ETM

ENGINEERING & TECHNOLOGY MANAGEMENT

# TRM for Household Refrigerator

Course: ETM 534 Technology Roadmapping

Instructor: Dr. Daim

Term: Summer 2013

Team 2

Jing Jiang
Justin Thompson
Nameer Al-Mulla
Zina Boulos

# 1. EXECUTIVE SUMMARY

Since the first refrigerator was patented in 1834, the technology, cost, and ease of use has made it an essential part of the home kitchen of today. General Electric (GE), one of the leading producers of refrigerators in the world is being modeled as the manufacturer of choice because they possess the diverse technological know-how to improve this product. GE was chosen as the model manufacturer because they exhibit the forward thinking traits and large business diversification to prepare a technology roadmapping study.

This paper will utilize technology roadmapping to create a plan for how GE could focus their effort and resources in their refrigeration business unit to develop a refrigerator in the future which will harness the market drivers to capture more of the market share.

Technology Roadmapping is collaborative process first developed by the CEO of Motorola and allows to experts and researchers in the field of study to determine the market drivers, technologies, products/components, and resources. These items are put to a time line during the iterative initial steps then are connected through links.

The benefit of using this method in this study is that it allows many different market drivers that consumers have to develop a refrigerator that largely meets those needs. In essence, GE wishes to find out the market pull to develop technologies that push consumers more towards their refrigerators.

This study will show that technology roadmapping can be successfully used to create a plan of action over a time span of only 20 years that will integrate existing refrigerator technology and identify gaps in those technologies. The refrigerator GE ultimately creates for this hypothetical future is not set in stone which comes from the fact that market drivers and other issues may change. Technology roadmaps are not commandments for an organization to follow, but must be adapted as new knowledge becomes available.

# 2. INTRODUCTION

A kitchen may be not only the best room in the house but also the most wasteful. According to the U.S. Department of Energy, lighting, refrigeration and cooking is estimated to consume 41.5% of a home's energy [1]. The refrigerator is the second-largest consumer (13.7%) of a home’s energy following the air conditioner (16%) [2]. In most households, the refrigerator may be the single biggest energy draining kitchen appliance.

It is estimated electricity generated with coal and natural gas dominates nearly 70% of U.S. electricity market. Released greenhouse gasses into the atmosphere contribute to climate change and pollute environment. If everyone in the US used a refrigerator which had earned the Energy Star, a total 715 million kWh per year would be saved and greenhouse gas emissions equivalent to those from about 100,000 cars would be reduced [3].

Recently, we have seen substantial innovation in the refrigerator sector [4-6]. Although energy efficiency in refrigerators have been gradually improved, radical innovations by which refrigerators would consume significantly less energy have not been paid much attention [9].

GE is a leader of radical energy innovation [10]. The purpose of this project is to provide a technology roadmap which guides the company's refrigerator R & D planning and resource allocation.

# 3. LITERATURE REVIEW

This project develops a technology roadmap from the perspective of GE and foresees the refrigerator evolvement. The technology roadmapping visually represents a powerful technique for supporting technology management and planning, and widely are used for exploring and communicating the dynamic linkages between technological resources, organizational objectives and the changing environment [11-12].

By the help of technology roadmapping, companies, industries and R&D organizations can plan what they must do to succeed in future markets. The uses and benefits of technology roadmaps:

- predict, based on well-informed assumptions, the market's future technology and product needs;
- identify the science and technology areas with the highest potential for an industry;
- identify critical enabling technologies that will be needed and the gap (in terms of technology development) between what exists and what is needed;
- support informed, strategic technology investment decisions;
- avoid risky, unproductive technology investments;
- increase collaboration and partnerships among companies through the sharing of knowledge;
- establish the consensus needed to move forward on a program of technology-development R&D;
- establish a framework to coordinate R&D and leverage R&D investments among companies;
- define the steps required to transfer technology to marketable applications [13].

R.N. Kostoff and R.R Schaller [14] categorize four different application level roadmaps: 1) science & technology maps or roadmaps; 2) industry technology roadmaps; 3) corporate or product-technology roadmaps; 4) product/portfolio management roadmaps. Based upon purpose—at a low level of developmental purpose, Phaal et al. [11] propose a summary of different types of roadmaps, which comprise product planning, service/capability planning, strategic planning, long-range planning, knowledge asset planning, program planning, process planning, and integration planning. One of the best visuals of roadmaps variations is purpose-driven roadmaps provided by Phaal et al. [11]. Technology planning and technology assessment, impact evaluation of technologies, is also assisted through technology roadmaps [15-16]. Technology roadmaps need to be integrated with technology forecasting tools [16–19] because they provide insight into the future. New product development decisions [20] can benefit by use of roadmaps which help select emerging technologies [21-22] and aid in industry-level R&D planning [23-24].

B. Wang et al [25] use technology assessment, forecasting, and roadmapping for sustainable energy including decision models for emerging economies. Other researchers [26-32] also use them to assess technologies and forecast the performance growth or the production of energy alternatives. M Amer et al. [33] use roadmaps to enable efficient technology planning. Fig. 1 shows the methodology for developing the technology roadmap.

