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Technology domain analysis: A case of energy-efficient advanced commercial refrigeration technologies

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A B S T R A C T

Effective and economical tools and techniques that contribute to a more efficient and faster association of ideas to support technology research and development efforts are important. Many methods, tools, and techniques to identify promising technology R&D opportunities require experts' opinion. Finding qualified experts is no simple task—but it is critical because such knowledge and experience directly determine the quality of the results. Since the 1960s, the idea of identifying the most important actors in a society or people with prestige in the community has gained interest. Social Network Analysis (SNA) is a common method for identifying knowledgeable people within a community. The SNA method is coupled with Bibliometric Analysis and Patent Analysis to determine experts in the field of advanced commercial refrigeration technologies, along with their corresponding affiliations and contact information. The results support the work of energy efficiency engineers at the Bonneville Power Administration (a federal wholesale electric utility in the United States) who desired such information to continue to develop and implement measures to drive regional energy conservation for their customer utilities.

Keywords: Energy efficiency; Refrigeration; Bibliometrics; Social Network Analysis

1. Introduction

The relationships inherent in research collaboration among experts – and how these relationships can be leveraged for benefit – have gained importance during the last decades, especially when it comes to technology research and development (R&D). Since the 1960s, the idea of identifying the main actors in a society or a person that has prestige in the community has gained interest (Shibata et al., 2011). However, the identification of experts knowledgeable in a topic is not necessarily easy, since it is often difficult to differentiate the respected experts in a given field from those who merely express opinions (Campbell et al., 2003). Moreover, the Identification of such experts can be problematic, since the information depends on location, type of knowledge, and type of information that can be uncovered about the experts (Fu et al., 2007). Further complicating this is the fact that communities of experts are broadly distributed, ever-changing, and sometimes isolated within organizations (Liu et al., 2013; Campbell et al., 2003). How to find experts is a question that should be answered based on a logical, tried, and proven process. Social Network Analysis (SNA) addresses the limitations of some other approaches and has become a reliable method for finding experts within a community (Liu et al., 2013; Campbell et al., 2003).

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A method to identify experts in energy-efficient advanced commercial refrigeration technologies using SNA, Bibliometric Analysis, and Patent Analysis has been developed. It uses as its source data citations in the Web of Science (WOS) and Compendex databases, which were then processed using a tailored piece of software developed with the R programming language. This work resulted in two groups of experts: one group based in the United States and the other group based internationally. Internet research based on these lists of experts and their affiliations led to the creation of a spreadsheet that included not only information available in the citations databases – names, affiliations, paper titles, and abstracts – but other publicly-available information such as emails, phone numbers, and postal addresses. This final deliverable provided the client precisely the kind of information needed for outreach, education, and networking to advance regional energy efficiency initiatives—and in doing so it reduced the client's workload significantly, saving time and money.

2. Literature review

2.1. *Commercial refrigeration*

Commercial refrigeration technologies are ubiquitous and fundamental to modern society and have significant economic and environmental effects on various industries. The market size of commercial refrigeration is estimated to grow by more than USD $17 billion in eight years, from USD $29 billion in 2014 to USD $46.40 billion by 2022 (Grand View Research Inc., 2016). All the while, as demand for more sustainable technologies is increasing to avoid environmental disasters caused by global warming and to save energy, various alternatives for commercial refrigeration are being actively researched.

When discussing commercial refrigeration technology R&D, the academic literature has mainly focused on two aspects: improving the energy efficiency of refrigeration systems and minimizing the negative environmental effects of greenhouse gas emissions (Tassou et al., 2010; Tangen et al., 2011; Mota-Babiloni et al., 2015; Llopis et al., 2015). Tassou et al. reviewed both state-of-the-art and emerging technologies for refrigeration applications with the framework of the potential to reduce the environmental impacts of refrigeration. Table 1 summarizes the characteristics and future applications of important emerging refrigeration technologies (Tassou et al., 2010). Several works have investigated the environmental impact of physical systems and commercial refrigerants. Wu, Hu, and Mo present a model for assessing the carbon footprint of food transport refrigeration systems, considering the influence on greenhouse gas emissions (Wu et al., 2013). They conclude that development of commercial refrigeration technologies needs to focus on increasing the coefficient of performance (COP) of refrigerators and the efficiency of appendant equipment to reduce the energy consumption and CO2 emissions. Similarly, Cascini et al. applied the carbon foot print assessment (CFA) to investigate environmental effects relevant to the life cycle of commercial refrigeration systems for medium- and low-temperature food storage. This enabled them to analyze the whole life cycle of the entity – including the refrigeration unit and refrigerant – with results used as environmental performance indices (Cascini et al., 2016). The authors derived that indirect emissions of greenhouse gases (GHS) arising from the energy consumption of refrigerating units is more detrimental than refrigerant leakage. Llopis et al. analyze the energy performance of vapor compression refrigeration systems with low global warming potential (GWP) refrigerants using the total equivalent warming impact (TEWI) analysis (Llopis et al., 2015). Their findings suggest that low-GWP refrigerants used in vapor compression systems are beneficial in preventing global warming and, in particular, they find that CO2 is a promising natural refrigerant that could replace synthetic refrigerants in warm regions. Finally, several studies have proposed and evaluated new CO2 refrigeration systems (Sanz-Kock et al., 2014; Cecchinato et al., 2010, 2012; Polzot et al., 2016). Different alternatives for refrigeration have been considered such as transcritical systems, in-cascade systems, and positions of Internal Heat Exchanger.

