Asia-Pacific
Economic Cooperation

Project Report on Promoting Renewable Power Generation with Fuel Cell

Beijing, China

Energy Working Group

October 2016

APEC Project: EWG 13 2015A – Promoting Renewable Power Generation with Fuel Cell

Produced by
Xu Dong, Jerry Chen, Wang Nong-zhang, Zhao Yi-ming
Guodian New Energy Technology Research Institute
2 Street, Future Science & Technology Park North, Changping District, Beijing, 102209, China

For
Asia-Pacific Economic Cooperation Secretariat
35 Heng Mui Keng Terrace
Singapore 119616
Tel: (65) 68919 600
Fax: (65) 68919 690
Email: info@apec.org
Website: www.apec.org

APEC#216-RE-01.24

Table of Contents

Project Report on Promoting Renewable Power Generation with Fuel Cell

Beijing, China

1. **Introduction**

As a new technique of power generation, fuel cell is playing a more and more important role in the energy area due to its own advances- high efficiency and zero pollution emission. Fuel cell technology is a promising approach to making the energy industrial green and environment friendly.

This report integrates the key findings of interviews, site visits, forum summary, commercial analysis results and secondary research. The greatest value of the report could be the first-hand information summary and in-depth analysis on the potential of integrating fuel cell into renewable energy generation projects.

The main discussion section of report composes of five parts: site visit summary, forum summary, project evaluation survey, commercial analysis report and fuel cell technical progress review report. The interview discussion has been integrated in the section of forum summary.

2. **Summary of the Site Visits**

From 10-15 August 2015, research delegates from Guodian New Energy Technology Research Institute （GNETRI） visited three different fuel cell related organizations and company in Chinese Taipei, to learn more about fuel cell industry and R&D base.

The first site visit is in the Green Energy and Environment Laboratories (GEEL) of Industrial Technology Research Institute of Chinese Taipei. GEEL has devoted its resources to develop novel green energy and environment technologies for a better future. Fuel Cell technology is one of its energy and environment topics. The scientists there introduced its upper, middle and lower reaches of the fuel cell industry. They mentioned the major research area focused on hydrogen produce and hydrogen storage. The visitors also looked around the project results exhibition center of Industrial Technology Research Institute of Chinese Taipei.

The second site visit is in Chinese Taipei Fuel Cell Partnership (TFCP), which aims to promote the application and promotion of fuel cell technology and industry in Chinese Taipei. During the visit, Dr Chunto Tso, Convenor of Chinese Taipei Fuel Cell Partnership introduced that the mission and goal of TFCP is to enhance public awareness and application of fuel cell technology and industry,to create a favorable environment and industrial growth of high-quality infrastructure in Chinese Taipei, and to promote the national attention to fuel cell technology and industry. Dr Chunto Tso also enhanced that Chinese Taipei has a mature and complete fuel cell industry chain, providing international manufacturers with excellent quality and affordable (cost down) fuel cell products and related key components. He recommended a novel fuel cell motorcycle pushing forward toward the market. Chinese Taipei has 15 million motorbikes/scooters popular for convenient transport and parking. At the same time, Low-pressure MH canisters are safe and easy to change for FC scooters in Chinese Taipei. Road tests have been successfully completed, demonstrating this superior manufacturing technology. Cross-strait as well as international collaboration in the development of FC scooters related technology is welcomed towards to all the visitors.

The third site visit is in Hephas Energy of Chinese Taipei, which is a company dedicating on fuel cell test equipment and fuel cell system parts supply in China and Chinese Taipei. The CTO of Hephas introduced to the visitors during the site communication that they provide variety of test equipment from material research, short stack evaluation and stack performance/durability testing. Besides the fuel cell IV performance, Hephas provide more electrochemistry diagnosis methods. Hephas owns 20 people engineering cover from mechanical, electrical, process engineering, and electrochemistry experts. The design and manufacturing center that has been visited and looked around is located in Hsinchu science part in Chinese Taipei. The core competence of Hephas shown to visitors is based on Temperature, Humidity, Pressure, Flow and electrochemistry control in different kinds of fuel cell testing requirement. It is known that Hephas working with global fuel cell partners like Sunfire (Germany), Hydorgenics (Canada), KIKUSUI (JAPAN), ELCOGEN (Finland), AvCarb (USA), etc, providing full range of fuel cell material and components supply, such as catalyst, gas diffusion layer, MEA, Stack, blower, pumps, and stacks. Hephas dedicate customer with best capability and service for customer satisfaction and the company owns 80% market share in Chinese Taipei and China fuel cell research market and revenue.