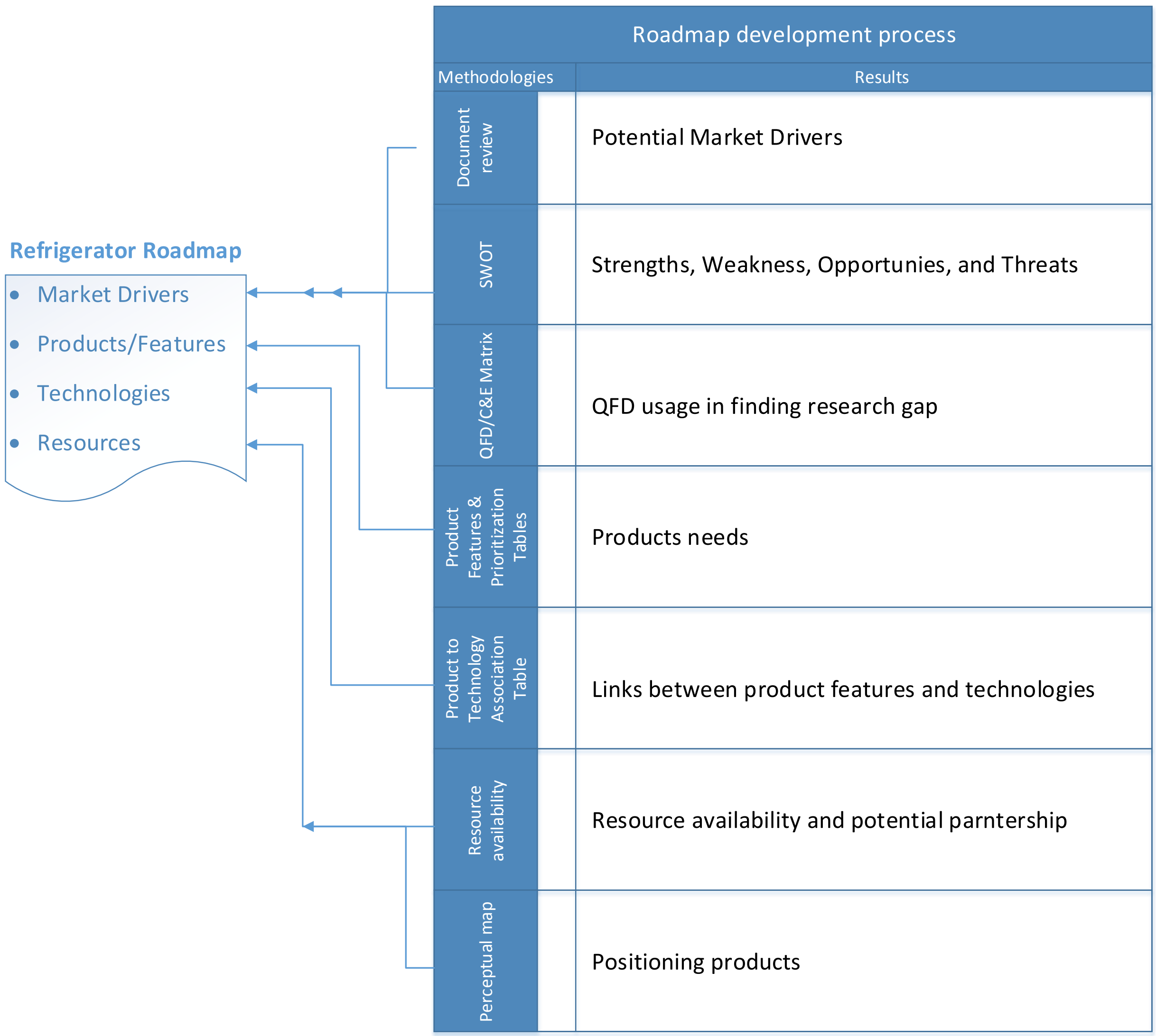



*Figure 1 - Roadmap development process*

# 4. ROADMAP DEVELOPMENT

This report demonstrates the development of a technology roadmap for a refrigerator for the leading manufacturer of commercial, industrial, and consumer products in the world, General Electric. The steps for the technology roadmap include:

- Market Drivers – technology for the relationships between different aspects of the refrigerator markets. Followed by an analysis of consumer market drivers for the home refrigerator.
- Business Drivers – business and operational aspects are explored in a SWOT analysis and related to the consumer refrigerator market.
- Quality Function Development – this mathematical evaluation of the relationship of market drivers to product features is created to contain and focus the technology roadmap into a manageable number of features
- Product Features – the features that are most important to consumers are factored in a table.
- Technologies – technologies that will fulfill the product features are identified.
- Resources – research and development, acquisitions, and partnerships are conceptualized for creation and application into the technologies identified. Gaps in GE's portfolio are identified for awareness.

## 4.1 Market Drivers

In order to develop refrigerator roadmaps, we need to make efforts to know refrigerators and grasp knowledge to build a roadmap. The availability and application of refrigeration technology significantly impact a society's standard of living. Examples of key contributors to quality of life are preservation throughout the food chain and medical applications. Although we cannot find integrated energy consumption information, this largest demand sector for refrigerants is estimated to use about 9% of world power generation capacity [34]. This consumption of global power-generation capacity means that the relative energy efficiency of alternatives can have a significant impact on indirect greenhouse-gas (GHG) emissions. Refrigeration applications vary widely in size and temperature level. Sizes range from domestic refrigerators requiring 60−140 W of electrical power and containing 40−180g of refrigerant, to industrial and cold storage refrigeration systems with power requirements up to several megawatts and containing thousands of kilograms of refrigerant. Refrigeration temperature levels range from –70°C to 15°C. Nearly all current applications use compression-compression refrigeration technology. The potential market size for this equipment may approach US$ 100,000 million annually. This diversity has resulted in unique optimization efforts over the decades, which has resulted in solutions optimized for different applications. The refrigeration market is divided into the five segments [34]:

- Residential segment: used for food storage;
- Commercial segment: used by retail outlets for holding and displaying frozen and fresh food for customer purchase;
- Food processing and cold storage segment: used for preserving, processing and storing food from its source to the wholesale distribution point;

- Industrial segment: used for chemical processing, cold storage, food processing and district heating and cooling;
- Transport segment: used for preserving and storing goods, primarily foodstuffs, during transport by road, rail, air and sea.

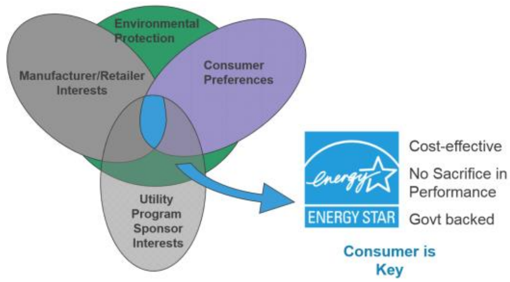



*Figure 2 - Energy saving drivers [35]*

In the project we only focus on consumer use – kitchen refrigerators. According to a 2001 home energy survey by the Energy Information Agency, a division of the U.S. Department of Energy, the refrigerator consumes 13.7%, followed by central air conditioners 14.1%, with the next highest amount of 42.2% going to the dryer, of the average home's energy usage [56]. The energy saving is our best interest, and the Figure 2 shows the drivers.

