Toward natural refrigerants:

An experience sharing on production-line conversion from Thailand RAC NAMA Project

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PREFACE

Cooling in Southeast Asia is as important as heating in Northern Europe. It provides not only human comfort, but also ensures healthy work environments and food security. From any perspective, it is a remarkable social and economic achievement that an increasing number of people have access to affordable cooling technologies.

But where there is light, there are shadows too. Today, more than half of Thailand's electricity is produced just to respond to the energy demands of air-conditioners and refrigerators. Despite all the energy efficiency gains Thailand has made in the past, electricity consumption in the country is on the rise, mostly due to the soaring demand for all kinds of cooling. This not only puts Thailand's energy security at risk, but also contributes largely to climate change in a country where fossil fuel electricity production is still the norm. The scale of this problem, which stretches beyond Thailand across all of Southeast Asia and many other tropical countries, is so huge that analysts from the International Energy Agency have named it the Cooling Crisis.

Amidst the Cooling Crisis, Thailand offers a special opportunity to reduce energy and to learn. Thailand is not only amongst the largest users of cooling technologies, but also one of the largest production hubs. One out of ten air-conditioners and refrigerators sold globally is "Made in Thailand", either by local brands or for foreign companies. And while it is important that these air-conditioners and refrigerators remain affordable, it is even more important that cooling is as clean and energy efficient as current technologies allow, and that the boundaries of cooling technologies are constantly pushed. This is what we call "green cooling".

Over the past five years, RAC NAMA has worked hard to make green cooling technologies a reality in Thailand. It took a lot of convincing, but today we are looking at many positive experiences. Ten producers in Thailand have adopted green cooling technologies, recent international standards have been adopted, and technicians are being trained. And it was not private households that were the first adopters, but businesses, who now benefit from a clean technology that is paying off thanks to the immense energy savings. Today, we see a growing alliance for Green Cooling Technologies in Thailand, and I would like to extend my thanks to all the partners that have made RAC NAMA happen.

This report aims to conserve and spread the experiences of the first movers in industry in switching to cleaner cooling: the barriers faced, the strategies developed, and the procedures followed. It will give guidance to other industry players who – hopefully – at a later time will follow suit with the technological trend RAC NAMA has initiated, and with the example that our partners in Thailand have set.

EXECUTIVE SUMMARY

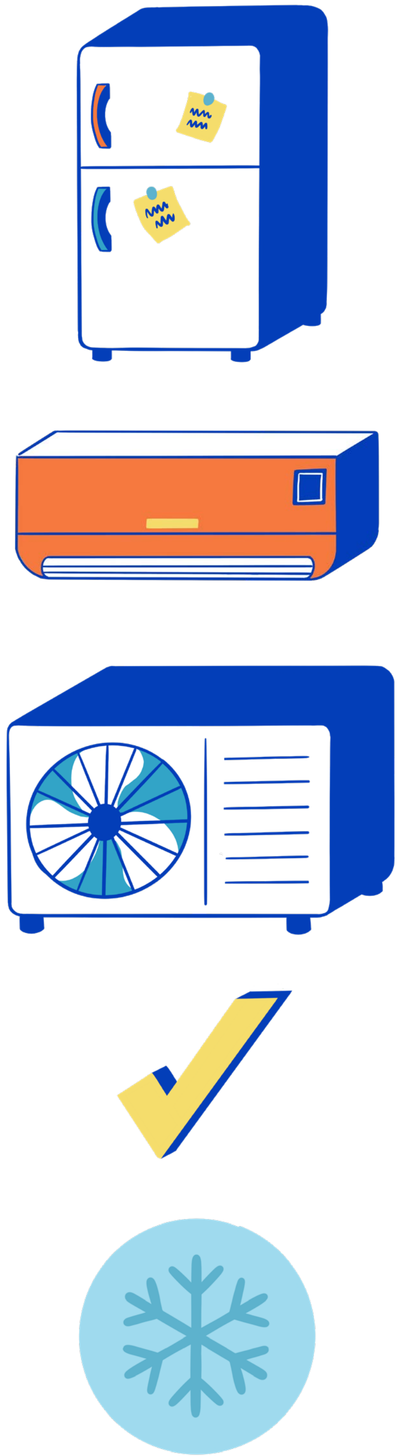
Thailand is an important manufacturing and export hub of refrigeration and air conditioning (RAC) equipment. It is therefore important that Thai producers keep up with global trends and regulations for environmentally friendly refrigerants to remain competitive. This report summarizes the knowledge and experiences of production-line conversion to natural refrigerants, especially R290 and R600a, from the RAC producers participating in the RAC NAMA project. Future producers aiming to convert their RAC production lines from the conventional refrigerant to climate-friendly refrigerants should benefit from this guideline, which will be disseminated to the rest of the industry.

The key investments for the production-line conversion are in the welding process, the refrigerant charging station and the safety equipment necessary for mitigating the flammability risk of hydrocarbon (HC) refrigerants. These include refrigerant leakage detector, electrical and ventilation system, HC-gas alarm management system, proper training for technicians and development of fire hazard and safety protocols. All of these play crucial roles in reducing the risks and ensuring the safety of operators. The manufacturers should pay special attention to acquiring skilled service technicians as well as to regulations on transportation and storage of HC refrigerants.

Besides the obstacles posed by the COVID-19 situation during the implementing phase in 2020, the main challenge for the conversion is the unavailability of input materials in Thailand, such as HC refrigerants and compressors, albeit normal when embracing a new technology. Nonetheless, as the market trend is shifting toward natural refrigerants, it is expected that a greater variety of these input materials will be available on the domestic market in the near future.

These climate-friendly technologies offer multiple benefits, among them a 50-70% reduction of refrigerant charge required for a product as well as 15-20% improvement in energy efficiency compared to conventional HFC and HCFC counterparts. These qualities substantially reduce the manufacturing cost, enhance the quality of the products, and present a significant return on investment. Lastly, the report provides practical checklists for before and after the production-line conversion and guidance to producers looking to start their own transition.

1/ Introduction



Both customer demand for refrigeration and air-conditioning (RAC) appliances and environmental concerns are growing substantially around the globe. Since Thailand is an important manufacturing and export hub of RAC equipment, Thai producers are constantly adapting to changing demands, trends and technical and regulatory advancements if they are to remain competitive. The shift away from climate-damaging technologies towards low-carbon technologies using natural refrigerant is considered one of the most effective responses to existing refrigerants. Getting to that point, however, requires significant investment and technical know-how in the development of green refrigerant product configuration as well as in the conversion of production lines to be compatible with them.

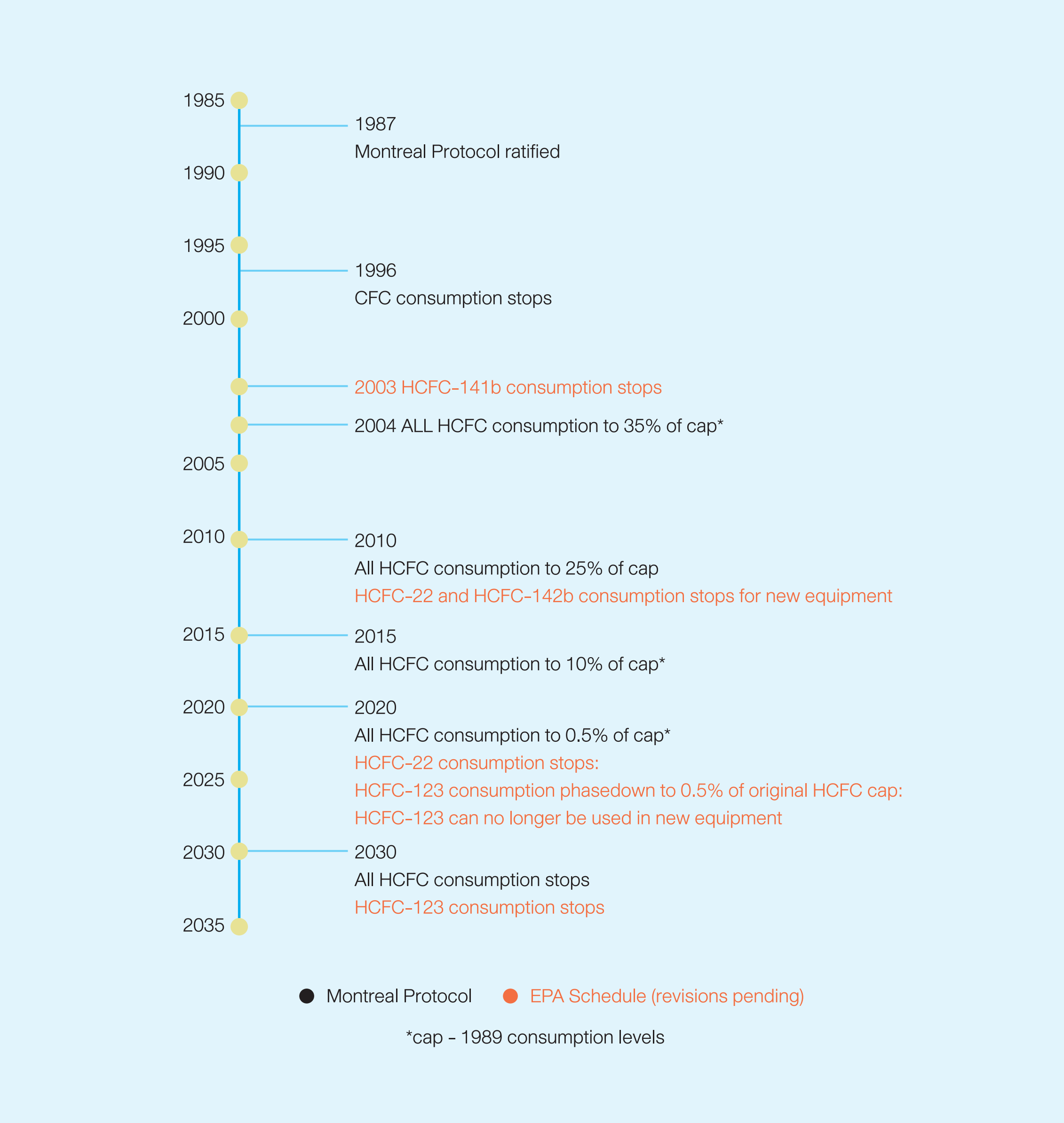


Figure 1 – Refrigerant phase-out

CFC refrigerants (which are ozone-depleting substances or ODS) were phased out under the Montreal Protocol (1989), which then targeted HCFC refrigerants from 2013. HFC refrigerants were the primary replacements as they have zero-ODP. However, HFCs have significant global warming potential (GWP) and became the target of international efforts for the phase-down and then phase-out with the Kigali Amendment (2016) under the Montreal Protocol in favour of low GWP refrigerants. For example, commercial hermetically sealed type refrigerators and freezers will be prohibited in EU countries starting in 2022 if the GWP level of the refrigerants is 150 or more (Regulation (EU) no 517/2014 2014). With this, most of the existing common refrigerants such as R32 (HFC) will be banned as it has a GWP of 675.

For this to happen, climate-friendly refrigerants are urgently needed in the RAC sector and natural refrigerants such as the hydrocarbons (HC), propane (R290) and iso-butane (R600a) derived from the petrochemical industry, are an excellent alternative with zero ODP and negligible GWP levels (Table 1).

Refrigerant	R290/R600a	R12	R134a	R22	R32
Chemical type	HC	CFC	HFC	HCFC	HFC
ODP	0	0.9	0	0.055	0
GWP	3	10,900	1,430	1,810	675
Boiling point (^{O}C)	-31	-30	-26	-41	-52
Latent heat (kj.kg)	367	145	189	100	382

Table 1 Refrigerants' physical properties (source: www.phaseoutfacts.org)

This report aims to disseminate the knowledge and experiences of production-line conversion towards natural refrigerants from the RAC producers participating in the RAC NAMA project to the rest of the industry. It provides a concise and integrated checklist, flow chart and practical guidelines for future producers aiming to convert their RAC production line from the conventional refrigerant to climate-friendly refrigerants, especially R290 and R600a. Ultimately, this report seeks to to enhance the competitiveness of the Thai RAC industry and support Thailand's goals on the reduction of energy consumption and GHG emissions.