3. Forum Summary

3.1. Basic information

On 18 and 19 January 2016, the APEC forum on Fuel Cell, initiated by China and co-sponsored by Hong Kong, China; Chinese Taipei; and the United States was successfully held in Beijing, China. The forum was sponsored by APEC Energy Working Group, National Energy Bureau and China Guodian Corporation and organized by Guodian New Energy Technology Research Institute.

The main purpose of the forum was to promote the development of fuel cell technologies. The forum aimed to provide a platform for in-depth discussion on the commercialization pathway of fuel cells, and to propose solutions to the technical bottlenecks through constructive communications and interactions among engineers, scientists and government leaders from major global fuel cell industries and world leading research organizations.

The forum covered four sections: (i) Review of fuel cell technology development and industry layout; (ii) Transportation fuel cell technology; (iii) Stationary fuel cell power generation technology; (iv) Hydrogen and its infrastructure construction. The tendency of the development of fuel cell technology was discussed and the newest products from global leading fuel cell research institutes and industrials were shared to all the delegates.

3.2. Forum organization

The Organizing Committee in the pre conference set up project team, by telephone, mail, visiting form and fuel cell of upstream and downstream industry chain enterprises of communication invited to participate in, and through traditional media, network platform, micro channel, the app, meeting the industry related media channels of the meeting of all aspects of promotion.

Introduction of the forum was shown at the website: http://www.gneti.net/zxgg/100558.jhtml. The event lasted for two tight working days, and the event agenda is shown in the following:

January18th,Monday,2016	
Time	**Agenda**
08:00-09:10	Registration
09:10-09:20	**Opening Speech**
09:20-09:30	**Zhang Shumin**, Chief Economist, China Guodian Corporation
	Review of fuel cell technology and its industry layout
09:30-10:00	**Fuel Cell Vehicle Technology and Development in China** Dalian Institute of Chemical Physics, China Bao-lian Yi, CAE academician/Professor
10:00-10:30	**U.S Fuel Cell Industry** Fuel Cell and Hydrogen Energy Association, USA Morry Markowitz, President
10:30-10:50	**Break**
10:50-11:20	**Stationary Fuel Cell Market and Development in Japan** TOSHIBA / ENE Farm, Japan Fumio Ueno, Technology Executive/Chair of IEC TC105
11:20-11:50	**Status and Opportunities for Hydrogen & Fuel Cell Technology In Korea** Korean Hydrogen Industry Association, Korea Hee-Chun Lim, Vice Chair
11:50-12:20	**Fuel Cell Industrial Development in Chinese Taipei** Chinese Taipei Fuel Cell Partnership, Chinese Taipei Chunto Tso, President/Convener
12:20-13:30	**Lunch**
	Stationary power generation field
13:30-14:00	**Low Temperature and High Efficiency Direct Biomass Fuel Cell** Guodian New Energy Technology Research Institute, China Hua Guo, Vice President
14:00-14:30	**Progress and Perspective of Fuel Cells at DICP** Dalian Institute of Chemical Physics, China Gong-quan Sun, Professor
14:30-15:00	**Fuel Cell Activities in Doosan and Korea** Doosan /Fuel cell BG, Korea Meenam Shinn, President
15:00-15:20	**Break**
15:20-15:50	**Novel SOC Based Applications for Today Challenges in the Energy Sector** Sunfire Gmbh, Germany Carl Berninghausen, CEO
15:50-16:20	**Development of Carbon-based Solid Oxide Fuel Cell** Tsinghua University, China Han Minfang , Professor