While energy conservation in the refrigerator is strong market driver it is highly evident that smartphones and tablet computers have gained wide adoption. It makes it possible for people to stay connected at all times. Through various social media networks, people tweet, post and update, and receive almost real-time feedback from friends, family and followers. Social media guides us every step of the way, so our home appliances – kitchen refrigerators is expected to do the same. Household refrigerators not only automatically tell us which recipes we can make from the ingredients they have on hand, but also discover that something has gone bad such as milk, just order more, providing a seamless experience [36].

Consumer expectations for the next generation of smart appliances have increased because the cost of the technology to manufacture and power smart appliances has decreased. Appliances, smart or otherwise are expected to provide interconnectedness, intelligence and longevity. These advanced features impact energy consumption which in turn affects consumers' utility bills. "If Americans are given the technological solutions in the form of smarter, more sophisticated and more environmentally friendly products and services, 74% of them are likely to change their energy usage to save money on their utility bills" [36]. However, the increased complexity of these products can lead to challenges in getting them to market quickly and may also increase the manufacturing costs. Therefore, the product will be expensive. This may prevent customers from adopting the product. The Figure 3 shows the market growth estimation of smart appliances.

In today's fast-paced market, our product must not only deliver what it promises, but also exceed customer expectations, so it can enable GE to establish and build potential buyers' trust in these new products, win valuable mind share and market share, thereby increasing GE profits.

Initially, we identified twenty market drivers which are categorized into operation, storage, reliability, kitchen, dispense, and cost.

*Table 1: Market drivers for Kitchen Refrigerators*

| Market drivers | | |
|---|---|---|
| **Catergory** | **Description** | **ID** |
| **Operation** | Low energy consumption | D1 |
| | Quiet | D2 |
| | Mantains temperature | D3 |
| | Smart Technology | D4 |
| | LCD display | D5 |
| | Preserves food & freshness | D6 |
| **Storage** | Maximize storage space | D7 |
| | Flexibility for changing storage needs | D8 |
| | Easy access & visibility | D9 |
| | Easy to clean | D10 |
| | Handles large containers & items | D11 |
| **Reliability** | Reliable, durable, and long service life | D12 |
| | Easy & low cost to service & maintain | D13 |
| | | |
| | | |
| **Kitchen** | Easy to deliver & install | D14 |
| | Coordinates with kitchen décor | D15 |
| | Fits in kitchen space | D16 |
| **Dispense** | Dispenses purified cold & hot water | D17 |
| | Provides & dispenses purified ice | D18 |
| | Dispenses coffee & tea | D19 |
| | | |
| **Cost** | Low price | D20 |
| | | |

Government subsidies are expected to drive the rapid development of the smart, energy-efficient home appliance market. Major manufacturers, supported by connectivity technology partners, will be another driving force, as consumers are expected to begin purchasing energy-efficient appliances such as refrigerators, dishwashers, clothes washers, dryers, stoves and ovens.

The market trends – market drivers for home appliances including refrigerators can be summarized in four main areas:

- Functionality - how easy the refrigerator operates within the kitchen
- Aesthetics – pleasing refrigerator styling an looks
- Technology – interconnected to power system, other home appliances, and networked devices such as smart phones or personal computers
- Energy efficiency – reduction in energy consumed for the same amount of output

Initially, we identified nineteen market drivers which are categorized into operation, storage, reliability, kitchen, dispense, and cost.

## 4.2 Technology Roadmap: Market Drivers

The drivers in Table 1 should meet customer demand and refrigerator market trends.

The first step was to perform a SWOT Analysis for GE's consumer refrigerator business unit. SWOT stands for Strengths, Weaknesses, Opportunities and Threats; these are organized into a two by two chart where participants can brainstorm the external and internal factors for each heading [37].

Strengths [38, 47-48]:

- Excellent research and development department
- Operating in 160 countries
- Diverse product range

*Figure 3 - SWOT analysis*

- Fourth most recognized brand in the world
- Fourth largest refrigerator manufacture
- Investment and funding from Government in radical cooling innovation for refrigerator

Weakness [47-48]:

- Weak credit rating
- Increasing instances of product recalls
- Short of technology and products for smart refrigerators such as LCD display, smart phones, OS, and etc.

Opportunities [47-48]:

- Gaining market share
- Introducing radical innovation refrigerator
- Creating partnership with other component companies

Threats [47-48]:

- High competition from Whirlpool, LG, Samsung and other manufacturers
- Competition from market entry of many competitors and copycat brands

From the SWOT analysis, we found that we should put effort on radical innovation cooling system to gain customer respect and increase our market share. If we can release the product earlier than other competitors, customers will adopt our products and become the number one refrigerator manufacturer. The SWOT also showed GE does not have “smartphone” and “wireless” technology which are required for smart refrigerators. Opportunities to explore and create mutually beneficial partnerships would be the best strategy because of existing communication standards currently in the market.

**Quality Function Deployment (QFD):**

QFD is a systematic way by which we develop products based on the needs of the market. The ability of QFD is to focus product designers and manufacturers on market needs. Halbieb et al. [38] define QFD as structured deployment of key requirements which assures that the product development team maintains its focus on these requirements and realizes customer needs and expectations repeatedly in the manufacture of the product. Hjort et al. [39] thinks a strength of QFD as a design for quality technique is its ability to facilitate the organization of unrelated data emanating from stakeholders in the product into insightful relationships which allow designers to focus on critical elements which can be changed to maximize customer satisfaction. Erikksen et al. [40] use QFD to maximize quality in development of customized computer software and claim QFD allows them to model the discussion between customers, software designers and other participants. QFD has been used successfully by manufacturers of consumer products to make products and services more competitive and user friendly in a consumer-focused market [41-45]. We use QFD quality tool to prioritize market drivers of kitchen refrigerators so we can keep these drivers manageable for the future product development. QFD tools are mathematically simple, however, this tool is subjective decision based upon the knowledge level of people involving the process so it is lack of scientific basis. Heuristic method for objective decision in the process is needed developing in the future.

A. M. Lamb et al [46] suggest that the number of market drivers should be narrowed to no more than five of the top drivers. Group discussion, the expertise of involved people, or quantitative decision-aiding tools can be used for narrowing [41].