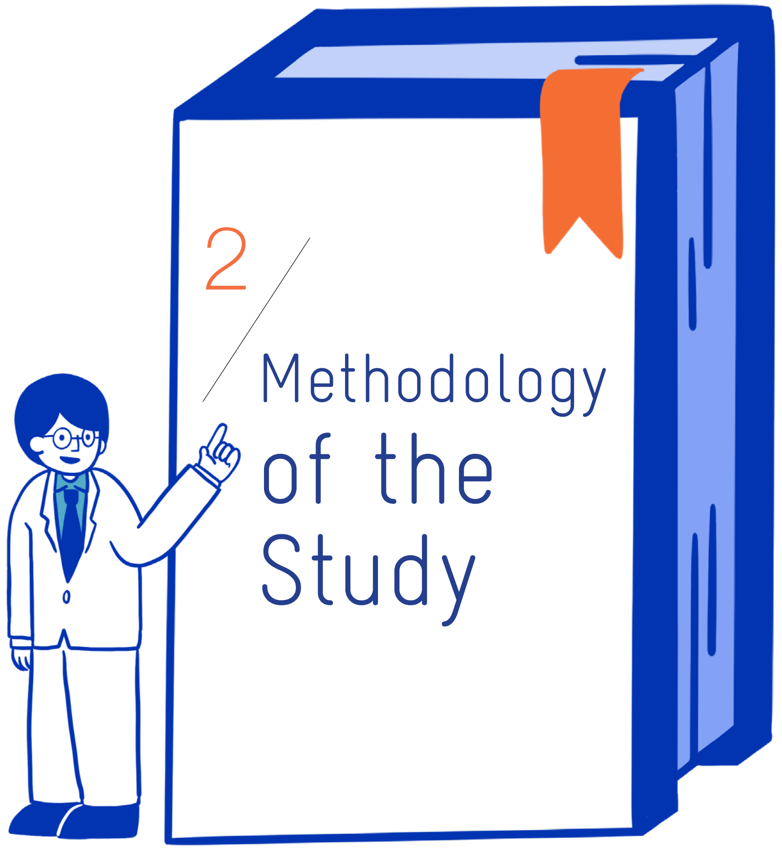
About the RAC NAMA project

Since April 2016, the Thailand Refrigeration and Air-conditioning Nationally Appropriate Mitigation Action Project, also called the RAC NAMA Project, has partnered with the Office of Natural Resources and Environmental Policy and Planning (ONEP), the Department of Alternative Energy Department and Efficiency (DEDE), the Electricity Generating Authority of Thailand (EGAT) and Thai domestic RAC producers to transfer technology and know-how, and provide financial support on natural refrigerant technologies as well as policy and technical advice to government agencies. The RAC NAMA Fund, a financial facility under the management of EGAT, was created to initiate the transformation alongside other financial tools to support the complete demand-and-supply chain, as well as the service sector, with technical support from GIZ and international experts. Through this close partnership between the government and private sector, the project is estimated to reduce GHG emissions by 0.94 MtCO2eq annually.

For more information, visit: www.racnama.org

1.1 Key elements of the report

- Illustrate the actions taken by local RAC producers and their experiences with the process of production-line conversion
- Provide step-by-step guidance for a production line transition for safe conversion under local and international rules and regulations, as well as the necessary changes for on-site storage of the finished product transportation, and servicing & training needed
- Support RAC producers with a concise and practical check sheet and/or flow chart as a guideline of the production-line conversion
- Illustrate the conversion process with a case study and/or a typical example to illustrate the implementation of hydrocarbon refrigerant conversion in the producer's factory



2 Methodology of the Study

When new technologies emerge, there are many aspects of the technology and market that need consideration and planning for successful and safe implementation, including production, raw material availability, economics, marketing, technical know-how, regulation & standards, safety, and psychological and sociological aspects (Narayan 2011 and Colbourne 2010).

This study carried out quantitative and qualitative research using 1) a survey and 2) interviews with the Thai RAC producers that have been involved in the project. Survey meetings with Thailand domestic producers were carried out for data collection and study and later carefully analysed. The questionnaire (shown in APPENDIX I) covered all aspects needed for a production-line conversion project execution: project design & engineering, Health, Safety, Security and Environment (HSSE), Operation and Maintenance (O&M), Quality assurance and Quality control (QA/QC), and Economics & Marketing.

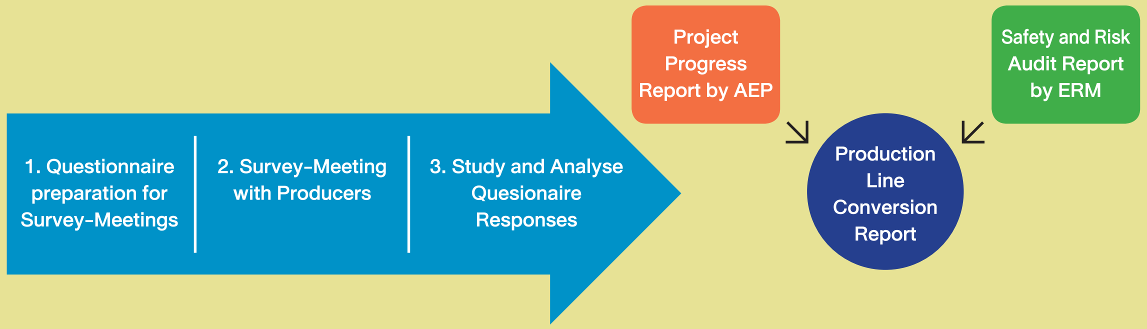


Figure2 - Research study method by surveys and interviews

Ten RAC producers joined the Thailand RAC NAMA project to receive technical and financial support for a production-line conversion toward natural refrigerants focused on HC refrigerants: R290 and R600a. For this study, data were collected from nine producers, namely, Bitwise (Thailand) Co., Ltd., Saijo Denki International Co., Ltd, Sanden Intercool (Thailand) Public Co, Ltd., Songserm Intercool Stainless (Thailand) Co. Ltd., Songserm Commercial Refrigeration (Thailand) Co., Ltd., Supreme CNB Corporation Co., Ltd, Thermedez Co., Ltd., Patana Intercool Co. Ltd, and Panasonic Appliances Cold Chain (Thailand) Co., Ltd. The research was conducted during September and October 2020 and involved meetings with top management of the participating producers and key heads of each producer's department.

It is important to note that the project was audited by two authorized third-party companies (Advance Energy Plus Co., Ltd. (AEP) and the Environmental Resources Management Company (ERM)) for project progress and project safety during the production conversion. The resulting project progress report by AEP and safety and risk audit report by ERM were included in the analysis alongside the survey and interviews. In the following chapters, the results of the study with relevant discussion (chapter 3) were provided with the conversion line's threads and barriers (chapter 4) and recommendations and guidelines for local RAC producers embarking on a production line conversion project (chapter 5). A key tool provided is an illustration of a production line conversion in the form of a flowchart and/or checklist.

3 Results and Discussion

The survey indicates that conversion projects generally have two stages:
1. a product-design stage which takes approximately 3 to 8 months, and
2. a conversion stage where production equipment is procured, installed and audited on safety taking 3 to 12 months. The design stage comes first and is followed by the installation stage with 2 to 3 months of overlap, resulting in 6 to 12 months for project completion.

Accounting for minor variations between producers,
there are 16 steps in the RAC production line (Figure 3).
These steps can be separated into 2 categories as given in point 3.1 below.

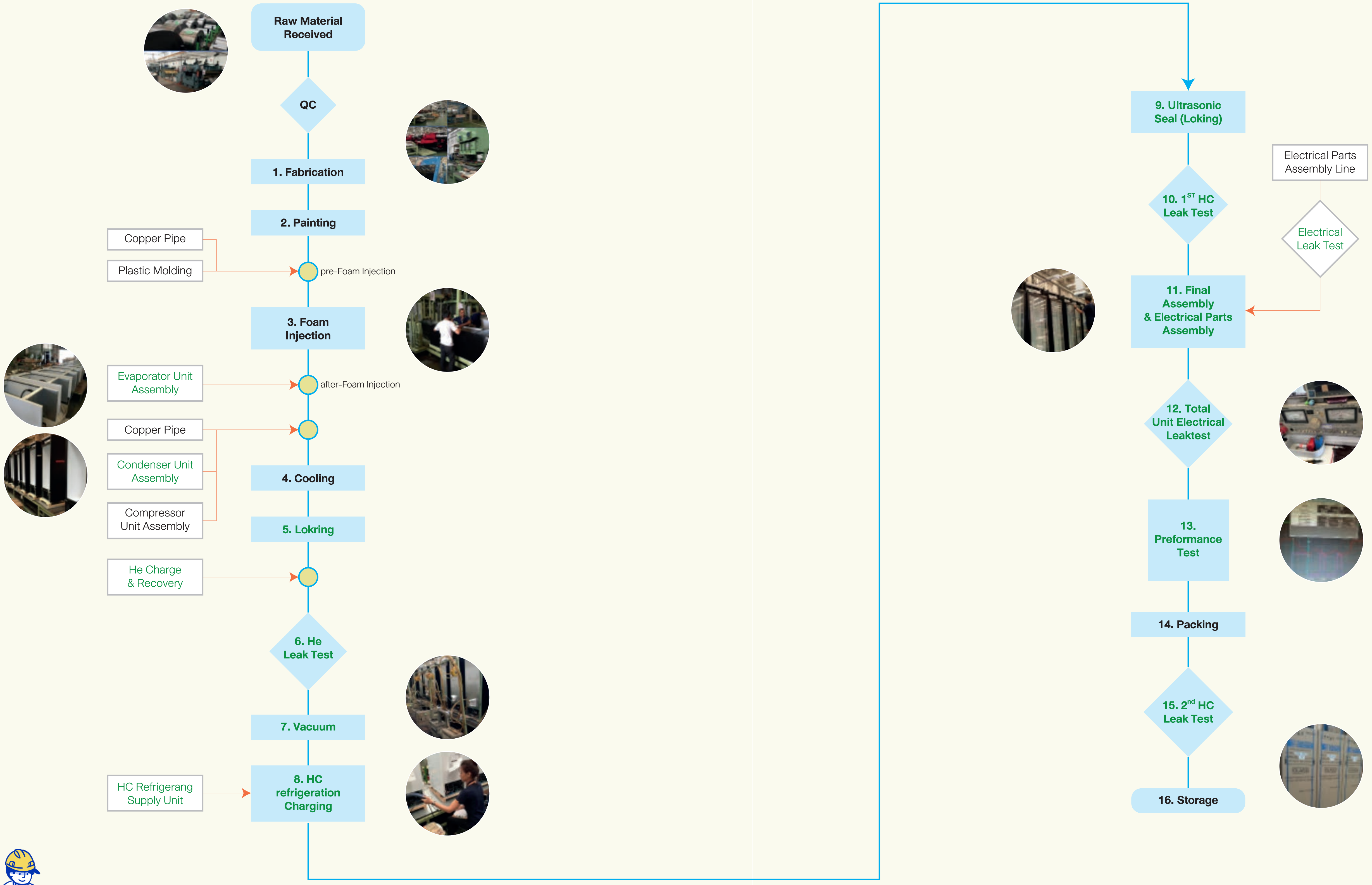


Figure3 - Typical production line conversion example

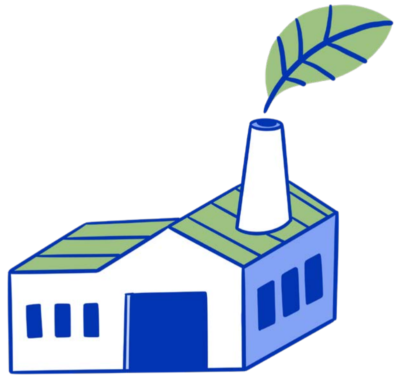
3.1 / Methods used for the transition: identifying similarities and differences

The 16 steps of the production line after conversion can be separated into two categories. The **"common steps"** (identified in BLACK text) are shown in both the non-HC refrigerant production line (before transition) and HC refrigerant production line (after transition). Later, the "HC refrigerant particular steps" are identified in GREEN text (Figure 3), because these steps are modified and/or (new) added to be able to produce HC RAC product according to the RAC NAMA project.

The list below outlines the equipment required in

"HC refrigerant particular steps"

of the production-line conversion toward HC refrigerants.



The nitrogen leak test is a typical method for a production line of non-HC RAC products. However, the precision leak test by helium and refrigerant (HC) leak detector is required to investigate a RAC product due to the high risk of flammable substances (items 2 and 6). Brazing welding has been superseded by LokRing technology and ultrasonic welding to avoid the risk of explosion from HC flammable refrigerants (item 1).

Existing refrigeration charging and leak detector equipment has been specifically changed to be compatible with HC refrigerants (items 3, 4, and 7). Flammability risks are mitigated through the use of explosion prevention equipment: electrostatic measurement and ignition protection (item 8) are compulsory for line conversion, especially for the storage area of HC refrigerants. Ventilation and safety systems are also essential to mitigate the risk of ignition events (item 5), as are performance tests, to ensure that equipment is performing as expected and to detect issues that arise (item 9) so as to address them early.

1. LokRing system and ultrasonic welding
2. Helium charge and recovery
   Helium leak detector
3. Vacuum kit
4. Refrigerant (HC) charging station
5. Ventilation & safety system
6. Refrigerant (HC) leak detector
7. HC discharge units
8. Electrical safety tester system
9. Performance test and recorder

3.2 HC refrigerant flammability – concerns and risk mitigation

To address the flammability concerns, the conversion must include electrostatic measurement, explosion-proof equipment, lightning protection system as well as a gas detector system. The electrostatic measurement investigation for an existing assembly line should be in the Risk Assessment during the project implementation. Proper earthing connections (ground circuit) and antistatic floor may be needed for the hazardous areas, depending on the Risk Assessment analysis e.g., HC refrigerant leakage. The Fire Triangle (Figure 4) is the principal guide to assess fire hazards and develop prevention systems.

When steps 1 to 7 (Figure 3) are assessed using the Fire Triangle's flow chart (Figure 4), there are no flammable substances involved in the converted assembly line. Therefore, no risk mitigation actions are required. However, from step 8, mitigation actions are needed since flammable substances are part of the process.

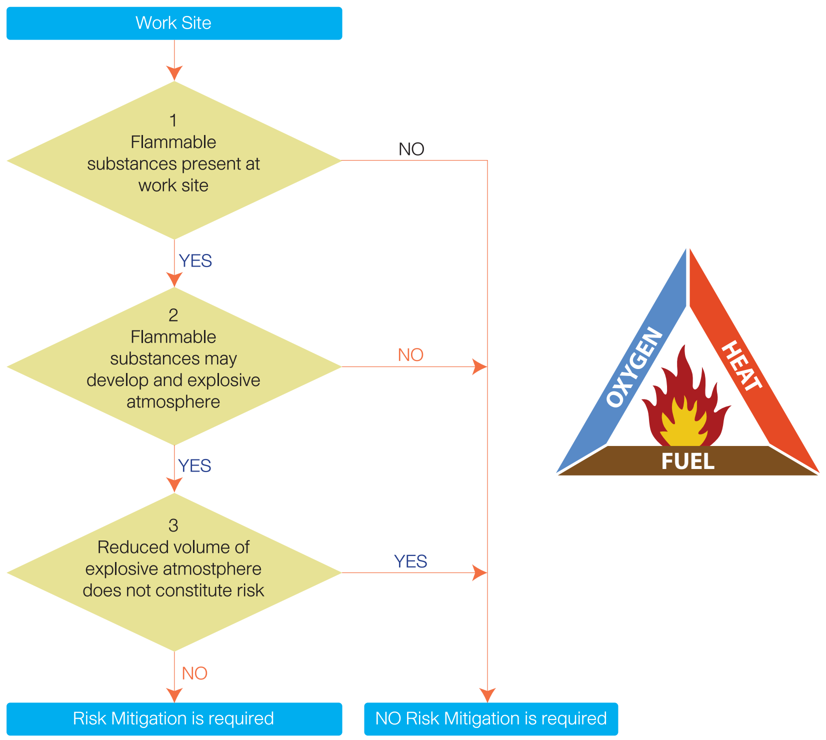


Figure 4 – Fire triangle and fire mitigation flow chart

Atmospheres Explosible (ATEX) zoning should be applied to the line conversion starting from HC refrigeration charging, step 8. ATEX zoning shall be identified at the start of the project feasibility study as required: 1) ventilation system, 2) adequate certified electrical equipment (explosion proof), 3) grounding system (electrostatic measurement), and 4) gas detector system.

The safety and audit report by ERM mentioned the need to improve the ventilation system as a result of the incomplete electrostatic system and recommended that the producers ensure risk mitigation. Proper ventilation design mitigates explosive risk by reducing the risk that explosive atmosphere volume is reached as shown in step 3) of the Fire Triangle's flow chart.

With regard to electrical equipment, any electrical component of the refrigeration system must be spark-free e.g., lighting, fan motors, relays, etc. This is essential to minimize the risk of explosion and fire hazard as clearly clarified in the safety audit reports.

Grounding measures for production-line conversions must be installed at the beginning of the conversion project to ensure the electrical safety of the production lines. Thus, the scope of work of the safety and audit report shall be specified clearly for the electrostatic measurement, including in the safety audit checklist by the third-party auditors.

Gas sensors and detector systems have been properly provided in ATEX area of line conversion, as clarified in the safety audit report. However, maintenance and operation for HC production line must be further encouraged among producers; therefore, work instruction (WI) shall be modified and updated. The logic behind an interlocking system to shut down the production line by the gas detection system will be discussed during a safety audit. As such, interlocking systems should be considered during the safety audit (Figure 5).

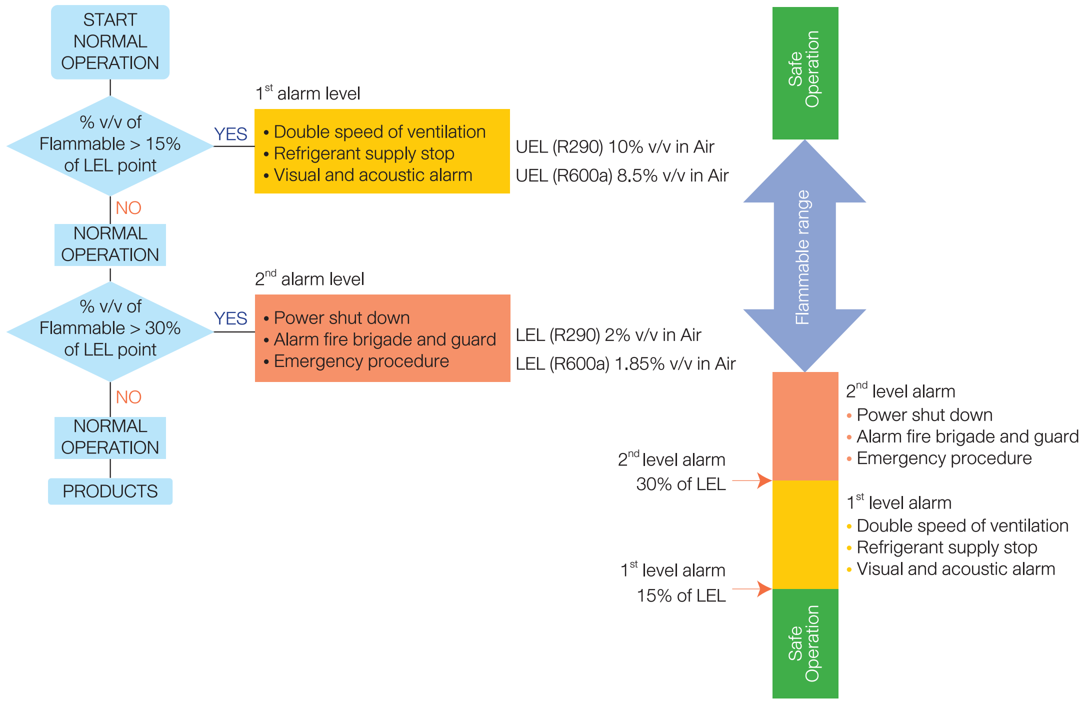


Figure 5 – Example of hydrocarbon gas alarm system and interlocking logic flow chart

Figure 5 illustrates an interlocking system related to gas flammability limits (Lower Explosive Limit: LEL and Upper Explosive limit: UEL) and interlocking setpoints (the 1st level setpoint and the 2nd level setpoint). LEL and UEL are specified in terms of percentage by volume (% v/v) and depend on each substance's level of flammability; the example shows the level for R290 and R600a. Gas concentrations in the atmosphere higher than UEL are "too rich" to burn (explode) as well as "too lean" to burn (explode) when gas concentrations in the atmosphere are lower than LEL.

The gas detectors provide 2 levels of alarm setpoints should there be a leakage of flammable gas (the 1st level alarm at 15% v/v of LEL and the 2nd level alarm at 30% v/v of LEL). If the levels are reached, an alarm is transmitted to the interlocking system and the system will mitigate the risk of ignition as follows:

- Ventilation speed will be doubled
- Refrigerant supply stops
- A visual and acoustic alarm will be generated to alert staff

If the mitigation procedures of the first alarm do not succeed in reducing the presence of the flammable agent sufficiently, the second alarm setpoint at 30% v/v accumulation of flammable gas triggers the following actions:

- Power shut down
- Call the fire department
- Emergency procedure

3.3 Reduced refrigerant charge and energy efficiency gains from using HC refrigerants.

Given the excellent thermal transfer properties of HC refrigerants, the transfer charge needed is much smaller than HFCs and provides energy efficiency improvements. This is a recognised advantage of HC refrigerants in terms of cost savings and market opportunities.

The refrigerant charge needed for HC RAC equipment is approximately 50-70 % lower than for HFC refrigerants. In their reports, AEP estimated this charge reduction (Figure 6) at 37.4 tonnes, 51.4 tonnes, and 70.1 tonnes of refrigerants between 2020 and 2022 if the planned conversions are completed. Thus, a total reduction of 158.9 tonnes can be achieved within 3 years. This information assists producers in their decisions due to significant cost reduction resulting from the conversion project.

Similarly, HC refrigerants enable greater energy efficiency in RAC systems compared with HFCs and HCFCs (Energy Research Institute 2018; Colbourne and Suen 2000; and Park and Jung 2007) reducing the energy consumption of such systems by 15-20%. Three years after launching a RAC product using HC refrigerant, AEP estimated accumulated energy savings of 4923 MWh as the minimum that can be achieved by the end of the third year if all conversions are completed (Figure 7).

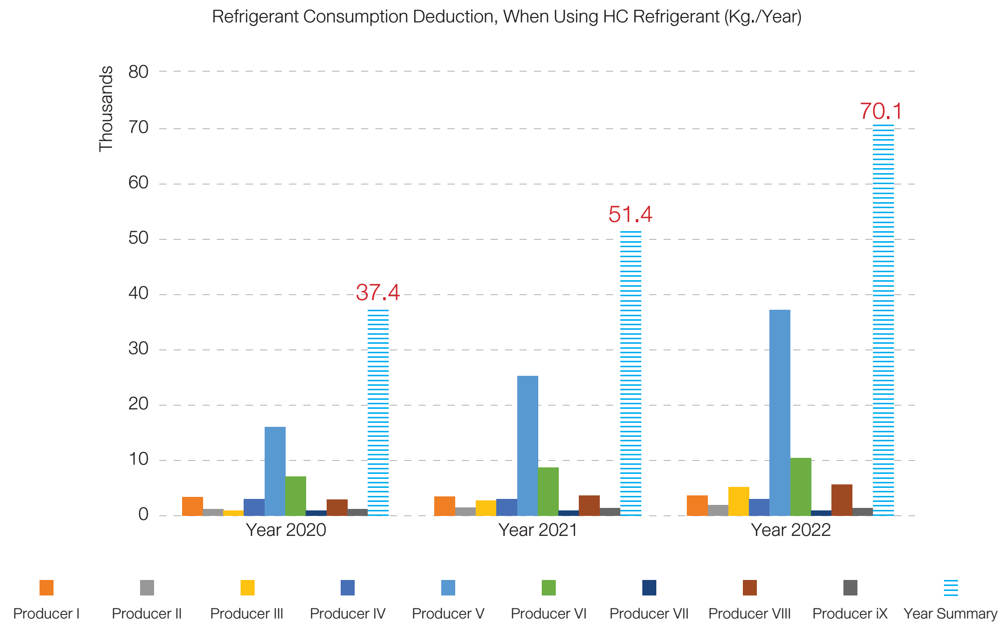


Figure6 - Refrigerant charge reduction using HC refrigerants (Source: AEP report and survey)

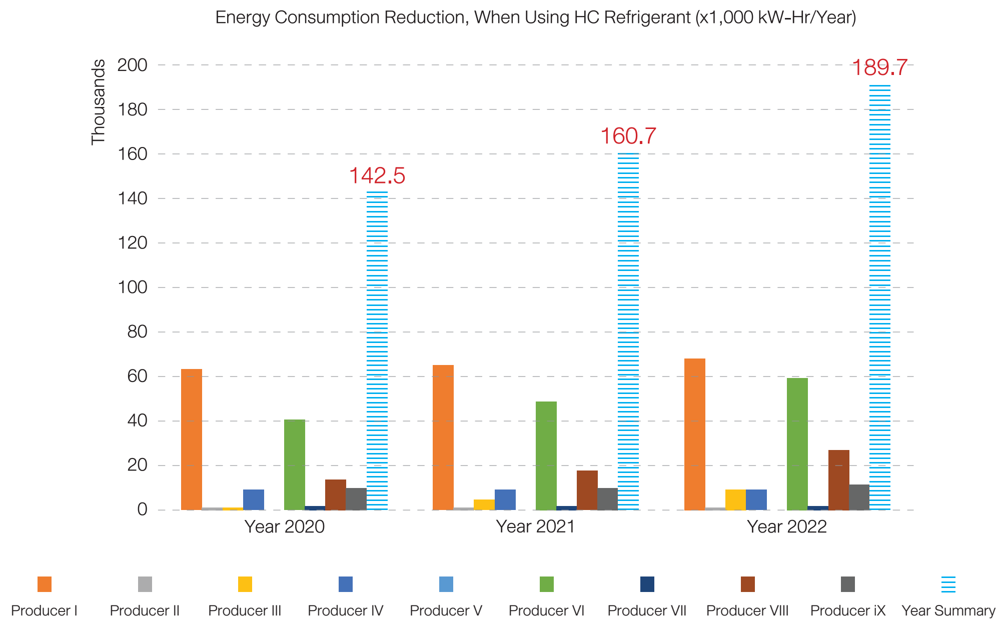


Figure7 - Energy consumption reduction with HC refrigerant (source: AEP report and producers' survey)

4

Process Highlights, Common Threats and Barriers

Narayan (2011) and Colbourne (2010) focused on barriers faced in production-line conversion in terms of technology, supply, availability (raw material), and economics and marketing. However, a more complete system analysis also highlights possible barriers arising from other components of the business's supply chain (Figure 8).

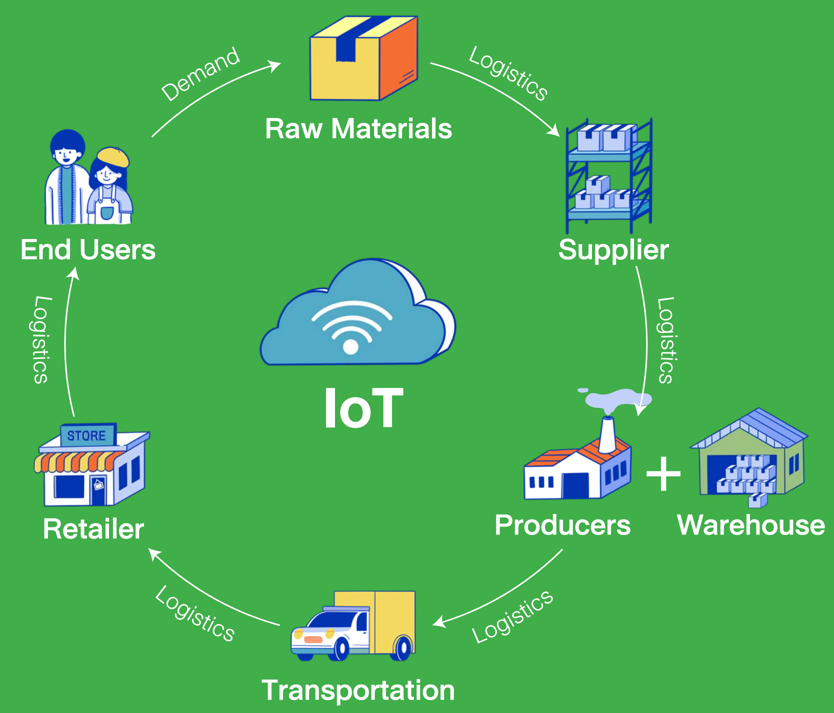


Figure 8 - Supply chain schematic (source: https://corporatefinanceinstitute.com)

4.1 Force Majeure (Covid-19 Pandemic)

Force majeure refers to situations that are outside the control of the producers and which little can be done to prevent. It usually refers to natural disasters such as floods, earthquakes, and similar events.

Of the ten domestic RAC producers, chiller producers, refrigerator producers, and air-conditioning producers which have been technically and financially supported by the RAC NAMA Fund, three had not completed the conversions at the time of the interview due to the Covid-19 pandemic.

- The restrictions of movement and trade associated with the COVID-19 pandemic have obstructed project execution, causing delays of around 6 months or more. Major effects range from a delay in machine delivery to technical specialists unable to enter Thailand for machine installation and commissioning.

4.2 Unavailability of suppliers

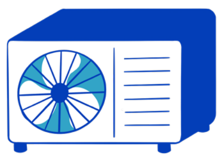
Another lesson learnt during the project execution in 2018 and 2019 relates to the obstacles posed by the unavailability or low availability of domestic suppliers of HC refrigerant, HC compatible compressors and other related specialized equipment. Hence, GIZ and HEAT GmbH are now supporting the mitigation of this issue through a market search for local suppliers. This could, in turn, support the development of an HC refrigerant supply chain in Thailand and develop a new market segment.

- HC refrigerants, such as R290 (propane) and R600a (iso-Butane), are derived mainly from the petrochemical industry. Indeed, LPG (a mixture of mostly propane and iso-Butane) has been freely traded in Thailand for usage as household cooking gas by LPG traders. However, most Thai producers have confirmed the unavailability of these HC refrigerants when contacting refrigerant suppliers. This is a normal issue for new technologies in a region.
- The unavailability of the HC compressor (CS), raised by producers during producer visit meetings, is another bottleneck. The next step is to seek for a solution.

There are three domestic HC refrigerant compressor suppliers – Siam Compressor Industry Co., Ltd., Kulthorn Kirby, and Hitachi Compressor (Thailand) Ltd – but the CS size range is a major limitation for RAC products. The Rechi compressor (Taiwan) and the GMCC compressor (China) were imported by some RAC producers. However, the compressors need to be certified by the Thai Industrial Standards Institute (TISI) as either imports or domestic products as per TIS 1529-25XX (20XX): มอก. 1529-25XX.

While options for R600a and R290 CS for domestic and commercial refrigeration are still limited, more CS models for HCs are now being locally produced in Thailand because demand has been on the rise in the past few years.

In terms of the technical prospects, the HC refrigerant provides higher efficiency compared with non-HC refrigerant (Energy Research Institute 2018; Colbourne and Suen 2000; and Park and Jung 2007). As a result, the HC compressor has the benefit of being cost-effective for industrial-scale production while offering the same capacity. This means that the price of the HC compressor on the global market is cheaper (Colbourne 2010)



NOTE:

Marketing research for HC refrigerant and compressor traders was carried out as part of a vendor list. The list is provided in APPENDIX IV.

4.3 Service sector skills with HC refrigerants – installation and maintenance

Another aspect of the adoption of new technologies is the availability of qualified service professionals who can support the deployment. This has been considered by various producers who wish to develop their capacities to provide service by qualified engineers to customers. It is also seen as a risk, as markets often rely on unqualified "handymen" for this type of work, raising the possibility of a negative event. However, some large, national-scale customers usually handle such work through their inhouse service (maintenance) department.

- During the interviews, the producers mentioned that the production-line conversion would be affected in terms of marketing, especially in relation to after-sale services, as only a few local RAC service contractors could undertake the RAC service work (maintenance work). This is largely due to the lack of know-how and special tool kits for service work as well as technical knowledge specific to HC RAC products.

NOTE:

The Thailand RAC NAMA project has established a training hub at King Mongkut's University of Technology North Bangkok (KMUTNB) and other 7 training centres throughout the country in cooperation with the Department of Skill Standard (DSD) and the Office of Vocational Education Commission (OVEC). Thus far, these training hubs have provided training in safe use and handling of flammable refrigerants (R Training) for Thai trainers (222 trainers trained). By 2022, the number of technicians is expected to reach 2,000 – 3,000.

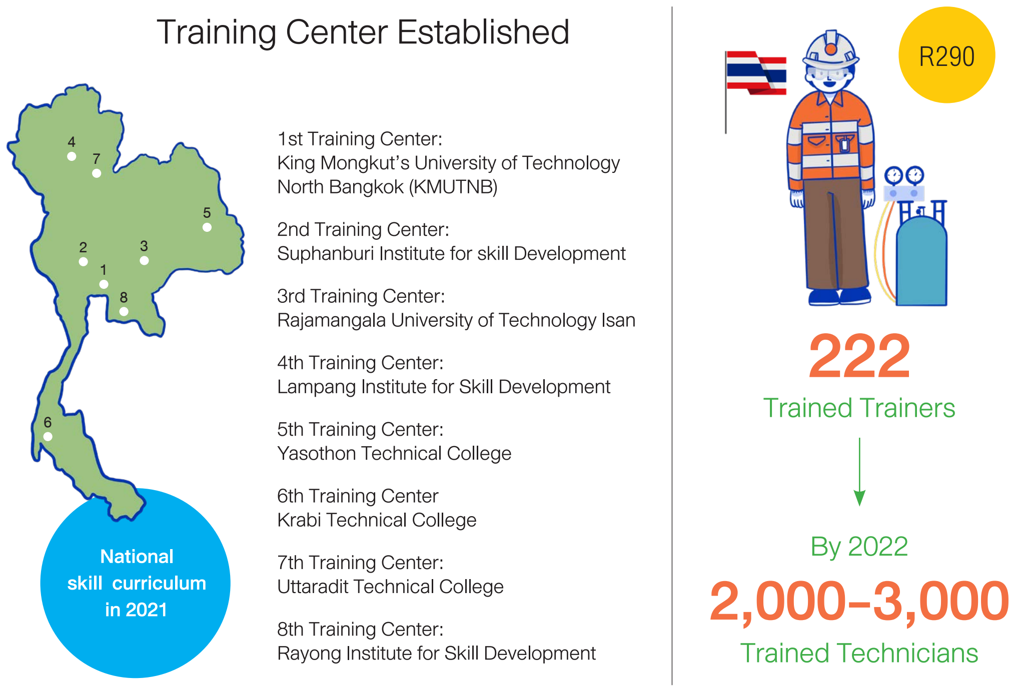
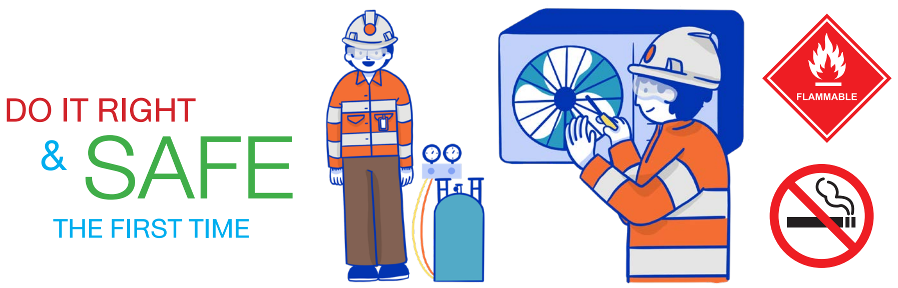


Figure 9 - Training plan and schedule of Thailand RAC NAMA



The training aims to minimize the associated risks when handling flammable HC refrigerants :

- Use an appropriate tool, equipment and Personal Protective Equipment (PPE)
- Correctly and safely handle flammable HC refrigerants during installation, maintenance, servicing and repair, dismantling and disposal
- Understand the concept of protection against hazards and be able to identify risks

Figure 10 - Risk mitigation for Thailand RAC NAMA project

4.4 Storage and Transportation of HC refrigerant and HC RAC products

The producer visit survey discussed most of the parameters in the Supply Chain system (Figure 8), except Warehouse (Storage), Transportation, End Users, and End-of-life treatment of RAC products. End Users and End-of-life treatment do not fall under the scope of this study. In addition to the unavailability of HC refrigerant and compressors (HC refrigerant) raised during producer visits, other possible common threats and the barriers faced in the production-line conversion were also mentioned. These are covered in the next chapter.

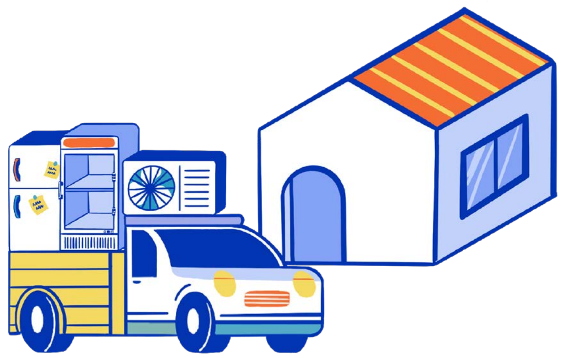
4.4.1 Storage method (Warehouse) for HC refrigerant

The storage method of flammable refrigerants (Warehouse) requires a safety and risk audit for production line conversion by authorized auditors to comply with Thai law and the Regulation of the Ministry of Labour, B.E. 2555 (2012). The regulation is compulsory for a safe workplace in Thailand as a general law and is relevant to every manufacturer. However, the application of HC as refrigerants rather than for cooking or burning in other processes is not specifically mentioned in the regulation. Nonetheless, the use of HC for green cooling technology of the Thailand RAC NAMA project is relevant for the Notification of the Ministry of Energy Subject B.E.2554 (2011). A "Suggestion Note" has been generated by GIZ and HEAT GmbH to provide advice on complying with regulations for transition projects and this can be found in APPENDIX V. Finally, a flow chart of LPG storage for production line conversion as a practical checklist is presented in point 5.2.1 as a guideline.

It is to be noted that not only is the HC refrigerant planned as a raw material for the production line, but it is also not categorized for usage as a household cooking gas.

4.4.2 Transportation for HC RAC products

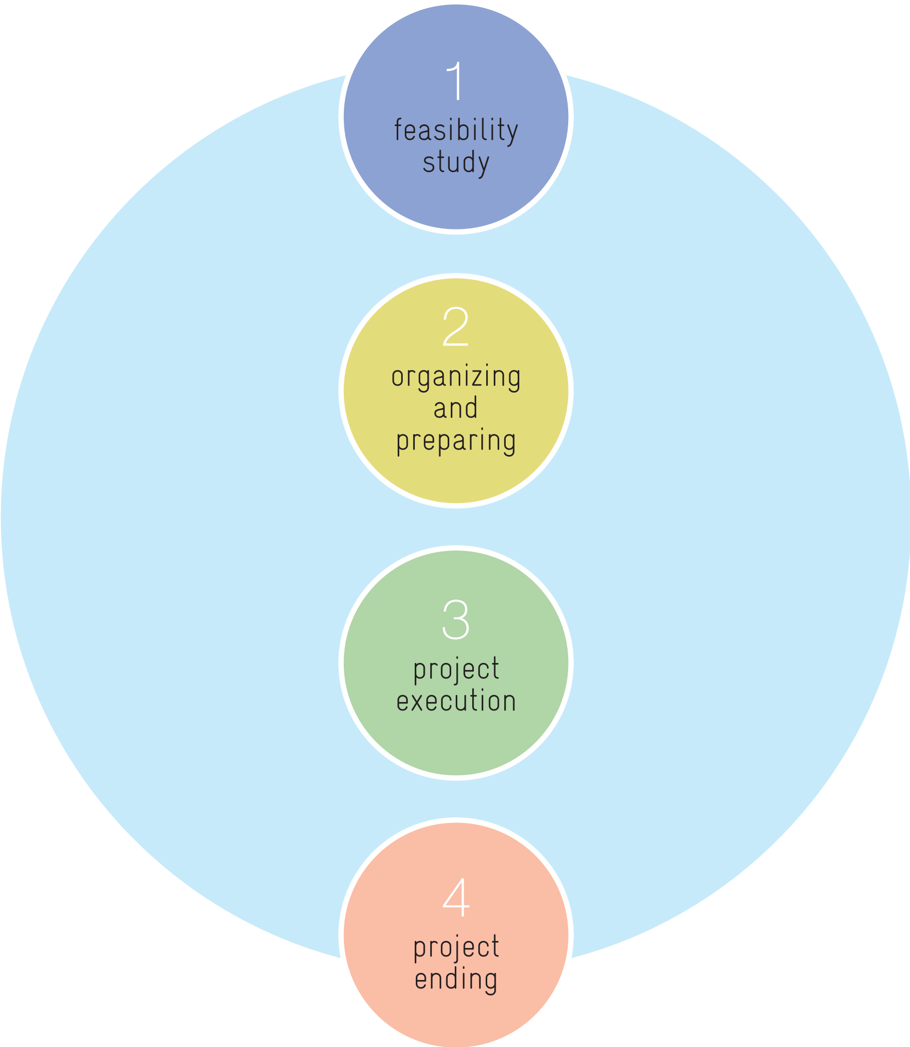
The Land Transport Act B.E. 2522 is a compulsory regulation affecting the transportation of all dangerous goods in Thailand. However, HC refrigerant has been exempted from the Hazardous Substances Act 1992 (B.E.2535) according to the Notification of the Ministry of Energy Subject B.E.2554 (2011). The rules and regulations to transport HC products should be in line with the law under the Department of Energy and/or Department of Land Transport. The checklist for transportation (if required) is presented as a flowchart checklist (Figure 13). Besides, the Thai Provisions Volume 2 (TP-2) (ข้อกำหนดการขนส่งสินค้าอันตรายทางถนนของประเทศไทย: 2547) has been developed for the transportation of dangerous goods for local regulation by the Department of Land Transport covering 1) driver and driver's license, 2) transport vehicles, and 3) transport operator. The provision refers to an international regulation, ADR: 2003 (European Agreement concerning the International Carriage of Dangerous Goods by Road:2003). It is the responsibility of producers to check compulsory laws and regulations and any changes to them.



Chapter 3 described and discussed the present condition and status of Thailand RAC NAMA line conversion and the threats and barriers assessment were covered in Chapter 4. This chapter provides recommendations and guidelines to support a safe and effective production line conversion. The primary and most important recommendation is to ensure that a safety and audit assessment is carried out and that a Management of Change (MOC) approach is implemented for line conversion. The MOC tools such as checklist and flow chart (Figure 11) can be used as guidelines during the project's feasibility study.

5.1 Summary of actions taken by producers (responsibility assignment matrix)

It is recommended that top management and/or the head of each producer's department have clear and well-structured duties for the line conversion project. This allows for better preparation and planning to support a successful project. The Association for the Advancement of Cost Engineering (AACE International 2005) recommends 4 steps for project planning and execution as follows.



Progress and project performance are assessed at the end of each stage to support decision making (go/no-go decision to the next step). The first and the second steps are the most important when considering project decision/execution. Equally, both stages require a work break down structure (WBS). A responsibility assignment matrix for each department of the producers is shown in Figure 11 – with roles and duty (project organization) in the YELLOW boxes versus WBS tasks (activities) in the BLUE boxes for a production-line conversion project. The matrix should be employed as a practical checklist for cost-effective project success.

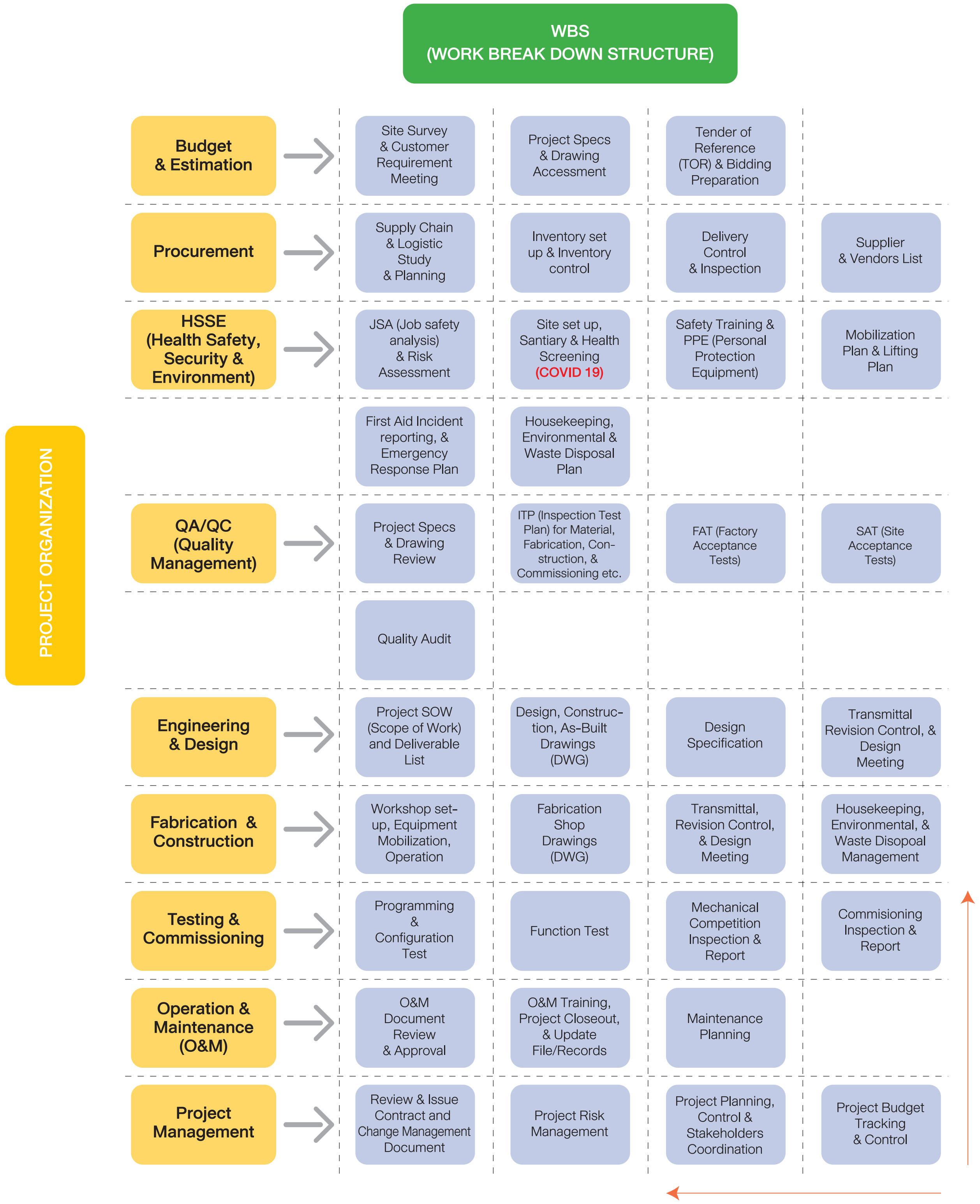


Figure 11 - Project organization versus WBS: efficient work allocation for a successful project.

5.2 Significant checklist for a factory audit before the conversion

In terms of the supply chain cycle of RAC products, 2 important vulnerabilities can be improved from lessons learnt during the project implementation. These are 1) local Thai law for HC refrigerant (LPG) storage, and 2) transport of products containing LPG

5.2.1 Recommended practice for HC refrigerant (LPG) storage

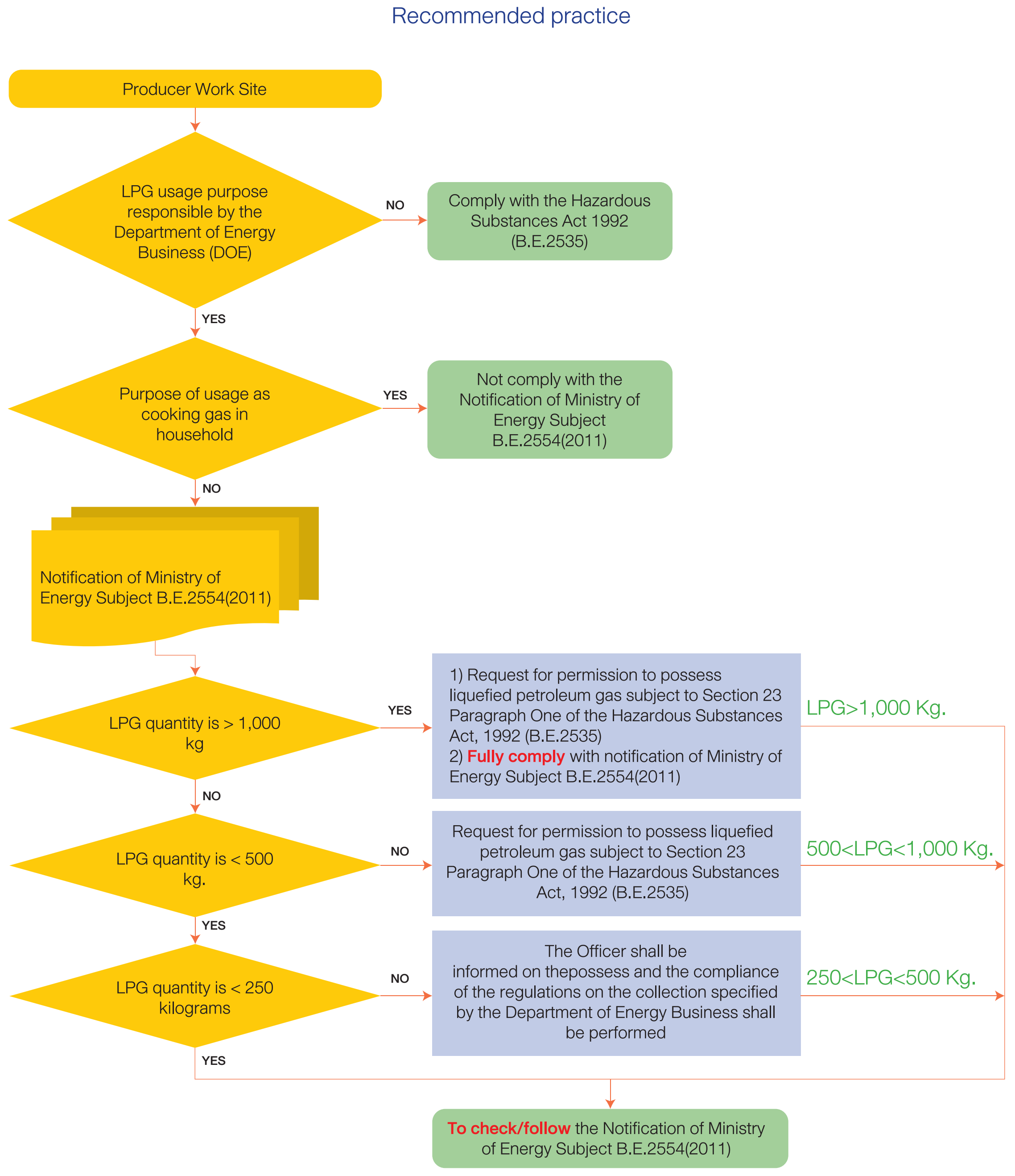


Figure 12 - Flow chart for HC refrigerant (LPG) storage for RAC producers

Producers' LPG storage areas must comply with the Notification of the Ministry of Energy Subject B.E.2554 (2011) as shown in Figure 12. Even where producers hold only a small stock of LPG, below 250 Kg, they must study and follow the regulation in terms of safety such as lightning protection and fire protection. Detailed practices have been specified in the SUGGESTION NOTE: SGN-01-2020_Refrigerant Storage _Rev B (APPENDIX V).

5.2.2 Recommended practice for HC refrigerant (LPG) transportation

Regulations relating to the transportation of LPG as a RAC product is ambiguous. LPG for RAC products should be clarified under the Ministry of Energy Subject B.E.2554 (2011). However, the law does not mention specifically the transportation of LPG when used as raw material for the RAC industry. This report recommends that if LPG for RAC product becomes specified as a "Dangerous product" in the near future, producers must ensure they understand the regulation and make preparations to comply with the Land Transport Act B.E. 2522 (Figure 13).

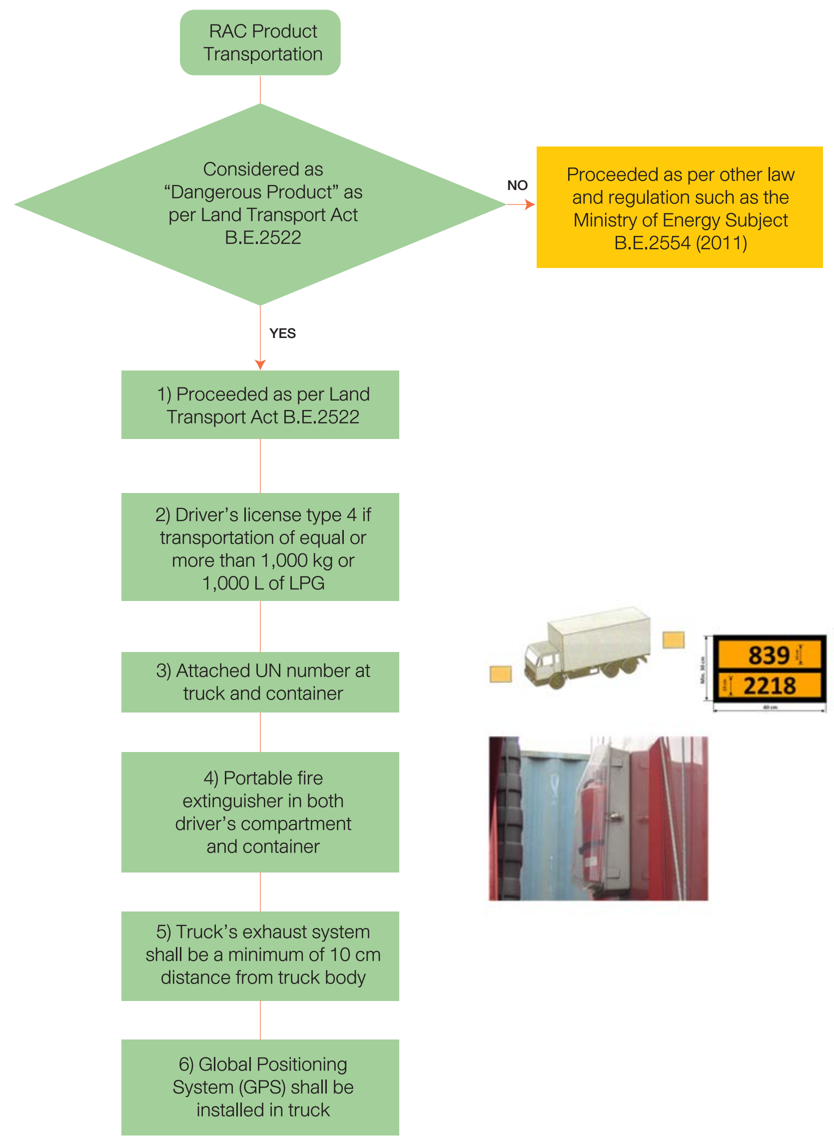


Figure 13 - HC RAC (LPG) product transportation

5.2.3 Recommended practice for electrical grounding system

Grounding is essential to avoid the build-up of static electricity resulting in the possibility of sparks that could light the flammable refrigerant and become a fire risk with or without the need for ATEX (Narayan 2011). Thai Law/Regulations relating to the electrical grounding system for the RAC production line are clearly defined in the following regulations:

- The Regulation of the Ministry of Industry, B.E. 2550 (2007), issued under the Factory Act, B.E. 2535 (1992), Re: Safety Standard for Electricity System
- The Regulation of the Ministry of Labour, B.E. 2558 (2014), Re: Management Standard on Safety Occupational Health and Working Environment Related to Electricity
- Notification of the Department of Labour Protection and Welfare, B.E.2558 (2015), Re: Criteria, Method, and Condition for Conducting Records for Inspection and Verification of Electrical System and Electrical Equipment

The following are good practices for grounding systems before the conversion:

- Ensuring new ground rod system and auxiliary are checked and tested to make certain they are operational.
- The grounding system testing and layout must be provided (including update of the information of the added grounding in the grounding test plan).
- An Inspection Test Plan (ITP) and maintenance programme for the electrical grounding system should be developed.

5.3 Technical recommendation on prototype design

GIZ was requested to provide technical support on prototype development and performance testing during the producer visits. RAC experts (HEAT GmbH) have provided technical guidelines to initiate prototype design from existing RAC experience. The guideline procedure can use time-saving and cost-effective budget methods, as shown as in the flow diagram "Recommended Practice for Prototype Design" (Figure 14) below.

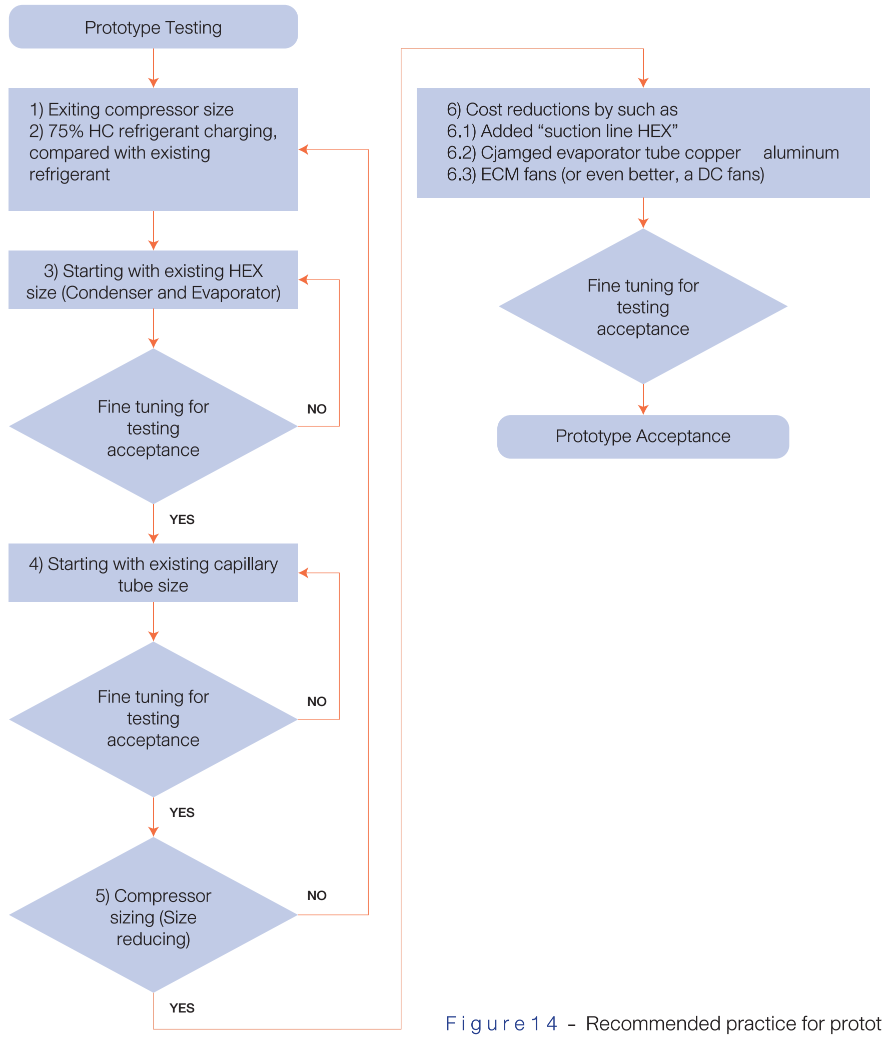


Figure 14 - Recommended practice for prototype design

Required safety features for prototype development implemented by producers must comply with local and international rules and regulations for flammable use, e.g., TIS 1529 Air Conditioner Safety Requirements. All refrigerant systems of the RAC product, as well as production line machinery & equipment, must comply with explosion-proof standards and have spark-free motors, fan, relay etc. Manipulation systems for flammable refrigerant, e.g., filling, discharge, storage, etc., must comply with local regulations and/or international standard (Colbourne 2010, Colbourne & Suen 2000, and Narayan 2011).

Following the flow chart for recommended practice for prototype design (Figure 14), the prototype should be built using the existing compressor with an HC charge approximately 75% compared to the existing HFC design (steps 1 and 2). Then, use the existing heat exchangers (HEX) initially for the evaporator and condenser then fine-tune them with testing of the prototype (steps 3 and 4). The compressor size can be obtained as part of this testing (step 6). In addition, the energy-saving performance of the RAC product can be tested in step 7) and other design features such as a suction line HEX, the use of an electronically commutated motor (ECM) or direct current fan (DC fan).

Practical detailed practice has been specified in the see APPENDIX VI.

5.4 / Checklist for a factory audit after the conversion

A factory audit after the conversion must be carried out, providing a safety and risk investigation report by third-party auditors, and include the followings:

- Review overall safety programmes and identify potential risks, unsafe and substandard conditions in operation and maintenance (O&M).
- Provide feedback report for effective improvement of the site's safety.

The checklist below provides a general guideline for producers to ensure a safe workplace according to local and/or international regulations as mentioned earlier.

Item	Description	Complied	
		YES	NO
1	Project overview	○	○
2	Plant layout/unit arrangement layout	○	○
3	New refrigerant process manual	○	○
4	Safety operating procedures (SOP) and Work Instructions (WI) for operation and maintenance of the new refrigerant process	○	○
5	Machine/unit inspection and test report & records: Inspection and Test plan (ITP)	○	○
6	Preventive maintenance (PM) plan and records for new refrigerant process	○	○
7	Safety certificates	○	○
8	Emergency preparedness and response plan and emergency drill records	○	○
9	Firefighting equipment inspection records	○	○
10	Training records for operators working on new refrigerant process	○	○
11	Chemical management procedure	○	○
12	Permit for work system and records	○	○
13	Hot work procedures and record	○	○
14	Grounding measurement (Electrostatic Measurement)	○	○
15	Lightning protection system	○	○

Table 2 Checklist for a factory audit after the conversion (Data from ERM report)

Based on the experience of the RAC NAMA Project, producers should pay close attention to the fire safety and emergency response, electrical safety and operation and maintenance.

With regard to the fire safety and emergency response, gas detection systems must be continuously operational in refrigerant charging areas, storage and testing lab. Fire hose cabinets should be provided in such areas with portable fire extinguishers as well as warning signs on fire hazard and the use of PPE. A fire-prevention plan, fire alarm system and emergency drill must be introduced to personnel who work in these areas in the forms of working instructions, a manual, and periodic training.

Accessible fire extinguisher with signpost

Fire protection for outdoor HC refrigerant storage

Ventilation for HC refrigerant storage

Security fence for HC feeding system

HC refrigerant storage shed

Figure 15 – Example of fire extinguisher for HC refrigerant storage and HC refrigerant feeding system with proper venting (Narayan 2011)

In addition, an Atmosphere Explosive (ATEX) guideline is advised. Safety valves to transfer line and explosive-proof fan must be installed in the storage and charging station. At the refrigerant charging station, there should be gas detector(s) and a ventilation system connected to an alarm as well as a wall around the charging station sealed and secured to the ground to contain refrigerants in controllable areas in cases of leakage. An uninterruptible power supply (UPS) system must be provided to all gas detection systems.

Refrigerant charging station

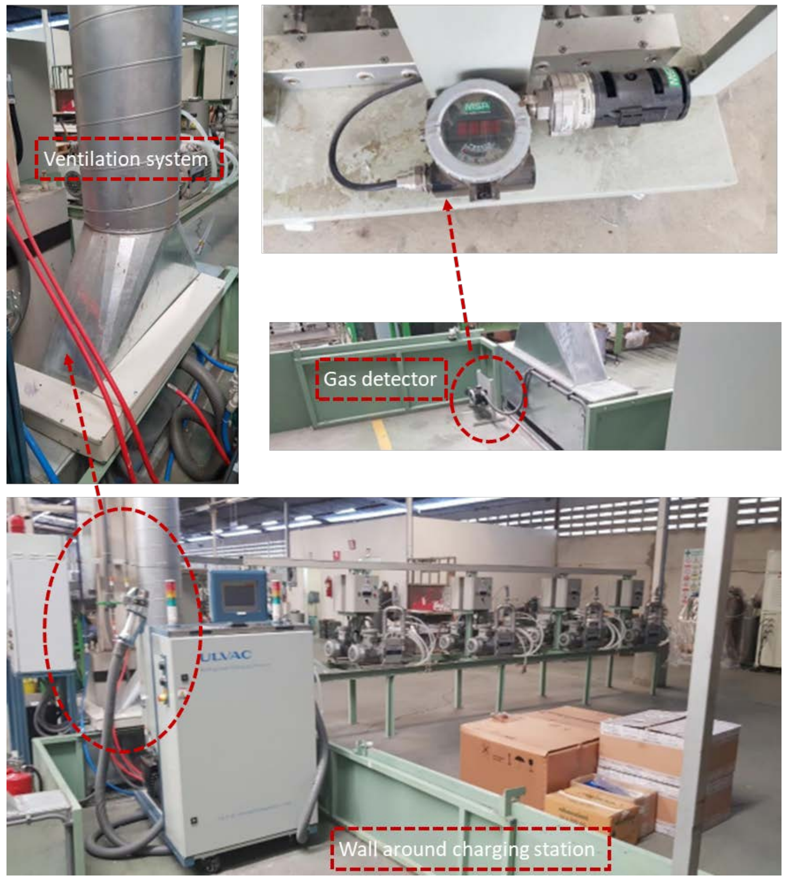


Figure 16 - Example of a refrigerant charging station with an installed detector(s), ventilation system, and a wall around the charging station (source: ERM safety and risk audit report)

For electrical safety, the pressure alarm system of the refrigerant pumping system must be in good condition and fully functional. An electrical grounding system must be properly installed in the blower's duct, ventilation system, charging station, and any other areas involving flammable refrigerants. Electrical hazard working signs must also be provided on-site. Bonding should be properly provided at the ventilation system, and on wiring, and piping to dissipate electrostatic build-up.

In terms of operation and maintenance, the work instruction (WI) must include operating and maintenance procedures with a preventive maintenance plan and record system. A training programme for operators on the new refrigerant process and equipment is strongly advised. An inspection programme and safety procedures for production materials, especially compressed gas cylinders of refrigerants, must be introduced as a new routine before accepting them from vendors and placing them into storage. Storage should be securely locked to prevent access by unauthorised personnel.

For more information

Production conversion of domestic refrigerators from halogenated to hydrocarbon refrigerants
giz2011-en-production-conversion-domestic-refrigerators.pdf (ctc-n.org)

Scan QR code here

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ANNEXES

APPENDIX I: Disclaimer

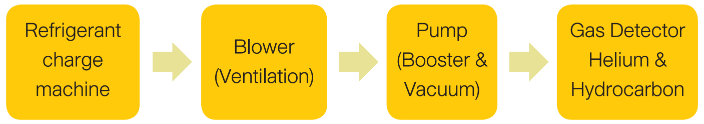
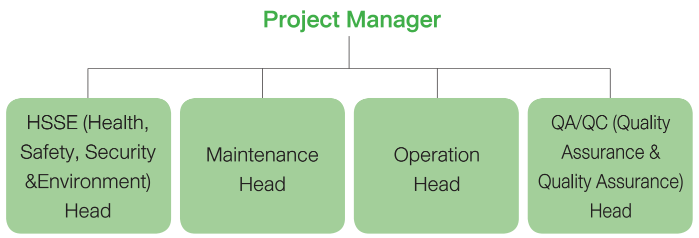
The report aims to provide a general idea of knowledge transformation for the conversion of an existing Refrigeration and Air Conditioning (RAC) production line to HC refrigerant (R290 and R600a) for domestic producers in Thailand. The guideline checklist and methodology have been prepared from Thai producers' experience under the THAILAND RAC NAMA funding since 2018, which is the start of the production line conversion.

GIZ does not assume liability for any statements or any actions taken by its readers or users, which may cause unintended damage or injury as a result of any recommendations or inferences made within this handbook. Although all statements and information contained herein are believed to be accurate and reliable, they are presented without guarantee or warranty of any kind, expressed or implied. Information provided herein does not relieve the reader or user from their responsibility of carrying out their own evaluation and analysis of the situation, and readers or users assume all risks and liability for use of the information, actions and events obtained. Readers or users should not assume that all safety data, measures, and guidance are indicated herein or that other measures may not be required. Here only general recommendations are made, which do not compensate for individual guidance and instructions. National laws and guidelines must be consulted and adhered to under all circumstances. The handling of flammable refrigerants and its associated systems and equipment is to be done by qualified and trained technicians only.

APPENDIX II: ABBREVIATIONS

AEP	Advance Energy Plus Company Limited
CFC	Chlorofluorocarbons
COVID-19	Coronavirus disease
CS	Compressor
DOI	Department of Industrial
EGAT	Electricity Generating Authority of Thailand
ERM	Environmental Resources Management
EU	European Union
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH
GWP	Global Warming Potential
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HFC	Hydrofluorocarbon
MOC	Management of Change
NAMA	Nationally Appropriate Mitigation Action
ODS	Ozone Depleting Substance
O&M	Operation and Maintenance
PFM	Project Fund Manager
QA/QC	Quality Assurance and Quality Control
RAC	Refrigeration and Air Conditioning
UNDP	United Nations Development Programme

APPENDIX III: Questionnaire for survey meeting study

Discipline/Question	Response	Remark
1. General		
1.1 Have any modifications been carried to the system since construction? Please summarise. 		
1.2 Is there a "Conversion Line Project Organization Team" and specific responsibility during design, construction, and commissioning? 		
1.3 Are there any other general issues? Please give details.		
1.31 Refrigerant availability in market issue		
1.32 Compressor (C/S) availability in market issue		
1.3.3 Business of the company		
1.3.4 Training & Seminar and Marketing & Promotion		
1.3.5 Design		
1.3.6 Performance		
1.3.7 Financial		

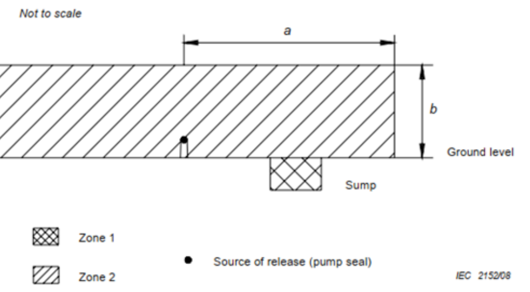
Discipline/Question	Response	Remark
2. HSSE		
1.1 Have any modifications been carried to the system since construction? Please summarise.		
2.1 Is there any special PPE (personal protective equipment) in case of leak & fire of refrigerant?		
2.2 Is there a Risk Assessment method & Review schedule (before & after the conversion)?		
2.3 Is there a special method for new product packaging after conversion?		
2.4 Is there a special method for supply chain and transportation of the product after conversion?		
2.5 What are the types of Fire Sprinkler and Fire Suppression Appli-cations?		
2.6 Is there a Hazardous zone specified for the conversion line?  Taking into account relevant parameters, the following are typical values which will be estimated for a pump having a capacity of 50 m^3/h and operating at a low pressure: *a* = 3 m horizontally from source of release; *b* = 1 m from ground level and up to 1 m above the source of release.		
3. Operation & Maintenance		
3.1 Operation		
3.1.1 Commissioning status		
3.2 Maintenance		
3.2.1 Is there any special inspection & maintenance plan such as PM (Preventive maintenance) or an advance method TPM (Total Productive Maintenance) after line conversion?		
4. QA/QC (Quality Assurance and Quality Control)		
4.1 Is there QA and QC for quality control management for the new conversion line?		

Table 3 Questionnaire for survey meeting study

APPENDIX IV: SUPPLIER LIST

1) HC refrigerant supplier list

Item	R290	R600a	Supplier	Address
1	✓	✓	Buranin Industry Co., Ltd. (Blue Planet Refrigerant)	27/7, Moo 1, Bangkratuek, Sampran, Nakhon Pathom, 73210 66 (0) 2 888 4700 www.blueplanet.co.th
2	✓	✓	Chaturong Cooling Limited Partnership, Luck 118 Enterprise Co., Ltd. (Chat Cooling)	39/4-5, SPK Factory Land, Moo 4, 345-Bangbuathong Road, Laharn, Bangbuathong, Nonthaburi, 11110 66 (0) 2 923 1102 66 (0) 2 923 1886 66 (0) 81 823 4061 chaturong@chatcooling.com Contact person: Dr. Chaturong Charastrakul, Managing Director 66 0 8 1823 4061 chaturong@chatcooling.com
3	✓	✓	R.C. Group	20/8, Moo. 1, Laem Yai Subdistrict, Mueang Samut Songkhram District, Samut Songkhram, 75000. 66 (0) 34 736 661 https://rcgroup-th.com/
4	✓	✓	GTS Asia Company Limited	62, Millenia Tower, Unit No. 1603, 16th floor, Langsuan Road, Lumpini, Pathumwan, Bangkok Thailand 10330 T. +662/085/4779 https://www.gtsspa.com/en
5	✓		SiamRefrig	102, Nuanchan 56, Nuanchan Rd., Buengkum Bangkok, 10230 66 (0) 2 944 2278 www. SiamRefrig.com
6	✓	✓	Linde (Thailand)	15th Floor, Bangna Tower A, 2/3 Moo 14, Bangna-Trad Road (K.M. 6.5), Bangkaew, Bangplee, Samut Prakan, 10540 66 (0) 2 338 6100 communication.lg.th@linde.com
7	✓	✓	BNF Corporation Co., Ltd	120/30, Moo 12, Soi Kingkaew, 21/2, Kingkaew Rd., Rachathewa, Bangplee, Samut Prakan, 10540 66 (2) 0 315 5498 http://www.bnf.com/gas_chemical.html
8	✓	✓	BJC Specialties Co., Ltd.	10th Floor, Berli Jucker House, 99 Soi Rubia, Sukhumvit 42 Road, Kwaeng Phrakanong, Khet Klongtoey, Bangkok 66 (0) 2 367 1212 bjcs.center@bjc.co.th
9	✓	✓	Brenntag Ingredients (Thailand) Public Company Limited	1168/98-100 Lumpini Tower 33rd Floor, Rama IV Road,, Thungmahamek, Sathorn, Bangkok, 10120 66 (0) 2 689 5999

Table 4 HC refrigerant supplier list

2) Compressor (HC refrigerant) supplier list

Item	Supplier	Address
1	Siam Compressor Industry Co., Ltd. (SCI)	979/72-74, 25th Floor, S.M. Tower, Phaholyothin Road, Phayathai, Bangkok, 10400 66 (0) 2-298-0371 – 77 www.siamcompressor.com
2	Hitachi Compressor (Thailand), Ltd.	1/65 Moo 5, Rojana Industrial Park, Tambol Kanham, Amphur U-Thai, Ayutthaya, 13210 66 (35) 330-819-29 http://www.hitachi-compressor.com
3	Kulthorn Kirby public Co., Ltd	126 Soi Chalong Krung 31, Chalong Krung Road, Khwaeng Lam Pla Thio, Khet Lat Krabang, Bangkok 10520 66 (0) 2 326-0831-6, 739-4893-5 https://compressor.kulthorn.com/contactus
4	Embraco brand (Beijing Embraco Snowflake Compressor Co. Ltd)	29 Yuhua Road Tianzhukonggang Ind B Zone Beijing, 101312 China 86 10 8048 2255 www.embraco.com Contact person: Herlon Eckermann da Silva, Sales Account Manager Asia Pacific 86 180 1017 3708 herlon.e.silva@embraco.com
	Embraco brand (Beijer B.Grimm: Thailand dealer)	Floor 7, Dr. Gerhard Link Building, 5 Krungthepkreetha Road, Huamark, Bangkapi, Bangkok 10240, Thailand 66 (0) 2710 3000 https://www.beijerrefthai.com/
5	Rechi Precision Co., Ltd. (Taiwan)	Rechi Precision Co., Ltd., 77/28(3,6) ชั้น 11 Sin Sathon Tower Thanon Krung Thon Buri, Khlong Ton Sai Khlong San Bangkok 10600 http://www.rechi.com/en/contact.jsp

Table 5 Compressor (HC refrigerant) supplier list

APPENDIX V

SUGGESTION NOTE

Refrigerant Storage Rule and Regulation for Line Conversion

Thailand RAC NAMA
Thailand Refrigeration and Air Conditioning Nationally Appropriate Mitigation Action (RAC NAMA)

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RELEVANCE OF LOCAL LAWS AND REGULATIONS FOR HYDROCARBON (HC) REFRIGERANT STORAGE AREA

- The Safety and Risk audit report by an authorized auditor will normally follow the processes outlined in item 1) below, Regulation of the Ministry of Labour, B.E. 2555 (2012). The regulation is compulsory for a safe workplace in Thailand as per the law.
  Where the HC refrigerant is planned as raw material for production line, it does not fall under the category for use as a household cooking gas. Thus, this application of the HC refrigerant for Thailand RAC NAMA shall be in accordance with item 2) below, Notification of Ministry of Energy Subject B.E.2554 (2011):
  - Regulation of the Ministry of Labour, B.E. 2555 (2012), Re: Management Standard on Safety Occupational Health and Working Environment Related to Fire Prevention and Protection
    (กฎกระทรวง กำหนดมาตรฐานในการบริหาร จัดการ และดำเนินการด้านความปลอดภัย อาชีวอนามัย และสภาพแวดล้อมในการทำงานเกี่ยวกับการป้องกันและระงับอัคคีภัย พ.ศ. ๒๕๕๕);
  - Notification of Ministry of Energy Subject: Regulations and Methods of Storage, Assignment of Responsible Special Personnel, and Exemption to Follow the Hazardous Substances Act 1992 (B.E.2535) for Areas of Liquefied Petroleum Gas Responsible by the Department of Energy Business 2011 (B.E.2554)
    (ประกาศกระทรวงพลังงาน เรื่อง หลักเกณฑ์ และวิธีการในการเก็บรักษา การกำหนดบุคลากรที่รับผิดชอบและการยกเว้นไม่ต้องปฏิบัติตามพระราชบัญญัติวัตถุอันตราย พ.ศ. ๒๕๓๕ สำหรับสถานที่ใช้ก๊าซปิโตรเลียมเหลว ที่กรมธุรกิจพลังงานรับผิดชอบ พ.ศ. ๒๕๕๔).
- Major content, related to HC refrigerant under Thailand RAC NAMA application, is under Part 5 Clause 14 (Fire suppression system with dry chemical and Fire water system) and clause 15 of the Notification of Ministry of Energy Subject, B.E.2554 (2011)
- The above two regulations are practical practices for a safe workplace in Thailand. However, the specification of a fire suppression system with dry chemical and a water system for fire should be seriously considered as shown in Notification of Ministry of Energy Subject, B.E.2554 (2011)

APPENDIX VI

SUGGESTION NOTE

Technology Conversion: R134a to R290 Under Counter Cooler

Thailand RAC NAMA
Thailand Refrigeration and Air Conditioning Nationally Appropriate Mitigation Action (RAC NAMA)

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THE INITIAL RESPONSE TO THE TECHNICAL SUPPORT QUESTIONS

Following information from Thermedez concerning the conversion of the under-counter cooler from R134a to R290 refrigerant, here are some initial recommendations:

- We would like to start with the safety element related to the use of flammable refrigerant R290:
  - All the refrigeration system electrical components must be spark-free e.g. lighting, fan motors, relays, etc.
  - Manipulation (e.g. filling, discharge, storage, etc.) of flammable refrigerant must comply with local regulations and/or relevant international standards, including production of prototypes.
- The idea is to reduce the cost of the prototyping exercise by taking, as a starting point, the existing R134a de sign and making the obvious modifications such as compressor and refrigerant:
  - Use R290 compressor cooling capacity similar to the R134a. One of the key parameters to determine the suitability of the compressor size is the number of OFF cycles e.g. a high number of OFF cycles means that the compressor is oversized. In comparison to the R134a compressor, the size of the R290 compressor could be reduced at a later stage once the design is final. This will reduce the cost and improve the energy efficiency.
  - Concerning the R290 refrigerant, we suggest starting with 25% less charge compared to the R134a system. Once the system is in steady mode, the producer can adjust the charge in such a way as to have the evaporator full of liquid e.g. same refrigerant temperature at the inlet and the outlet of the evaporator. Usually, the R290 system has a charge at least 25% lower than or the same/comparable R134a system.
- The cooling capacity is related to the internal volume of the cooler. It is important to understand if the 400W cooling capacity is suitable for this cooler. A decision can be made after we get the results of the first lab test.
- To start and to avoid design modifications at this point in time, we recommend using the same heat exchangers (condenser and evaporator) the producer has on the R134a system. Later, and in view of cost reduction and charge reduction, we can fine tune the design of these HEX. Most probably an 8mm OD could work well. We will also investigate the use of a steel condenser which has a significant impact on the BOM cost.
- Capillary tube: the design of this element shall follow the same process as designing an R134a cap tube. Only lab tests can determine the final design. We suggest starting with the current R134a cap tube and fine tuning while testing.
- Another element to be considered later is the addition of a suction line heat exchanger. This simple element will improve the system's cooling capacity and energy efficiency while adding a marginal extra cost that can be covered by the cost reduction coming from other elements e.g. the condenser and evaporator.
- Another cost reduction opportunity is to convert the evaporator from copper tubes to aluminium. To be evaluated later.
- If not already the case, the use of ECM fans (or even better, DC fans) and LED lighting will further improve the energy efficiency.
- Another parameter to be monitored while running the first lab tests is the approach temperature e.g. the difference between ambient temp and the temp at the exit of the condenser. This difference shall not exceed 5 degree Celsius at the maximum. This parameter will help in fine tuning the condenser design.

The results of the first lab tests will guide the redesign of the whole system to improve cooling capacity and energy performance.

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