16:20-16:50	**On the Road to Commercialization of SOFC Technology** Ningbo SOFCMAN Energy, China Wang Weiguo, Chair of the Board and CEO
January19th, Tuesday,2016	
Time	**Agenda**
	Transportation Field
09:00-09:30	**Toyota's FCV Developmentand Efforts Toward Sustainable Mobility** Toyota, Japan Kawai Taiyo, Project General Manager
09:30-10:00	**Fuel Cell-The Next Step of Daimler** Daimler, Germany Wolfram Fleck， Manager, RD/EFE
10:00-10:30	**Hyundai's FCEV** Hyundai, Korea Jungik Kim, Senior Research Engineer
10:30-10:50	**Break**
10:50-11:20	**Fuel cell technologies in Sunrise Power** Sunrise Power, China Pingwen Ming, President/CEO
11:20-11:50	**FCEV Commercialization, Social and Economic Studies at Nissan Motor** Nissan, Japan Takuya Hasegawa, Senior Innovation Researcher
11:50-12:20	**PEMFC Technology and Product for Medium and Heavy Duty Vehicles** US Hybrid, USA Abas Goodarzi, President/CEO
12:20-13:30	**Lunch**
	Hydrogen and its infrastructure construction
13:30-14:00	**NICE/Shenhua Perspectives of Hydrogen Energy** National Institute of Clean-and-Low-Carbon Energy, China Chang Wei, President
14:00-14:30	**Issues Ahead for Deployment of Fuel Cells: A Response to Global and Local Drivers** International Partnership for Hydrogen and Fuel Cells in the Economy, Belgium Tim Karlsson, Executive Director
14:30-15:00	**Development of Hydrogen Infrastructure in China** Tongji University, China Cun-man Zhang, Professor
15:00-15:20	**Break**
15:20-15:50	**Ballard Technology & Market Leadership—Putting Fuel Cells to Work**

	Ballard, Canada Randy MacEwen, president/CEO
15:50-16:20	**Honda Fuel Cell Vehicle Development and Toward theHydrogen Society** Honda, Japan Moriya Takashi, Senior Chief Engineer
16:20-16:50	**MW-Scale PEM Electrolysis for Energy Storage and Grid Stabilization Applications** Proton OnSite, USA David T. Bow, Senior Vice President
16:50-17:00	**Closing Remark** Hua Guo, Vice President, Guodian New Energy Technology Research Institute

400 booklets that mainly include the contents of 23 experts biography and their presentation outline, attentions, conference agenda, transportation were distributed to the participants.

This forum represents the highest level in the global fuel cell field. More than 400 delegates from major fuel cell associations, well known fuel cell companies and top research organizations inside and outside of the APEC economies such as Canada, China, Indonesia, Japan ,Korea, Peru, Thailand, Chinese Taipei, U.S. and German gathered together to give presentations, share information and communicate for the industry development trend. The speakers and delegates had a hot discussion on the topic of fuel cell and hydrogen generation. Annex 1 shows the all of the 400 and over participant contact list.

Amazingly, 23 experts from different economies presented the progress of fuel cell technology in a global view. The speaking experts are all from top world-level fuel cell industries like Toyota, Daimler AG, Ballard, Hyundai and etc., and they have shared their working experiences with the audience. Detailed introduction of their biographies, speech topics, and presentation outline is as described in annex2. Among 23 excellent presentations, 13 of which were confirmed to be able to share the PDF version PPT among the interested stakeholders.

Conference site had nearly 20 domestic media participation, including CCTV, Beijing TV station, China Automotive News, auto finance, China economic news, Sina, Sohu, Tencent, and so on, according to the development trend of fuel cell of experts interview and after do in-depth and thematic.

The forum has been broadcasted among a few domestic influenced media, which are shown in annex 3.