*Table 2: Product features*

| Product features | |
|---|---|
| ID | description |
| PF1 | Smart insulation |
| PF2 | Balancing load according to the grid |
| PF3 | Glass fridge door |
| PF4 | Efficient EC fan |
| PF5 | Cools the refrigerator after frequent door openings |
| PF6 | Efficient fan system |
| PF7 | Reduction compressor power consumption. |
| PF8 | High efficiency compressors |
| PF9 | Smart defrost |
| PF10 | Zero ozone depletion levels |
| PF11 | Extra door storage |
| PF12 | Adjustable shelf |
| PF13 | Troubleshooting feature - early error detection |
| PF14 | Performance control |
| PF15 | Connects to service technician to diagnose issues remotely |
| PF16 | Send information to smart phones |
| PF17 | Remotely access the fridge to find out contents |
| PF18 | Peer to peer appliances communication |
| PF19 | Track inventory |
| PF20 | Create a shopping list |
| PF21 | Pre-programmed settings for hot food and drink preparation. |
| PF22 | Keeps food garden fresh |
| PF23 | Surface protection |
| PF24 | Life time motor |
| PF25 | Hot food and drink preparation |
| PF26 | Customizable drawer functions |

QFD design for this project starts from determination of ***Important Weighting*** which is the most important measure. We used it to narrow the number of market drivers. The figure of weight quantifies the relative importance of each of the market drivers from our perspective. A quadratic measure scale weight is used to identify the importance of each market drivers: 9 – high important, 3 – moderate important, 1 – low important, blank – not important. Although other options such as linear scale, constant sum, conjoint analysis, and 10-1 scale can be used for this purpose, the quadratic measure is the best for this project. These weights are pulled out of air by us or determined by literature review or group discussion.

After determination of important weighting, the strength of relationships between drivers and supporting features are determined. Four classifications are used. If they are strongly related, a value of 9 or a red disk is marked in the respondent cell. Moderate relationships are given a 3 or a green square. Weak relationships are given a 1 or a blue triangle. No relationship is given a 0 or left blank. The logarithmic 9-3-1 scaling method has been adopted by most QFD users. These correlations can be represented with either symbols or numbers. Because of timing and resource limitations, strength of relationships was chosen based upon our literature review and our intuition.

By multiplying each cell's value by the weight of the market driver and totaling the column for each product features, we get scores shown in the row labeled "Score". The overall score for each column shows the importance of that feature in meeting the market drivers. Features with low scores receive little consideration, but this does not necessarily mean that they will not be used in the product design. They may still be necessary for contractual or other reasons. In order to meet market requirement, we must focus on features with the highest scores. This is the main purpose of the QFD analysis.

Table 2 below lists product features which will be associated with market drivers. Those are features from engineering perspectives. Fig 5 demonstrates the QFD analysis results.

*Figure 4 - QFD analysis - Market drivers vs. Product features*

Strongly related: ●
Moderately related: ■
Weakly realted: ▲
Unrelated:

| | Market drivers | Important weight | PF1 | PF2 | PF3 | PF4 | PF5 | PF6 | PF7 | PF8 | PF9 | PF10 | PF11 | PF12 | PF13 | PF14 | PF15 | PF16 | PF17 | PF18 | PF19 | PF20 | PF21 | PF22 | PF23 | PF24 | PF25 | PF26 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Operation | Low energy consumption | 9 | ● | ● | | ● | | ● | ● | ● | ● | | | | | | | | | | | | | | | | | |
| Operation | Quiet | 3 | | | | ● | | ● | | | | | | | | | | | | | | | | | | | | |
| Operation | Mantains temperature | 9 | ● | ▲ | | | ● | | ● | | | | | | | | | | | | | | | | | | | |
| Operation | Smart Technology | 9 | | ● | | | | | | | ● | | | | ■ | ● | ● | ● | ● | ● | ● | ● | | | | | | |
| Operation | LCD display | 3 | | | | | | | | | | | | | | | | ● | | ● | ● | | | | | | | |
| Operation | Preserves food & freshness | 9 | ● | ▲ | | | ■ | | ● | | | | | | | | | | | | | | | ● | | | | |
| Storage | Maximize storage space | 3 | | | | | | | | | | | ● | | | | | | | | | | | | | | | ■ |
| Storage | Flexibility for changing storage needs | 3 | | | | | | | | | | | | ● | | | | | | | | | | | | | | ● |
| Storage | Easy access & visibility | 3 | | | ● | | | | | | | | | | | | | | | | | | | | | | | |
| Storage | Easy to clean | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Storage | Handles large containers & items | 1 | | | | | | | | | | | ▲ | ■ | | | | | | | | | | | | | | |
| Reliability | Reliable, durable, and long service life | 9 | | | | | | | | | | | | | | | | | | | | | | | ● | ● | | |
| Reliability | Easy & low cost to service & maintian | 3 | | | | | | | | | | | | | ● | ● | ● | ● | | | | | | | | ▲ | | |
| Reliability | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Reliability | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Kitchen | Easy to deliver & install | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Kitchen | Coordinates with kitchen décor | 1 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Kitchen | Fits in kitchen space | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Dispense | Dispenses purified cold & hot water | 3 | | | | | | | | | | | | | | | | | | | | | ● | | | | ● | |
| Dispense | Provides & dispenses purified ice | 3 | | | | | | | | | | | | | | | | | | | | | ■ | | | | | |
| Dispense | Dispenses coffee & tea | 3 | | | | | | | | | | | | | | | | | | | | | ▲ | | | | | |
| Dispense | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cost | Low price | 3 | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Cost | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
| Score | | | 253 | 180 | 81 | 162 | 108 | 162 | 253 | 81 | 162 | 0 | 28 | 30 | 54 | 108 | 108 | 253 | 81 | 162 | 162 | 81 | 39 | 81 | 81 | 30 | 9 | 36 |
| Rank | | | 1 | 2 | 5 | 3 | 4 | 3 | 1 | 5 | 3 | 12 | 10 | 9 | 6 | 4 | 4 | 1 | 5 | 3 | 3 | 5 | 7 | 5 | 5 | 9 | 11 | 8 |

In QFD analysis, the findings are facts the QFD provide a large number of priority market drivers and a few items have the same number. This implies high diversities in the refrigerator industry – different approaches can get the same results or drivers and associated features have the same priority. We also have to evaluate the difficulty measure so that these features can be implemented appropriately. Table 3 below shows the features ranking 1 or 2 in the product feature list. They will be highly recommended to support.

*Table 3 - Planned product features*

| Planned product features based upon scores | | | |
|---|---|---|---|
| ID | Description | Score | Rank |
| PF1 | Smart insulation | 253 | 1 |
| PF7 | Reduction compressor power consumption. | 253 | 1 |
| PF16 | Send information to smart phones | 253 | 1 |
| PF2 | Balancing load according to the grid | 180 | 2 |

## 4.3 Product Features

Based upon market drivers and market trends, low energy consumption and smart technology are the target. Smart and low energy consumption refrigerators are our goal in near and far future. In the near term, we need to release smart refrigerator and improve energy efficiency. In the long run, we need to make radical cooling innovation.

Refrigerator can be divided into a few subsystems based upon the functionalities [49] and we create a map between product features and the subsystems. The map is shown in Table 4. The findings are that technology innovation or feature enhancement mostly happen in refrigerator cycle and control/display subsystem.

*Table 4 - Refrigerator subsystems*

| ID | Subsystems | Description | Features |
|---|---|---|---|
| PS1 | Refrigerator cycle | Cools the inside of the refrigerator and freezer compartments | PF5, PF7, PF8, PF10, PF22 |
| PS2 | Ice maker/dispenser | The Ice Maker is located in the freezer compartment that automatically fills ice trays, freezes the water, and dispenses the ice into a storage bin. The Ice Dispenser, when activated, dispenses the ice out of the storage bin and through an exit hole in the freezer door for use. | PF25 |
| PS3 | Doors and insulation | The Doors act as both an opening for refrigerator use and extra storage. On the inside of the doors and main cabinet, Insulation is used to keep the temperature of the refrigerator from being affected by the temperature of the environment. | PF1, PF3, PF11 |
| PS4 | Cabinetry and Shelves | The Cabinet is the material that houses the entire refrigerator while the shelves provide more usable storage space inside the refrigerator. | PF12, PF26 |
| PS5 | Air flow | Circulates the air inside the compartments in order to create uniform temperature gradient for both the refrigerator and freezer | PF4, PF6, PF24 |
| PS6 | Controls/display | Allows the user to define a preferred temperature for both refrigerator and freezer compartments, comminicate witth other appliances , remote control system, and smart phones, and display information | PF2, PF9, PF13, PF14, PF15, PF16, PF17, PF18, PF19, PF20, PF21, |

Refrigerator cycle is the fundamental system of a refrigerator. R & D efforts [50-53] are new radical cooling innovation, making low energy consumption, and reducing or even free greenhouse gas.

Except traditional control functionality, control/display subsystem makes refrigerator smart and intelligent. Smart grid can let the utility provider regulate the refrigerator's power consumption and curtail operations during more expensive peak-demand times.

Based upon GE current residential refrigerator families, the following three features are recommended in midterm:

- Smart insulation (PF1)
- Send information to smart phones (PF16)
- Balancing load according to the grid (PF2)

In fact, PF2 feature depends on PF16. Refrigerators communicate with not only smart phones but also other remote control centers such as utility providers.

In the long run, we need to make radical cooling innovation, so that refrigerators consume very low energy consumption and are greenhouse gas free:

Reduction compressor power consumption (PF7) – radical refrigerator cycle innovation

Providing rich features in products will add manufacturing cost so that the price of products will go higher. We are expecting customers would like to adopt our new products, and get out “CHASM” gap quickly.

## 4.4 Technologies

After we narrow down product features, we focus on developing technologies supporting these features.

For PF1, Vacuum-insulated panel (VIP) technology is widely developed. VIP is based on the principle that an air vacuum reduces conductivity so that it will reduce the amount of heat transfer between the exterior wall and ambient environment. VIP reduces not only energy consumption but also insulation thickness so that refrigerator capacity is expanded [54]. The U.S. Department of Energy highly recommends this technology [52] for further R&D.

Both wired network and wireless network technology can be used for realizing PF16 and PF2. 10:1 scale is used to evaluate the quality of connection and easiness of interference. Wired network has solid connection, but it needs a more network infrastructure in the kitchen. Wireless is flexible, but is easily compromised by interlopers. It also has wireless coverage issue, meaning that if there is no wireless coverage this refrigerator would not function as intended, therefore the infrastructure must be in place. Although Bluetooth and Zigbee have low energy consumption, it is hard for them to be used to hook the refrigerator to home network because they are normally used for short distance communication, for example, communication between appliances in the kitchen.

*Table 5 Networked/Connected technologies analysis*

| Networked/Connected technologies | Quality | Priority | Energy consumption |
|---|---|---|---|
| Wired | 10 | 1 | High |
| Wireless - WiFi | 8 | 1 | Moderate |
| Wireless - Bluetooth | 7 | 2 | Low |
| Wireless - Zigbee | 7 | 3 | Low |

Once the refrigerator is online, Smart grid technology is needed to support the feature PF2. Utility companies are able to offer time-of-use pricing structure.

In order to meet PF7, we need to estimate available technologies and prioritize them and focus on the one with highest priority. The traditional refrigerators consume most energy powering the vapor-compression cycle, which uses a compressor and multiple heat exchangers to transfer heat from inside the food compartments to outside the refrigerators. Table 6 below lists technologies with radical innovation for the refrigerator cycle [53], and we prioritize them with 10:1. If left blank, we won't consider it.

*Table 6 - Radical refrigerator cycle innovation*

| Technologies | Description | Priority |
|---|---|---|
| Acoustic refrigeration | Uses sound waves to produce cooling | 10 |
| Ammonia | Uses ammonia to drive the cooling system | |
| Electrocaloric refrigeration | Uses the ability of a material to change temperature by applying an electric field | 10 |
| Hydraulic refrigeration | Uses water pressure to compress and condense the refrigerant | 10 |
| Magnetic refrigeration | Uses magnetocaloric effect | 1 |
| Optical cooling | Uses anti-Stokes fluorescence principal | 10 |

From Table 6 above, magnetic refrigeration has highest priority and should be used for the radical refrigerator cycle innovation. It has no compressor, so it operates very quiet. It can be 50% more energy efficient than conventional techniques, it doesn't rely on environmentally harmful gas [55].

Table 7 below shows the link between product features and technologies

*Table 7 - Product features and Technology association*

| Product features and technology association | | |
|---|---|---|
| **ID** | **Description** | **Links** |
| PT1 | VIP | PF1 |
| PT2 | Networked/Connected | PF16 |
| PT3 | Refrigerator cycle innovation | PF7 |
| PT4 | Smart grid | PF2 |

## 4.5 Resources

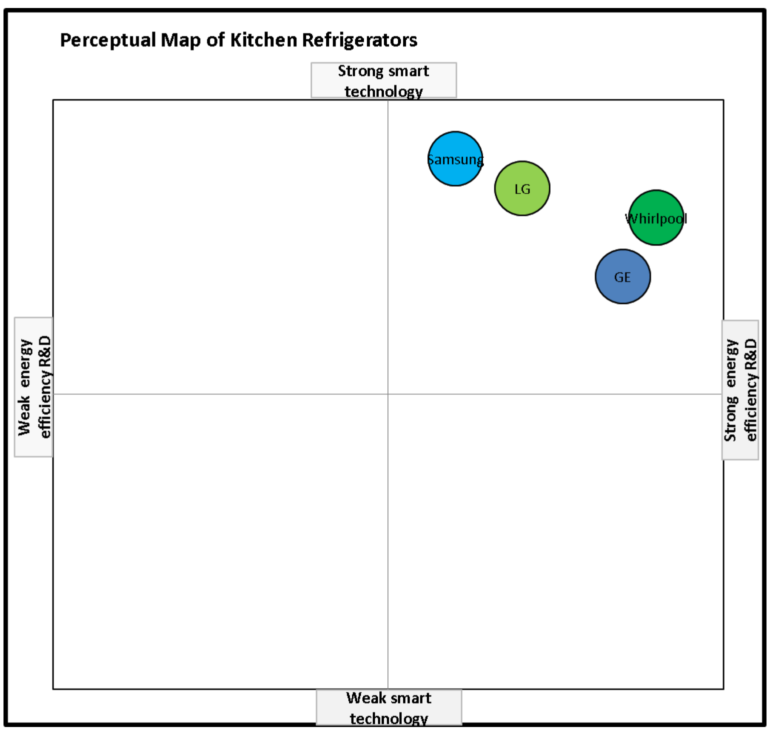
After we resolve links between product features and technologies, we need to consider resources and partnerships to support these technologies.

VIP technology (PT1) is currently available, but the performance is inconsistent. GE is the leading company on this area and files a few patents for the technology. In the mid-term (2-3 years), R & D efforts for GE are [52]:

- Test characterization on products having inconsistent performance
- Find out root causes for contributing performance inconsistencies
- Optimize the supply chain of all materials and processes used in the manufacture of VIPs
- Reduce costs

GE is short of networked/connected technology. The shortage can be resolved by partnership such as a smart phone company, solid component supplement, supporting software, and OS such as android. R & D efforts are software and integration. GE needs to optimize its smart grid technology via software optimization.

*Figure 5 - Perceptual Map of Kitchen Refrigerators*




GE started magnetic research in 2010 funding from US Department of Energy [50], GE R&D efforts in 5 years still are:

- Further understanding of magnetic refrigeration cooling principles
- Optimization of individual components of the system
- Demonstration of required cooling capacity
- Cost reduction

Fig 6 below shows perceptual map of kitchen of kitchen refrigerators. The findings are gaps GE needs to be improved.

Fig 7 shows the TRM for GE Kitchen Refrigerators

*Figure 6 - TRM for GE Kitchen Refrigerator*

| | | Current | Mid-term | Future |
|---|---|---|---|---|
| Drivers | Operation | **D1** - Low energy consumption | | |
| | | **D3** - Mantains temperature | | |
| | | **D4 -** Smart Technology | | |
| | | **D6 -** Preserves food & freshness | | |
| | Reliability | | | |
| | Kitchen | | | |
| | Dispense | | | |
| | Cost | | | |
| Features | Refrigerator Cycle | | | PF7 |
| | Ice maker/dispenser | | | |
| | Doors and insulation | | PF1 | |
| | Cabinetry and shelves | | | |
| | Air flow | | | |
| | Controls/display | | PF2 | |
| | | | PF16 | |
| Tech | Insulation | | PT1 | |
| | Communication | | PT2 | |
| | Software optimization | | PT4 | |
| | Cooling technology | | | PT3 |
| Resources | Intenal R&D | VIP R&D | | |
| | | Optimization SW for smart grid | | |
| | | Magnetic refrigerator R&D | | |
| | External | Materials for magnetic refrigerator | | |
| | Parntership | Wired/wireless and smart phone application | | |

# 5 RECOMMENDATIONS

This study proves that the use of technology roadmapping in the development of a refrigerator for General Electric to produce is a viable methodology for experts within GE to come together to identify the market desires, technology developments, and policy requirement which will shape their business to come.

What is lacking from this study are real world costs and margins for each of the technologies identified for inclusion into the refrigerator of the future. Without that information it is entirely possible that the concept refrigerator we came up with largely a pie in the sky product. That is not to say that this was not a useful exercise because it is possible that with cost reduction in technologies, changes in market drivers, and changes in policy requirements that some technologies will be kept and others will be left by the wayside.

# 6 CONCLUSION

As described above, this technology roadmapping study was performed by the authors as self-described experts working in General Electric's home consumer refrigeration business unit. The technology roadmap we provide in this study can help GE leverage their technological acumen through their diverse product lines, partnerships, and research and development to create, potentially, the ultimate refrigerator.

Through this study we performed a SWOT analysis which found organizational gaps and beneficial structures GE has for future growth. This was an initial step for the process of looking into GE as a contender in the refrigerator market.

We looked into Quality Function Deployment to identify and prioritize the market drivers, features, technologies, and resources which identified low energy consumption and smart technology as the most important driver. Therefore, radical refrigerator cycle – magnetic refrigeration innovation, networked/connected, VIP, smart grid technologies are needed to be improved or developed within the U.S.

Through these steps we have created a useful device in the form of a technology roadmap for General Electric to make educated acquisitions, focused research and development, and have an easily accessible communication tool for stakeholders and internal developers to create the potentially ultimate refrigerator.

# 7 REFERENCES


1. Olivia Zaleski, “Energy Efficient Appliances to Upgrade Your Kitchen,” Internet: www.thedailygreen.com/green-homes/latest/green-remodeling-energy-efficient-kitchen-appliances-460212#slide-1, [Aug 2, 2013]
2. Saving Eletricity, “How much electricity does my refrigerator use?” Internet: michaelbluejay.com/electricity/refrigerators.html, June 2013, [Aug 2, 2013]
3. Energy Star, “Refrigetors for Consumes,” Internet:www.energystar.gov/index.cfm?fuseaction=find_a_product.showProductGroup&pgw_code=RF, [Aug 2, 2013]
4. theKitchen, “Is This the Refrigerator of the Future,” Internet: www.thekitchn.com/is-this-the-fridge-of-the-future-187356, [Aug 2, 2013]
5. Lesie Claggett, “Smart Refrigerators,” Internet: www.kbbonline.com/Smart-Refrigerators-3252.shtml, May 15, 2012, [July 31, 2013]
6. Wireless Integrated, “Smart Refrigerator,” Internet:www.wirelessintegrated.com/smart-refrigerator-samsung-t9000.html, March 11, 2012 [July 31, 2013]
7. Companies and Markets.com, “US refrigerator market dominated by Whirlpool Corp with 20% of volume sales, ” Internet: www.companiesandmarkets.com/News/Consumer-Goods/US-refrigerator-market-dominated-by-Whirlpool-Corp-with-20-of-volume-sales/NI5976, [Aug 2, 2013]
8. Carbon Trust, “Refrigeration Road Map,” Internet: www.epa.gov/greenchill/downloads/RefrigerationRoadmap.pdf, [July 21, 2013]
9. U.S. Department of Energy, “Research & Development Roadmap for Next-Generation Appliances”, March, 2012 [July 31, 2013]
10. GE Industrial Solutions, “New Products”, Internet: www.geindustrial.com/pressroom/press_releases/electrical/new_products/launch_Industrial_energy_efficiency_coalition.htm, [Aug 2, 2013]
11. Phaal, R., Farrukh, C. J. P., & Probert, D. R., “Technology roadmapping—A planning framework for evolution and revolution,” Technological Forecasting and Social Change, Vol. 71, pp. 5–26, 2004
12. Phaal, R., & Muller, G., “An architectural framework for roadmapping: Towards visual strategy,” Technological Forecasting and Social Change, Vol. *76, No.* 1, pp. 39–49, 2009
13. Government Canada, “Technology Roadmapping: A Guide for Government Employees,” Internet: www.google.com/#bav=on.2,or.r_cp.r_qf.&fp=111dd949e5b38d4b&q=technology+roadmap+benefits, [Aug 4, 2013]
14. R.N. Kostoff and R.R. Schaller, “Science and technology roadmaps,” IEEE Trans. Eng. Manage., vol 48 , no. 2, pp. 132-143, May 2001
15. T. Tran and T. Daim, “A taxonomic review of methods and tools applied in technology assessment,” *Technological Forecasting and Social Change*, vol. *75, no.* 9, pp. 1396–1405, 2008
16. A. Lamb et al., “Forecasting airplane technologies,” J. Transport. Sys Eng. Inf. Techno., vol 12, no. 6, pp. 38-54, 2010.
17. T.U. Daim at al., “Forecasting emerging technologies: Use of bibliometries and patent analysis,” *Technological Forecasting and Social Change, vol. 73, no. 8, pp. 981-1012, Oct. 2012*

18. T. Daim et al., "Forecasting powertrain technologies," J. Transport. Sys Eng. Inf. Techno., vol 11, no. 2, pp. 58-69, 2011.
19. J. Kim et al., "A look at the future of wireless technologies," Technol. Anal. Strat. Mange., vol. 22, no. 8, pp. 925-943, 2010
20. I. J. Petrick and A. E. Echols, "Technology roadmapping in review: A tool for making sustainable new product development decisions," Technol. Forecast. Social Change, vol. 71, pp. 81–100, 2004.
21. H. Chris and M. Ferrill, "The application of operation and technology roadmapping to aid singaporean SMEs identify and select emerging technologies," Technol. Forecast. Social Change, vol. 72, no. 3, pp. 349–357, Mar. 2005, Managing Emerging Technologies in Asia.
22. O. Saritas and M. A. Oner, "Systemic analysis of UK foresight results: Joint application of integrated management model and roadmap- ping,"Technol.Forecast.SocialChange,vol.71,Roadmapping:From Sustainable to Disruptive Technologies, no. 1–2, pp. 27–65, Jan./Feb. 2004.
23. S. Lee, S. Kang, Y. S. Park, and Y. Park, "Technology roadmapping for R&D planning: The case of the Korean parts and materials industry," Technovation, vol. 27, no. 8, pp. 433–445, Aug. 2007.
24. N. Intarode and T. Daim, "Technology roadmapping: 2010 to 2050 global cement product roadmap," Int. J. Technol., Policy, Manage., vol. 11, no. 2, pp. 173–186, 2011.
25. B. Wang, D. Kocaoglu, T. Daim, and J. Yang, "A decision model for energy resource selection in China,"EnergyPolicy,vol.38,no.11,pp. 7130–7141, 2010.
26. K. Cowan, T. Daim, and T. Anderson, "Exploring impact of technology development and adoption for sustainable hydroelectric power and storage technologies in the Pacific Northwest United States," Energy, vol. 35, pp. 4771–4779, 2010.
27. T. Daim, G. Kayakutlu, and K. Cowan, "Developing oregon's renewable energy portfolio using fuzzy goal programming model," Comput. Industrial Eng., vol. 59, no. 4, pp. 786–793, 2010.
28. K. Cowan and T. Daim, "Assessing renewable energy portfolio fu- tures with multiple perspectives," Technol. Society, vol. 32, no. 4, pp. 255–263, 2010.
29. T. Daim, W. Schweinfort, and G. Kayakutlu, "Technology assessment of two energy portfolios using a hierarchical decision model," Int. J. Energy Sector Manage., vol. 4, no. 1, pp. 24–43, 2010.
30. G. Harell, N. Third, and T. Daim, "Is Nuclear energy an alternative: A caseoftechnologyassessmentinoregon,"Int.J.NuclearGovernance, Economy, Ecology, vol. 3, no. 2, pp. 150–179, 2010.
31. I. Kockan, T. Daim, and N. Gerdsri, "Roadmapping future powertrain technologies: A case study of ford otosan," Int. J. Technol., Policy, Manage., vol. 10, no. 1–2, pp. 157–184, 2010.
32. D. Cinar, G. Kayakutlu, and T. Daim, "Development of future energy scenarios with intelligent algorithms: Case of hydro in Turkey," En- ergy, vol. 35, no. 4, pp. 1724–1729, 2010.
33. M. Amer and T. Daim, "Application of technology roadmaps for re- newableenergysector,"Technol.Forecast.SocialChange,vol.77,no. 8, pp. 1355–1370, 2010. [32] P. Kofman, "The production of wood pellets," Coford Connects, vol. Processing/Products, no. 10, 2007, Dublin, Ireland: National Council for Forest Research & Development.
34. Sukumar Devotta et al., "IPCC/TEAP Special Report: Safeguarding the Ozone Layer and the Global Climate System," Internet: www.google.com/#bav=on.2,or.r_cp.r_qf.&ei=Y9D-UfOrE4OoiQKLw4C4CA&fp=111dd949e5b38d4b&q=refrigerator+market+drivers&sa=N&start=60, [Aug 4, 2013]
35. EPA, "ENERGY STAR Residential Refrigerators and Freezers," Internet: www.google.com/#bav=on.2,or.r_cp.r_qf.&ei=Fcn-

Ua3JJ6WViALcxoCADA&fp=111dd949e5b38d4b&q=refrigerator+market+drivers&sa=N&start=50, July 25, 2011 [Aug 4, 2013]
36. Intertek, "Evolving Smart Technologies Across Home Appliance and Consumer Electronics Markets", Internet:www.google.com/url?sa=t&rct=j&q=&esrc=s&frm=1&source=web&cd=25&cad=rja&ved=0CFkQFjAEOBQ&url=http%3A%2F%2Fwww.appliancedesign.com%2Fext%2Fresources%2FAM%2FHome%2FFiles%2FPDFs%2FEvolvingSmartTechnologies.pdf&ei=0db-UfzRNqnriwLEwICICQ&usg=AFQjCNG4uAlap38pBIpS3zqI-MsUaoTlJA&sig2=fR1JFBAKCyckrxpBerZzqQ, [Aug 2, 2013]
37. Wikipedia, "SWOT analysis," Internet: en.wikipedia.org/wiki/SWOT_analysis, [Aug 2, 2013]
38. L. Halbeib, P. Wormington, W. Cieslak, and H. Street, "Application of QFD to the design of a lithium battery," *IEEE Trans. Comp., Hybrids,Manufact. Technol.*, vol. 16, pp. 802–807, Aug. 1993.
39. H. Hjort, D. Hananel, and D. Lucas, "Quality function deployment and integrated product development," *J. Eng. Design*, vol. 3, no. 1, pp. 17–29, 1992.
40. I. Erikkson and F. McFadden, "QFD: A tool to improve software quality," *Inform. Software Technol.*, vol. 35, no. 9, pp. 491–498, 1993.
41. A. Terry et al., "A Tutorial On Quality Function Development," Engineering Management Journal, Vol. 5, No. 3, pp. 24-35, 1993
42. Gilbert D. Logan et al., "Potential for Use of a House of Quality Matrix Technique in Rehabilitation Engineering," IEEE Trans on Rehabilitation Engineering, Vol. 5, No. 1, pp. 106-115, 1997
43. A. Tolga Bozdana, "Quality Function Deployment (QFD)", Internet: www1.gantep.edu.tr/~bozdana/ME530_2.pdf, [Aug 10, 2013]
44. Creative Industries Research Institute, "Quality Function Deployment,", Internet: www.ciri.org.nz/downloads/Quality%20Function%20Deployment.pdf, [Aug 10, 2013]
45. Clemson University, "Quality Function Deployment,", Internet: www.clemson.edu/ces/credo/classes/Lect4016.pdf, [Aug 2, 2013]
46. A. M. Lamb et al., "Wood Pellet Technology Roadmap," IEEE Transactions On Sustainable Energy, Vol. 3, No. 2, pp. 218–230, 2012
47. Slideshare, "GE Appliances," Internet: www.slideshare.net/9855274090/presentation1-ge-appliances-10012716, [Aug 11, 2013]
48. Slideshare, "General Electric," Internet:www.slideshare.net/scholarballer51/general-electric-presentation-13254459, [Aug 11, 2013]
49. GICL, "Refrigerator Whirlpool," Internet: gicl.cs.drexel.edu/wiki/Refrigerator_Whirlpool, [Aug 11, 2013]
50. Tracey Schelmetic, "Getting Closer To Magnetic Refrigeration," Internet: news.thomasnet.com/green_clean/2010/07/07/getting-closer-to-magnetic-refrigeration/, July 7th, 2010 [Aug 4, 2013]
51. Andrew Gaved, "Magnetic refrigeration technology set to break through," Internet: www.racplus.com/news/magnetic-refrigeration-technology-set-to-break-through/8648701.article, May 30, 2013 [Aug 2, 2013]
52. US Department of Energy, "Research & Department Roadmap for Next-Generation Appliances", March 2012
53. Carbon Trust, "Refrigeration Road Map", March 2010

54. PRODUCTGUIDE, "LG-One 21 cu.ft French Door Refrigerator with Smart ThinQ$^{TM}$ Technology (LFC31995)," Internet: www.electronichouse.com/product/details/french_door_refrigerator_with_smart_thinq_technology/, [Aug 14, 2013]
55. Greenfootsteps, "Magnetic Refrigeration - the new eco-friendly way to keep things cool?" Internet:www.greenfootsteps.com/magnetic-refrigeration.html#sthash.MQIzAr3Z.trsgRReE.dpbs, [Aug 14, 2013]
56. EIA, "End-Use Consumption of Electricity 2001," Internet: www.eia.gov/emeu/recs/recs2001/enduse2001/enduse2001.html, [Aug 15, 2013]