Thermal Engineering Research Group (GIT) (2016b) have analyzed the use of energy and refrigeration cycle for commercial refrigeration based on direct multiple compression. As Thermal Engineering Research Group (GIT) (2016b) mentioned, the analysis of refrigeration cycles implements transcritical systems to reduce the energy consumption of the past and present technologies based on cycles configuration. Thermal Engineering Research Group (GIT) (2016a) studied and compared different CO2 refrigeration technologies. These studies are focused on analyzing these technologies according to specific climates. Sánchez et al. (2017) studied and tested in the lab the conversion of a direct HFC134a/CO2 direct HFC134a-secondary fluid/CO2 cascade refrigeration system to an in-cascade for commercial applications, mainly motivated for the reduction of green gasses by reducing the use of fluorinated with high GWP. These tests showed a decrease of the evaporation temperature for indirect systems and therefore a variation of energy consumption.

The use of energy and efficiency of internal heat exchanger in CO2 transcritical refrigeration plant was studied by Torrella et al. (2011). Their results showed an increase of cooling capacity and efficiency. With the same motivation, energy analysis, Sánchez et al. (2014) studied a new position of IHX (Internal Heat Exchanger) in plants using CO2 refrigeration. They found an improvement of the coefficient of performance and cooling capacity.

2.2. *Expert identification*

Formal approaches to identifying leading experts within a community of practice began to be developed in the 1960s by sociologists that took into account the prestige, social status, and position in the communication system of actions groups (Pascaru, 1976). Experts, in this context, can be considered as leaders in a certain community of knowledge They are people that can influence the opinions, beliefs, motivations, and behavior of others (Valente and Pumpuang, 2006). Approaches for identifying such people have continued to evolve over the intervening decades. While old techniques focused on the identification of experts manually, current methods include automated processes based on document contents and indicators (Balog, 2006). Applying a particular set of tools and methodologies allows one to investigate and analyze key aspects about the experts (Pascaru, 1976).

The expert identification process is based on a few key considerations. Prior research has defined the experts-finding process as the probability of identifying a candidate given a query topic (Fu et al., 2007). Expert mapping can be defined as

Table 1 – Characteristics and applications of emerging refrigeration technologies (source: (Tassou et al., 2010)).

Technology	State of development	Colling/refrig. Capacity of presently available or R&D systems	Efficiency/COP of presently available or R&D systems	Current/potential application area
Tri-generation	*"Large capacity bespoke systems available. Smaller capacity integrated systems at R&D stage"*	12 kW–MW	Overall system efficiency 65%–90%. Refrig. system COP: 0.3 at −50° C, 0.5 at −12° C	Food processing; cold storage; food retail
Air cycle	*"Bespoke systems available"*	11 kW–700 kW	0.4–0.7	Food processing; refrigerated transport
Sorption-Fadsorption	*"Available for cooling applications> 0 °C. Systems for refrigeration applications at R&D stage"*	35 kW–MW	0.4–0.7	Food processing; cold storage; retail; refrigerated transport
Ejector	*"Bespoke steam ejector systems available"*	Few kW–60 MW	Up to 0.3	Food processing; refrigerated transport
Stirling	*"Small capacity 'Free' piston systems available. Lager systems at R&D stage"*	15–300 W	1.0–3.0	Domestic refrigerators; vending machines; refrigerated cabinets
Thermoelectric	*"Low cost low efficiency systems available"*	Few Watts–20 kW	0.6 at 0 °C	Hotel room mini bar refrigerators; refrigerators for trucks; recreational vehicles; portable coolers; beverage can coolers
Thermoacoustic	*"R&D stage. Predicted commercialization: 5–10 years"*	Few Watts–kW	Up to 1.0	Domestic and commercial refrigerators, freezers and cabinets
Magnetic	*"R&D stage. Predicted commercialization 10 plus years from now"*	Up to 540 W	1.8 at room temperature	Low capacity stationary and mobile refrigeration systems

the process of locating and identifying leaders with specialized knowledge corresponding to databases about the communication of social networks (Campbell et al., 2003). The experts are considered based on their knowledge, research, and applications in a given area of specialization by contributing to a "collaborative research" network. Müller, Groesser and Ulli-Beer defined collaborative research as connecting people interacting around the study problem (Müller et al., 2012). A topic is defined according to the needs that pertain to a certain knowledge domain. In this context, experts can be identified according to five methods that vary based on the position, reputation, opinion leadership, decision making, and social participation of the respective community (Warner and Galindo-gonzalez, 2014).

One common method of expert identification is Social Network Analysis, fundamentally based on interviewing people and following-up with referrals until the right person is found. A more efficient method of doing this is to mine the data automatically and determine who possess the desired certain characteristics (Campbell et al., 2003). Valente and Pumpuang identified experts with 10 different methods including celebrities, self-selection, self-identification, staff-selected, positional approach, judge's ratings, expert identification, snowball method, sample sociometric, and sociometric (Valente and Pumpuang, 2006). Of these methods, snowball method, sample sociometric, and sociometric are based on algorithms and empirically-derived and, therefore, included within the Social Network Analysis approach (Liu et al., 2013).

While expert identification can be performed applying different methods, the use of a specific method depends on project objectives, type of expertise, and end-use of the resulting information. According to Ehrlich, Lin, and Griffiths-Fisher, personal networks are important if the objective is to get immediate answers. Such networks are usually small and are not suitable for finding experts with the right information (Ehrlich et al., 2007). In an organizational level, Campbell et al. applied a method using "email communications" to identify experts based on skills, experience, and expertise (Campbell et al., 2003). Based on naturally-formed social networks in an organization, this is a method that asks workers, managers, or senior employees directly if they know someone with specific qualities, and then following these recommendations directions until the expert is found. Questioning of searching documents and using algorithms, Ehrlich, Lin, and Griffiths-Fisher also used algorithms to search documents as part of a study of social-context expertise they called "SmallBlue". The SmallBlue approach automatically identifies and analyzes social networks formed from email and chat logs in user machines (Ehrlich et al., 2007).

2.3. *Bibliometric analysis*

Researchers and managers have come to regard database tomography as an important knowledge source for scientific and technological knowledge that have proliferated through the publication of technical literature. Bibliometric analysis is a quantitative and statistic tool for analyzing the distribution patterns of scientific and technological literature within a specific topic field (Park et al., 2015). It has been widely applied as a useful tool to analyze research-related activities in science and technology fields and to measure the degree of uncertainty in a product's technological innovation (Yeo et al., 2015). Moreover, Bibliometric analysis has been regarded as a useful tool for establishing technology strategies and policies by providing the insight of subject matter expertise through demonstrating and mapping the global network of knowledge (Rafols et al., 2014; Sakata et al., 2013; Huang et al., 2014). In forecasting emerging technologies unavailable to collect historical data, Bibliometric analysis is available to provide useful data (Daim et al., 2006; Yoon and Park, 2007). Through Bibliometric analysis, researchers and managers are available to capture information such as (Kostoff et al., 2001);

- Authors producing the most recent papers within a topical area
- Journals containing many topical area papers
- Institutions producing numerous topical area papers
- Keywords used most frequently by the topical area authors
- Authors whose papers are cited most frequently in the topical area papers
- Papers and journals cited most frequently in the topical area papers

Various methodological contributions have been proposed to facilitate a Bibliometric analysis. Most of these start with developing possible keyword sets related to specific research topics from literature sources. Keyword set development is usually originated from recasting keywords extracted from titles and abstracts of various bibliometric resources – including conference proceedings, academic journal papers and patents – by using natural language processing, stop word removal, fuzzy term matching, and other techniques (Newman et al., 2014; Roepke and Moehrle, 2014). A key consideration underlying all of these approaches is that the quality of Bibliometric analysis depends on understanding the corresponding technological topics (Newman et al., 2014).

For achieving the data mentioned above, several methodologies investigate frequencies of key terms, themes, and demographic information (Kostoff et al., 2004). Other methodologies grasp the relationships among keywords or authors (Shibata et al., 2011; Sakata et al., 2013; Ávila Robinson and Miyazaki, 2013; Fujita et al., 2014) and classify them to characterize technological information (Roepke and Moehrle, 2014). For example, Fujita et al. investigated the performance of different types of weighted citation networks to detect emerging research fronts (Fujita et al., 2014).

For this study, the authors compared the citation patterns by applying some measures to weighted citations. Another exemplary study conducted by Ittipanuvat et al. revealed linkages between technologies and social issues to elucidate plausible contributions of science and technology for solving social issues (Ittipanuvat et al., 2014).

The metrics used in bibliometrics focusing on authorships are scholarly output (number of publications), the number of citations, field-weighted cited impact, and outputs in the top percentile, and H-index. These metrics are focused on the number of publications and citations or a combination of both. However, these metrics have issues and limitations because citations are different between study fields and the fact that highly cited authors and papers could not measure the quality of the publications. Therefore, it is necessary to use bibliometrics together with other data (i.e. patents) and combine with other methodologies (The University of Leeds, 2014).

2.4. Social network analysis

SNA is the mapping and measuring of relationships and flows between entities, such as people, groups, organizations, and computers. As is shown in Fig. 1, nodes represent actors and connections are relationships among actors. This shows that SNA measures relationship among actors by using metrics based on network and graph theories.

SNAs are more easily done to find experts within a publically-accessible community (such as is represented by citation and patent databases) and not in restricted environments such as inside an organization. SNA has been applied in many studies that use social network-based expertise propagation through emails and algorithms to analyze the database and probabilities to reduce the list of experts (Fu et al., 2007). Also, at an organizational level, prior research presents a model for finding experts on a specific topic by using social influence analysis, work that requires a topic search, candidate filter, and index construction (Liu et al., 2013). Topical Affinity Propagation (TAP) is a similar approach applied to a large network and models the "topic-level social influence." As part of this method, a Topical Factor Graph (TFG) model evaluates social influence networks based on an algorithm that is part of the "map-reduce programming model" (Tang et al., 2009). Mueller-Prothmann and Finke use SNA for expert localization and knowledge transfer by adapting the SELaKT method to SNA to analyzed an organizations' internal and external networks (Mueller-prothmann and Finke, 2004). Some research has shown, however, that finding experts with specific characteristics in large networks (such as large enterprises) becomes infeasible (Liu et al., 2013).

As previously discussed, SNA maps relationships among agents who are most important and relevant in a knowledge domain. There are centrality measures used within SNAs to achieve this. In the present study, the initial list of the potentially most suitable centrality metrics was:

- Degree: Number of direct connections in a network for node i.
- Betweenness: Number of shortest paths between two nodes that node i resides on.
- Closeness: Distance of node i to all other nodes in a network.
- Eigenvector: A high eigenvector score is assigned to a node that is connected to other high-scoring nodes.

The client sought to identify the leading authors and centers of research within the field of advanced commercial refrigeration technologies. Based on this need, the researchers found that betweenness centrality was preferred because it best characterizes the importance of authors in the network and can also be combined with frequency data such as a number of publications and/or number of citations. Whereas degree of centrality provides connections limited to co-authors of the same paper, betweenness centrality evaluates inter-relationships among authors of the same papers as well as relationships among other papers and sub-networks. Closeness centrality and Eigenvector centrality are not useful for expert identification since these metrics highlight the location of actors and power to influence the network.

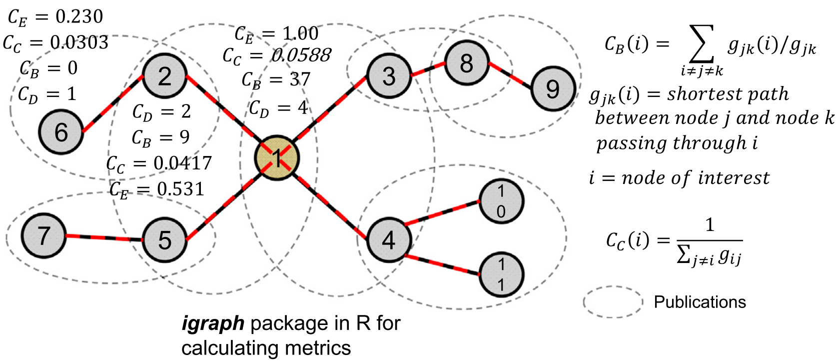

Fig. 1 – SNA Basics.

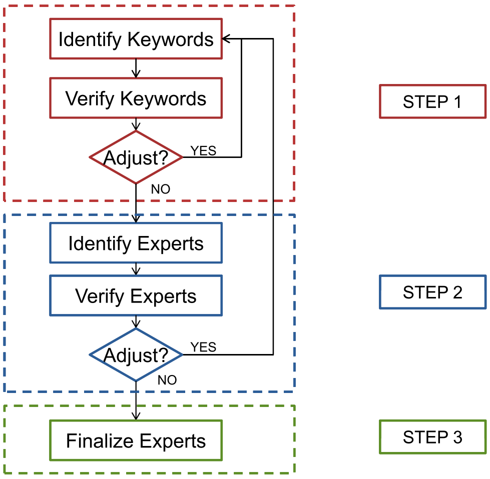

Fig. 2 – Whole process of expert identification.

3. Methodology applied to energy-efficient advanced commercial refrigeration technologies

For the client, the methodology was built on an interactive SNA process combined with Bibliometric analysis. Whereas this process is similar to previous studies (Tangen et al., 2011; Mota-Babiloni et al., 2015), the current study's contribution is that it illustrates a systematic application of SNA and Bibliometric analysis (including data mining) within a pragmatic approach for direct industry application.

3.1. *Process*

The process of expert identification was founded on three steps specified in previous studies and then incorporating client feedback to adapt the process. Thus, a theoretical base process was adjusted, as needed, to provide an efficient and pragmatic solution to real-world needs. Fig. 2 summarizes this process.

3.1.1. *Step 1: Process of keyword identification and database selection*

Step 1 focused on keyword identification and data mining. Keyword identification starts with a literature review limited to the documents appropriate to the subject. This first set of keywords is categorized according to technology or topic area under study. Elaborating a technology characterization can be useful in identifying areas, fields, functions, and components. These keywords are used to conduct a literature search within a digital library to expand and refine the list of keywords. Expert input is then needed to review this refined list. This process is repeated as many times as required and finalized when a sufficient number of citations are obtained—300 to 500 citations is an appropriate range. It is suggested for the search query to use a deductive method going from a general to a more specific perspective. It is important to evaluate the list of citations to ensure that the content does, indeed, reflect the topic of interest to the client and that duplications are eliminated.

3.1.2. *Step 2: Social network analysis*

The second step is focused on obtaining citations and calculating centrality metrics. Centrality metrics are obtained based on three research stages (Martino, 2003): Basic research, applied research, and development. Basic research is directly associated with academic articles found in Web of Science, while applied research is focused on engineering articles found in the digital library Compendex. Finally, the development stage is associated with patents. In this particular case Sumobrain was used to mine the data. The second step is completed by calculating centrality metrics. The process of calculations can be varied according to the type of data, availability of software, and capability of programming. In the specific case of this study, it was used a software interface based on R and Shiny package that can calculate the centrality metrics and the frequency of publications and citations as well obtaining the information of authors. For the graphical analysis is used Gephi software.

Similar to the previous step, the second step requires iterative collaboration with the client in order to evaluate the results of the centrality analysis. The list of experts needs to include all relevant information such as co-authors and institutions, with experts ordered in the list based on the highest level of centrality. The cycle ends when the number of articles (300 to 500 number of articles recommended) and the topics are highly relevant (information verified by experts).

The method and process for identifying experts in these studies are established based on finding the most relevant experts in commercial refrigeration and avoiding misidentification of authors with no relevance in the field through the identification of the correct keywords and verification by experts in refrigeration technologies. At the same time, the results are verified in each step, and the identified authors' information are obtained with the corresponding publications. However, some imperfections of the database can occur and induce to misidentification of relevant experts. To eliminate these imperfections, it is important to follow the established steps and constantly work with specialists in the field.

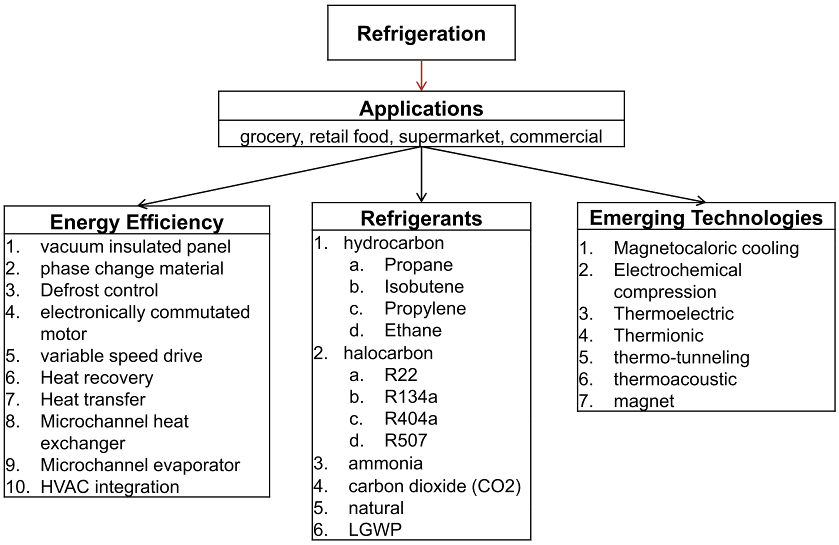

Fig. 3 – Keyword Identification.

3.1.3. *Step 3: Finalization of experts*

Step three finalizes the list of experts. It requires the final filtration of authors corresponding to the knowledge domain, institutional affiliation, postal address, email address, phone numbers and, if applicable, websites. Client input is again needed to confirm the list.

3.2. *Software*

Another contribution of this research was a software tool developed to help automate this process as much as possible. The software was built in R, with the Shiny tool used for data visualization. This software allows researchers to obtain centrality metrics based on co-authors for each of the R&D stages (basic research, applied research, and development). At the same time, it provides each author's name, publications, and contact information. Additionally, the software provides the results, original data, and the edge matrix to be used for generating the network graph using Gephi or other software for more advanced data visualization.

4. Case study — commercial refrigeration

The Bonneville Power Administration (BPA) is a federal wholesale electric utility based in the U.S. Pacific Northwest. As a Power Marketing Administration within the United States Department of Energy, BPA markets electrical power and transmission services to customers in Idaho, Oregon, Washington, western Montana (and smaller portions of four other states). The Agency has been in existence since 1937, but a law passed in 1980 – the Northwest Power Act (Public Law 96-501) – significantly influenced its mandate in requiring it to look to conservation (a.k.a., energy efficiency) as its first choice in meeting regional energy needs (before looking to such things as market purchases or generating resources). Since the early 1980s, BPA's experts in energy efficiency have partnered with other stakeholders to help make the Pacific Northwest a leader in identifying promising technologies, confirming the effectiveness of these technologies, and introducing conservation measures that have achieved 6000 aMW of energy savings (equating to half of the region's energy demand over that time) (Energy Efficiency, 2017).

In early 2015, a member of the BPA Energy Efficiency Engineering Services Team sought to learn more about the landscape of advanced commercial refrigeration technologies. His goal in doing so was to help further the Agency's work in driving regional energy conservation within the commercial sector—particularly in grocery and supermarket refrigeration technologies, because this sub-set of the sector offered the potential for appreciable energy savings, but new utility conservation measures would be required (Northwest Power and Conservation Council, 2010). Another motivating factor were impending changes to federal laws governing refrigerants (US EPA-OAR-OAP, 2017). Topics of interest included system design; technologies and components; quantifying energy efficiency; low global warming potential (GWP) refrigerants; and application of existing heating, ventilation, and air conditioning (HVAC) technologies in the commercial refrigeration space. Institutions of interest focused on research universities, national laboratories, manufacturers, and refrigeration system design firms. The primary deliverables desired from this project were two lists of experts in this domain (one based in the U.S. and the other based internationally) in which the experts would be prioritized based on degree of betweenness and associated with their relevant publications and contact information. The project commenced in January 2015 and ended in March with an "SNA 101" tutorial provided to other interested Agency staff.

4.1. *Step 1: Keyword identification*

The literature review and iterative work with the client resulted in a final keyword list focused on commercial-sector applications (such as grocery stores, retail outlets, and supermarkets) and was organized into three groups: energy efficiency, refrigerants, and emerging technologies. The "energy efficiency" grouping corresponded to terms generally applicable to commercial refrigeration, while the "refrigerant" and "emerging technologies" categories contained keywords for specific materials, substances, and technologies. See Fig. 3.

4.2. *Steps 2 & 3: Social network analysis and expert identification*

The data obtained in Step 1 was processed and used to build the corresponding network and calculate centrality

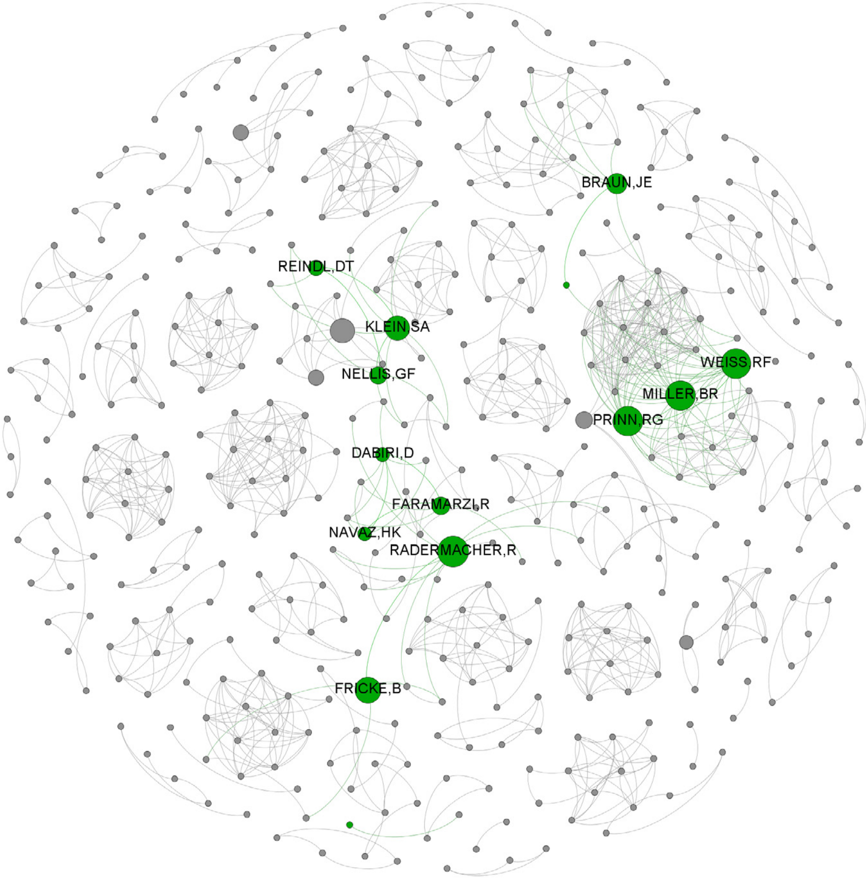

Fig. 4 – US based author network.

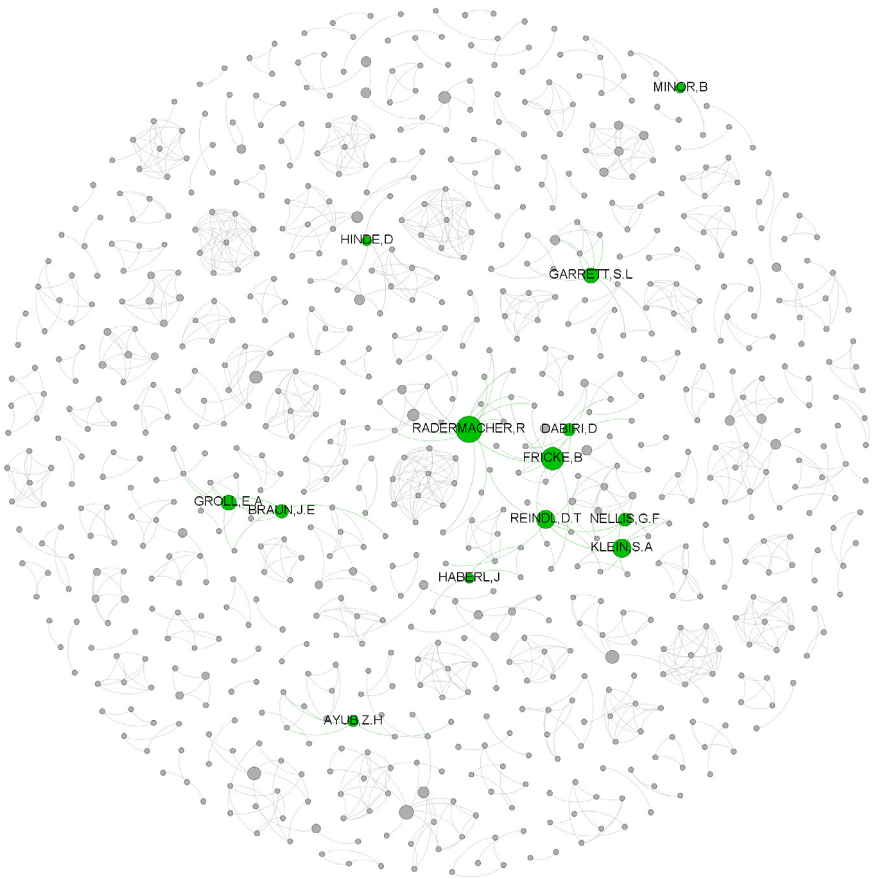

Fig. 5 – Non US based author network.

Table 2 – Leading US Authors.

Author	Affiliation	Article Titles
Radermacher, Reinhard	University of Maryland	1. An evaluation of the environmental impact of commercial **refrigeration** systems using alternative r**efrigerants** 2. An experimental study of the performance of a dual-loop refrigerator freezer system 3. Review of secondary loop **refrigeration** systems 4. Comparison of **R-290** and two HFC blends for walk-in **refrigeration** systems 5. Application of tandem system to high-**efficiency refrigerator**/freezer 6. Transient Simulation of a Transcritical **Carbon Dioxide Refrigeration** System
Fricke, Brian	Oak Ridge National Lab	1. Comparative analysis of various **CO2** configurations in **supermarket refrigeration** systems 2. An evaluation of the environmental impact of commercial refrigeration systems using alternative **refrigerants** 3. Comparison of Vertical Display Cases: Energy and Productivity Impacts of Glass Doors Versus Open Vertical Display Cases 4. Development of **Low Global Warming Potential Refrigerant** Solutions for Commercial Refrigeration Systems using a Life Cycle Climate Performance Design Tool
Abdelaziz, Omar	Oak Ridge National Lab	1. **R-410A** Alternative **Lower GWP Refrigerants** Drop in Testing: System and Components 2. A Comparative Study on the Environmental Impact of **CO2 Supermarket Refrigeration** Systems 3. An Evaluation of the Environmental Impact of Different Commercial **Supermarket Refrigeration** Systems Using **Low Global Warming Potential Refrigerants** 4. Reducing the Carbon Footprint of Commercial Refrigeration Systems Using Life Cycle Climate Performance Analysis: From System Design to **Refrigerant** Options

metrics. Fig. 4 shows the output of the R and Shiny tools – as processed using Gephi – where circle size represents the relative measure of a given author's betweenness centrality, with the larger circle corresponding to the highest betweenness value. Green dots designated authors selected based on high betweenness, while gray dots indicate non-selected authors. To create this visualization in Gephi, edge information shaped by the Fruchterman–Reingold layout algorithm was used. Visualizing networks in this way provides insights that cannot be discerned when the data is presented in only tabular format, such as clearly showing relative values of various authors within the network; identifying knowledge areas centered on key experts; and suggesting relationships that could be forged between sub-networks and topics.

4.2.1. *U.S. Expert Network*

The U.S.-based author network derived from the Web of Science database is presented in Fig. 4, and an excerpt of these results is presented in Table 2. This graphic highlights the fact that many sub networks exist, which is a product of the data being based on co-authorship. From this visualization it is clear that some sub networks tend to be more important than others, as in the case of authors Weiss, Miller, and Prinn, who dominate a significant number of actors (authors) and their connections inside of their main sub network and also the relationship of these authors with other authors located in different subnetworks.

4.2.2. *Non U.S. expert network*

As Fig. 5 shows, in the case of Non U.S. Experts derived from the Web of Science database, though the network is denser, it shares characteristics of the U.S.-based authors' network such as multiple subnetworks, predominance of important authors and their corresponding networks, and the connection to other subnetworks. There are also some international authors found in both the basic research and application networks due to the academic nature of the respective publications. The network diagrams clearly show the actors/experts/authors with highest betweenness centrality are concentrated in the biggest and denser subnetworks, which are connected to other subnetworks with authors that appear important in their respective subnetworks (see Table 3).

The full list of leading researchers and their research is provided at the end of the paper in the Appendix.

5. Conclusions

While the process of identifying experts described in this study is based on a theoretical foundation, as modified in the case of energy-efficient advanced commercial refrigeration technologies it is also a pragmatic process for fast and accurate results. This significantly reduced the time required for identifying experts; however, there are some key caveats to be aware of. First, using the correct keywords is critical, because otherwise, the results will be meaningless—"garbage in, garbage out". Though the R, Shiny, and Gephi

Table 3 – Leading non US authors.

Author	Affiliation	Article Titles
Hafner, Armin	SINTEF Energy Research, Norway	1. Multi-ejector concept for **R-744 supermarket refrigeration** 2. Simulation models in the supersmart **supermarket** energy-benchmark tool 3. **R744 refrigeration system** configurations for **supermarkets** in warm climates 4. A computational model of a transcritical **R744** ejector based on a homogeneous real fluid approach 5. Oil-free **R744** systems for industrial/commercial applications 6. **R744** ejector supported parallel vapor **compression** system
Minetto,Silva	National Research Council, Construct Technologies Inst, Italy	1. Experimental analysis of a new method for overfeeding multiple evaporators in **refrigeration** systems 2. Simulation models in the supersmart **supermarket** energy-benchmark tool 3. Recent installations of **CO2 supermarket refrigeration** system for warm climates: data from the field 4. Energy performance of **supermarket refrigeration** and air conditioning integrated systems working with **natural refrigerants** 5. Energy performance of **supermarket refrigeration** and air conditioning integrated systems 6. A critical approach to the determination of optimal heat rejection pressure in transcritical systems 7. Commercial **refrigeration** system using **CO2** as the **refrigerant**
Maidment,Graeme	London South Bank University, England	1. Modeling thermostatic expansion valves 2. Potential life cycle carbon savings with low emissivity packaging for **refrigerated** food on display 3. A retail road map for **supermarkets** 4. Combined cooling heat and power in **supermarkets** 5. Combined cooling and heating using a gas engine in a **supermarket** 6. Application of combined heat-and-power and absorption cooling in a **supermarket** 7. Analysis of the expansion valves used for controlling **refrigerant** feed into delicatessen cabinets in **supermarkets**

Table A.1 – Full list of leading authors.

Author [Surname, First name(s)]	Affiliation	Article Titles
RADERMACHER, REINHARD	University of Maryland, Department of Mechanical Engineering	1. An evaluation of the environmental impact of commercial refrigeration systems using alternative refrigerants 2. An experimental study of the performance of a dual-loop refrigerator freezer system 3. Review of secondary loop refrigeration systems 4. Comparison of R-290 and two HFC blends for walk-in refrigeration systems 5. Application of tandem system to high-efficiency refrigerator/freezer 6. Transient Simulation of a Transcritical Carbon Dioxide Refrigeration System

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tools allow for a significant degree of process automation, user input is still required to determine the validity of results. Another caveat is that the source(s) of data consulted to generate network analyses come with their own strengths and weaknesses—for example, only experts who publish their results will be identified using citation databases.

With the above in mind, there are also additional opportunities for the client to use the results from this project. The analysis can go far beyond simply identifying experts. For instance, research areas of focus can be identified from the text in publication titles and abstracts, which can help align an organization's technology roadmaps

Table A.1 (*continued*)

Author [Surname, First name(s)]	Affiliation	Article Titles
FRICKE, BRIAN	Oak Ridge National Lab	1. Comparative analysis of various CO2 configurations in supermarket refrigeration systems 2. An evaluation of the environmental impact of commercial refrigeration systems using alternative refrigerants 3. Comparison of Vertical Display Cases: Energy and Productivity Impacts of Glass Doors Versus Open Vertical Display Cases 4. Development of Low Global Warming Potential Refrigerant Solutions for Commercial Refrigeration Systems using a Life Cycle Climate Performance Design Tool
ABDELAZIZ, OMAR	Oak Ridge National Lab	1. R-410A Alternative Lower GWP Refrigerants Drop in Testing: System and Components 2. A Comparative Study on the Environmental Impact of CO2 Supermarket Refrigeration Systems 3. An Evaluation of the Environmental Impact of Different Commercial Supermarket Refrigeration Systems Using Low Global Warming Potential Refrigerants 4. Reducing the Carbon Footprint of Commercial Refrigeration Systems Using Life Cycle Climate Performance Analysis: From System Design to Refrigerant Options
KLEIN, SANFORD	University of Wisconsin, Department of Mechanical Engineering	1. Refrigeration system malfunctions 2. Recent developments in room temperature active magnetic regenerative refrigeration 3. Dedicated mechanical subcooling design strategies for supermarket applications 4. Investigation of ammonia-secondary fluid systems in supermarket refrigeration systems
BRAUN, JAME E. GROLL, ECKHARD	Purdue University, Department of Mechanical Engineering	1. Performance of vapor compression systems with compressor oil flooding and regeneration 2. Adaptive tuning of an electrodynamically driven thermoacoustic cooler 3. Application of CFD models to two-phase flow in refrigerant distributors 4. Fault detection and diagnostics for commercial coolers and freezers
FARAMARZI, RAMIN	Southern California Edison, Refrigeration Technology & Test Centre	1. The application of advance methods in analyzing the performance of the air curtain in a refrigerated display case 2. Efficient display case refrigeration 3. Comparing older and newer refrigerated display cases
NELLIS, GREGORY F.	University of Wisconsin	1. The commercial feasibility of the use of water vapor as a refrigerant 2. Recent developments in room temperature active magnetic regenerative refrigeration
DABIRI, DANA NAVAZ, HOMAYUN K.	University of Washington Kettering University	1. Tracer gas technique: A new approach for steady state infiltration rate measurement of open refrigerated display cases 2. Experimental Investigation of the Effect of Various Parameters on the Infiltration Rates of Single Band Open Vertical Refrigerated Display Cases with Zero Back Panel Flow 3. The application of advance methods in analyzing the performance of the air curtain in a refrigerated display case
MILLER, JOHN B. PRINN, RONALD G. WEISS, RAY	University of Colorado Boulder, Cooperative Institute for Research in Environmental MIT, Center for Global Change Science University of California, Scripps Institution of Oceanography	1. HFC-23 (CHF3) emission trend response to HCFC-22 (CHClF2) production and recent HFC-23 emission abatement measures 2. Global emissions of refrigerants HCFC-22 and HFC-134a: Unforeseen seasonal contributions
REINDL, DOUGLAS T.	University of Wisconsin	1. Sequencing & control of compressors: Industrial refrigeration 2. The commercial feasibility of the use of water vapor as a refrigerant 3. Refrigeration system malfunctions

(*continued on next page*)

Table A.1 (*continued*)

Author [Surname, First name(s)]	Affiliation	Article Titles
AYUB, ZAHID H.	Isotherm, Inc., Arlington, TX	1. New technologies in ammonia refrigerating and air-conditioning systems 2. Experimental investigation of evaporation heat transfer and pressure drop of ammonia in a 60 chevron plate heat exchanger 3. Ammonia refrigeration heat transfer enhancement 4. Evaporation heat transfer and pressure drop of ammonia in a mixed configuration chevron plate heat exchanger
GSCHNEIDNER, KARL PECHARSKY, VITALIJ K.	Iowa State University	1. Advanced magnetocaloric materials: What does the future hold?
BAXTER, VAN RICE, KEITH	Oakridge National Lab	1. Field testing of an advanced low-charge supermarket refrigeration system 2. Modeling Supermarket Refrigeration with EnergyPlus 3. Energy and global warming impacts of HFC refrigerants and emerging technologies 4. IEA Annex 26: Advanced Supermarket Refrigeration/Heat Recovery Systems 5. Energy Simulation of Integrated Multiple-Zone Variable Refrigerant Flow System
BROWN, J. STEVEN	The Catholic University of America	1. A thermodynamic analysis of refrigerants: Performance limits of the vapor compression cycle 2. A thermodynamic analysis of refrigerants: Possibilities and tradeoffs for Low-GWP refrigerants 3. Introduction to Alternatives for High-GWP HFC Refrigerants 4. Sustainability with prospective refrigerants 5. Possibilities, Limits, and Tradeoffs for Refrigerants in the Vapor Compression Cycle
MCLINDEN, MARK O.	National Institute of Standards and Technology	1. An extended corresponding states model for the thermal conductivity of refrigerants and refrigerant mixtures 2. Computational Design of New Refrigerant Fluids Based on Environmental, Safety, and Thermodynamic Characteristics 3. Possibilities, Limits, and Tradeoffs for Refrigerants in the Vapor Compression Cycle
HEHLEN, MARKUS P.	Los Alamos National Lab	1. Electrocaloric refrigerator using electrohydrodynamic flows in dielectric fluids 2. Measurement of solid-state optical refrigeration by two-band differential luminescence thermometry 3. Development of the Los Alamos solid-state optical refrigerator
GARRETT, STEVEN L.	Pennsylvania State University	1. Performance estimates of a helium-based thermoacoustic-Stirling chiller 2. Thermoacoustic refrigeration 3. Thermoacoustic refrigerator for space applications
HINDE, DAVID.K	Department of Research and Development, Hill Phoenix	1. Secondary coolant systems for supermarkets 2. Carbon dioxide in North American supermarkets
MINOR, BARBARA	DuPont Fluoroproducts	1. Low GWP R-404A alternatives for commercial refrigeration 2. Experimental study of R-134a alternative in a supermarket refrigeration system 3. Compressor Performance Analyses of Refrigerants (R22 and R407C) with Various Lubricants in a Heat Pump
HABERL, JEFF S.	Texas A&M University	1. Reducing energy consumption in grocery stores: Evaluation of energy efficiency measures 2. Study of energy use in grocery stores

with emerging research topics. Further, changes in research over time can be analyzed to estimate future technological changes.

With the cluster analysis that has emerged from this study, the opportunity for future research presents themselves. Within the area of commercial refrigeration technologies, this could include analyzing the interactions of coauthor sub networks. Such a study could include peripheral analyses, the density of network analyses, relationships among authors showing the highest correlation with different clusters, and assessing centrality metric relationships with particular network distributions and configurations.

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Appendix

See Table A.1.

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