3.3. Interviews and experts voice

Expert speakers shared the highest achievement of their companies and organizations to all of the participants. The selected speakers and attendants were interviewed regarding as their image to the forum. They finally expressed that they felt quite satisfied with the overall organization and have learnt the most advanced fuel cell / hydrogen technologies and industrial trend during the two-day forum. They all believed that was a distinguished gathering in talking the progress of fuel cell & hydrogen development. The active discussion during the speech improved the deep understanding of fuel cell. The communication during coffer break and dinnertime also promoted the interaction and knowledge sharing of the stakeholders in fuel cell field. Some of the influenced experts introduced as the following:

As the Fellow of Chinese Academy of Engineering, Prof. Baolian Yi from Dalian Institute of Chemical Physics (DICP), Chinese Academy of Sciences, gave a talk on “Fuel Cell Vehicle Technology and Development in China”. In the presentation, Prof. Yi described the status of fuel cell vehicle development in China and analyzed the technical issues for its commercialization. He proposed that the development of fuel cell vehicle in China should be improved by researches on the critical component in the fuel cell system, enhancing the operating stability of cell stacks and building more hydrogen stations.

Dr Morry Markowitz, as the president of Fuel Cell & Hydrogen Energy Association of the United States, did his presentation titled as "U.S. Fuel Cell Industry" and discussed the industrial development of fuel cell and hydrogen energy in U.S. He also provided a general overview of the public-private collaboration to advance FCEVs and hydrogen infrastructure in the U.S. (H2USA).

The delegate from Guodian New Energy Technology Research Institute presented their research on "High-efficiency and low-temperature direct biomass fuel cell" and described a novel fuel cell technology where raw biomass could be used as fuel directly. With this technique, electricity is generated directly from straw, wood chips and other biomass with a power density of thousands of times of microbial fuel cells. This technology was demonstrated to have a promising potential in the area of biomass-to-electricity with an environment friendly approach.

3.4. Forum challenges

Only 5 APEC funded participants from Malaysia, Thailand and Peru attended the forum, even there still be some non-funded participants from Chinese Taipei, US, Japan, Canada, Korea, Belgium, Australia. Thus if more inviting information distributed to support more APEC funded participants would be more perfect. That is some points that we should learn.

The media mostly focus on Chinese side, so if more international media being involved would be more effective and influential.

4. Discussions of the project outputs

4.1. Discussion of the project evaluation survey

APEC Project Evaluation Surveys were conducted during the conference period. The total number of participants was 380, 380 questionnaires were provided and 188 were covered, of which 119 questionnaires were valid questionnaires. The statistical results was collected and analyzed.

Overall, most of participants of the meeting expressed satisfaction toward the organization of the forum, they also put forward more suggestions and ideas. Some honored guests hope that the proposal, the organizing committee should regularly organize such a professional forum as a fixed and representative meeting among fuel cell field each year, and they hoped that a global and professional fuel cell industry platform for resource sharing and project network communication could be built vie the forum. They wished the participants could form a team to analyze fuel cell industry trend from a strategic height point, to explore the fuel cell industry solutions in technical depth, and to share the latest information on the fuel cell industry from global perspective. They believe that the fuel cell industry will achieve sustainable development and greater space under such important and meaningful forum. Detailed survey information and the concluded results from participants of 119 questionnaires are shown below：

Evaluation Survey Part 1：

Instructions: Please indicate your level of agreement with the statements listed in the table below.

Evaluation Survey Part 1 - Statistical data analysis:

	Strongly Agree（Select NO.）	Agree（Select NO.）	Disagree（Select NO.）	COMMENTS (Continue on back if necessary)

The objectives of the training were clearly defined	**98**	**21**	**0**	
The project achieved its intended objective	**87**	**32**	**0**	
The agenda items and topics covered were relevant	**101**	**17**	**1**	
The content was well organized and easy to follow	**99**	**19**	**1**	
Gender issues were sufficiently addressed during implementation	**89**	**27**	**3**	
The trainers/experts or facilitatorswere well prepared and knowledgeable about the topic	**113**	**6**	**0**	
The materials distributed were useful	**75**	**39**	**5**	
The time allotted for the training was sufficient.	**97**	**19**	**3**	

Evaluation Survey Part 2：

1. How relevant was this project to you and your economy?

NO.: 5: very; 4: mostly; 3: somewhat; 2: a little; 1: not much

Statistical data analysis result,：

	Select NO. 5	Select NO. 4	Select NO. 3	Select NO. 4	Select NO. 5
How relevant was this project to you and your economy?	**89**	**25**	**4**	**1**	**0**

Conclusion of the explainations:

- This forum made a deep interpretation to the development of fuel cell. Our company, s stack manufacture (SAIC), is from government development zone and we have the demand for hydrogen production and hydrogen station construction. I did security authentication for fuel cells. I also did academic research in universities and this forum will play a guiding role for my further research.
- Topics were related to our company, especially one of the enterprise researches. We are from an electrical vehicle company and we have strong interest in research on hydrogen separation problem, Yutong Bus has the related business as fuel cell bus and hydrogenation infrastructure.
- We are the hydrogen gas supplier, mainly providing filling and gas supply scheme. Our company is focused on hydrogen production from wind power.

2. In your view what were the project's results/achievements?

Statistical data analysis result, conclusion of the explanations:

- This forum focused on the fuel cell and hydrogen technology and promoted its development, and it helped us have a understanding and get to know the industrial development trend.
- To keep pace with international tendency and to promote industrial development, technology and information exchanging is very adequate.
- Business prospects in the fuel cell technology are clearer.
- It is at the highest level that I have participated in the hydrogen energy forum.
- We have fully recognized the existing difficulties, the application prospect of fuel cell vie the forum.
- This is a constructive forum for the knowledge exchanging with precious opportunity to know the leading edge of the fuel cell trend and realizing a FC development consensus.
- Fuel cell development in China has played a very good role in promoting the development of fuel cells in the domestic research and exchange platform.

3. What new skills and knowledge did you gain from this event?

Statistical data analysis result, conclusion of the explainations:

- It is honored to know more of the development of hydrogen energy.
- We have had a deeper understanding for foreign current situation and existing problems of internal and external fuel cell.
- It increased us with the knowledge of the industry and the understanding of the fuel cell all around the world.
- The strategic and global knowledge have been learnt by attending the forum, with a well understanding of the industrial trends and key business priorities.
- It is so satisfying to accept so much sufficient technical information. We believed that the scope of the FC field has been expanded, especially the status of the latest fuel cell development.
- The forum offered a chance to understand the fuel cell market and its application both in vehicles and households, to know the domestic and foreign markets, and more alliances and the profit model of successful enterprises.

- It is found that U.S. fuel cell commercial vehicle technology has been basically resolved, with the commercialization of the promotion of the conditions. It will be not too far wary that FC is replaced to the traditional car.

4. Rate your level of knowledge of and skills in the topic prior to participating in the event:

NO.: 5: very high; 4: high; 3: medium; 2:low; 1:very low

Statistical data analysis result：

	Select NO. 5	Select NO. 4	Select NO. 3	Select NO. 2	Select NO. 1
Rate your level of knowledge of and skills in the topic prior to participating in the event:	**11**	**52**	**45**	**9**	**2**

5. Rate your level of knowledge of and skills in the topic after participating in the event:

NO.: 5: very high; 4: high; 3: medium; 2:low; 1:very low

Statistical data analysis result：

	Select NO. 5	Select NO.4	Select NO. 3	Select NO. 2	Select NO. 1
Rate your level of knowledge of and skills in the topic after participating in the event:	**11**	**64**	**38**	**6**	**0**

Some of the Explainations:

- To know more friends and companies.
- More in-depth understanding of the relevant knowledge.
- Learnt a lot of professional knowledge and broadened my horizons.
- Had a better understanding of basic knowledge.
- More FC knowledge and skills needed to be introduced.
- Learnt Knowledge of all aspects of fuel cells.
- Knowledge and skills are supposed to be exchanged and accumulated.
- Will digest the knowledge step by step.
- Good to the industry development, as most of the participants are from industrial.

- Just one forum cannot help me too much, and hope to organize a series of such activity under support of APEC.

6. How will you apply the project’s content and knowledge gained at your workplace? Please provide examples (e.g. develop new policy initiatives, Organize trainings, develop work plans/strategies, draft regulations, develop new procedures/tools etc.).

Statistical data analysis result, conclusion of the explainations:

- To grasp the development direction of hydrogen.
- Not only to increase the hydrogen battery research but also pay attention to the value of other markets and achieve overall balance.
- Will make strategic planning and technical reserves for fuel cells.
- Confirming the company's strategic plan for fuel cell.
- Developed more challenging fuel cell development plans.
- Will make some investment plan and developed new policy initiatives.
- Shenhua Corporation is going to develop hydrogen energy strategy with the highest evaluation level and will be the best choice for the supplier.
- The introduction of fuel cell system products into consideration can be applied to distribute energy systems.
- Will revise development strategy and target and develop large-scale catalyst.
- It helped me understand my own research direction and plans more clear.

7. What needs to be done next by APEC? Are there plans to link the project’s outcomes to subsequent collective actions by fora or individual actions by economies?

Statistical data analysis result, conclusion of the explainations:

- Pay attention to the forum and improve the strength.
- Continue to in-depth exchanging in various organizations.
- Continue to organize the mainstream of international resources to carry out collaboration and cooperation.
- To concrete implementation of the specific implementation.
- Continue to organize such theme of the forum and it can be separated from the macro development strategy and technology development series of sub forum.

- Continue to cooperate with Professional Companies.
- Pay attention to the development of SOFC distributed power station.
- Made the forum as the industry landmark conference, organization and establishment of enterprise alliance and meeting, and vigorously promote.
- To set up a joint organization or association, promote hydrogen energy industry development in China.
- Continue to integrate resources, promote progress.
- It needs for in-depth understanding of technology, strengthening the exchanging of industrial companies, drafting the industrial standards, and promoting the healthy development of the industry.
- The government should make more recommendation to encourage the application of hydrogen and fuel cell technology, and to promote more for the policy and subsidies to reduce costs.
- The government should also organize such influenced conversations and meetings every year.
- A comprehensive introduction to the China should include projects and progress of science and technology development fund and Integration of industrial cooperation.
- A win-win status can be achieved.
- Should present more examples of practical applications.
- I wish to build the forum into a brand forum and provide high-end communication platform.
- Hope to continue to hold activities like this forum and someday it can be developed into the most influential domestic fuel cell authority forum to promote the industrialization and commercialization.
- Wish to have more cooperation between China hydrogen and FCV, power generation and international.

8. How could this project have been improved? Please provide comments on how to improve the project, if relevant.

Statistical data analysis result, conclusion of the Excellent Explains:

- Wish to see some specific project docking.
- Serious discussion of the FC's ecological environment is facing threat.
- The cost of funds gathering and leadership of the status of the company's real

views.

- Screens should be larger and I couldn’t see clearly sitting in the back.
- Organizations need to establish development funds, mainly focusing on the support from industrials.
- In the Q&A time, some of the speakers were lack of understanding of English and did not answer to the question directly.
- In order to enhance the national fuel cell development, government support should play an important role.
- I hope that APEC identity can be the forum where opinions would be concluded after submitted to the relevant government ministries and to guide the policy toward to the fuel cell industry.
- Wish to have more communicating time and funds to support specific projects.
- Encourage all APEC economies to participate.
- I hope there will be more activities, for example, two meetings per year - one is business related and the other referring to technique related.
- Proposed jointly with UNDP (United Nations Development Program).
- Suggested that there are APEC hydrogen &FC-China's special annually.
- Strategy research should be increased.

4.2. Discussion of the commercial analysis report

The commercial analysis report (full text information of this report is detailed narrated in Annex 4) includes two parts. One part is the analysis of the fuel cell industry market, which contains introduction of the main capital cost and the market competitiveness with comparison to other renewable power generation system. Proton exchange membrane fuel cells (PEMFCs) have recently passed the test or demonstration phase and move to commercialization stage. In worldwide, North America, Europe, Japan, China and Korea are key region developing the fuel cell product. In past decade, the market trend shows that PEMFC have the most promising applications to buses, recreation vehicles, and micro-CHP systems. Government support in those areas was described in this report and the status of each region. PEMFC applications on transportation, stationary and portable market has been introduced and discussed. In addition, this paper describes and summarizes the relative prospects and the different leading company's solution of PEMFCs in these fields.

One more extremely important part of this commercial analysis report is the capital cost analysis of the novel biomass fuel cell technology. China Guodian got significant progress on the green energy development, especially on the collaborated project- "Novel high-efficiency direct biomass fuel cell" with Georgia Institute of Technology. This is a brand new fuel cell system where biomass is used directly to generate power and it promotes the biomass utilization in the area of green energy. The novel bio-fuel cell product design concept has been developed by this project, which is consistent with the project application proposal. The performance and the economic analysis been discussed in the report. The capital cost result shows the most intuitive advantage of this biomass fuel cell technology. The comprehensive commercial analysis also finds out the merits and drawbacks of the fuel cell technology, put forward suggestions to reduce the capital cost of fuel cell construction, and then promote its market competitiveness and its fast development.

4.3. Discussion of the progress review report

Progress review report of fuel cell technology inside and outside APEC economic region has been also conducted, detailed full text information of which is shown in Annex 5. The report includes both the technology and industry development and gives a description of a few different types of fuel cell and its major players and suppliers.

A fuel cell is a device that uses hydrogen as a fuel to produce electrons, protons, heat and water. A fuel cell does not require recharging the same as a battery. In theory a fuel cell will produce electricity as long as fuel is constantly supplied. The basic design of a fuel cell involves two electrodes on either side of an electrolyte. Hydrogen and oxygen pass over each of the electrodes and through means of a chemical reaction, and then electricity, heat and water are produced. Different types of fuel cell (PEMFC, SOFC and DMFC) were introduced in this report. The report discusses the fundamental of different fuel cells about the fuel types and the stack/system layout. In past decade, fuel cell experienced a few breakthroughs in technological development and becomes competitive with other advanced power generation technologies, such as in bus, back power and forklift market. The major supplier and key developing technologies were listed. Fuel cells may help to reduce our dependence on fossil fuels and pollute emissions into the atmosphere due to the high efficiency electrochemical process compared to conventional engine process. By using clean hydrogen, fuel cells only produce water, thus eliminating locally all emissions otherwise caused by electricity production. The material and product lifetime breakthrough will be next challenge in fuel cell technology developing.

5. <u>**Overall impact and lessons learned**</u>

Fuel Cells have recently entered the mobility market (FC Bus) as a clean energy (low emission) alternative to traditional engine based vehicle. Most countries start the demonstration program and build the hydrogen infrastructure (production, delivery and dispense) to speed up the fuel cell vehicle technology commercialization. Fuel cells have various advantages compared to conventional power sources in vehicle, such as internal combustion engines or batteries. Recently, China also starts large scale FC bus demonstration program and hope to get more information from the real field testing result. Generally, fuel cell technology has following benefits:

- Higher efficiency than diesel or gas engines.
- Low noise, operate silently, compared to internal combustion engines.
- For hydrogen fueled fuel cells, the only by-product at point of use is water. Almost no pollution compares to fossil fuel or natural gas engine.
- Hydrogen can be made from the electrolysis process which driven by renewable energy, then using fuel cells eliminates greenhouse gases if take carbon foot print into account.
- Operating hours are much longer than with batteries. The fuel cell energy system density is much higher than battery in high energy demand. It can reduce the whole weight on bus and extend the cruise range.
- Unlike batteries, fuel cells have no "memory effect" when they are getting refueled.
- The maintenance cost of fuel cells is low, due to the less moving parts in the system.

With its great dependency on fossil fuels, China faces a great challenge in reducing its greenhouse emissions and tackling its air pollution. FCV represents an innovative solution to help mitigate impacts of climate change in China while improving the lives of many. