acting unanimity, decide to acquire each information.
(h) Reports on Work Performed under the Task. The Operating Agent shall prepare reports on all work performed under the Task and the result thereof, including studies, assessments, analysis, evaluations and other documentation, but excluding proprietary information, in accordance with paragraph 11(c) above.
(i) *Copyright.* The Operating Agent, or each Participant for its own results, may take appropriate measures necessary to protect copyrightable material generated under this Task. Copyright obtained shall be the property of the Operating Agent, for the benefit of the Participants provided, however, that Participants may reproduce and

distribute such material, but shall not publish it with a view to profit, except as otherwise provided by the Executive Committee.
The Contracting Parties understand and agree that the name, acronym and emblem of the IEA has been notified to the World Intellectual Property Organisation (WIPO) Secretariat per Article 6 of the Paris Convention for the Protection of Industrial Property, as amended on 28 September 1979. The Contracting Parties further understand and agree that the OECD/IEA shall retain the copyright to all IEA deliverables, materials or publications published or to be published by the IEA or jointly by the IEA and a third party to this Annex. Should the Contracting Parties use any such deliverables, materials or publications they shall give full acknowledgement to the OECD/IEA as being the source of the material with a copyright notice in the following form: © OECD/IEA, (year of publication).

(j) Authors. Each Participant shall, without prejudice to any rights of authors under its national laws, take necessary steps to provide the co-operation from its authors required to carry out the provisions in this paragraph. Each Participant shall assume the responsibility to pay awards or compensation required to be paid to its employees per the laws of its country.

12. Operating Agent

Optimized Thermal Systems, Inc. (OTS) in collaboration with the U.S. Department of Energy (DOE) is designated as Operating Agent.

Contact information for the Operating Agent:

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Name	
Affiliation	
Postal address	
Telephone number	
E-mail address	

13. Participants in this Annex

The Contracting Parties which are Participants in this Task are the following:

Organisation	**Country**	**Participating**
Italian National Research Council	Italy	Participate
New Energy and Industrial Technology Development Organization	Japan	Participate
The Ministry of Knowledge Economy (MKE)	South Korea	Participate
The Swedish National Energy Administration	Sweden	Participate
Department of Energy	USA	Participate

14. Research organisations participating in this Annex

The contracting parties are the ones signing the contract, but others may carry out the research work, states those parties in the table below.

Organization, Name, address and website	Contact person, phone and e-mail	Country	Annex NT leader (Y/N)
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JCI	Paul De Larminat, Paul.DeLarminat@jci.com	France	N

Participation is open for twelve (12) months after this legal text is approved.

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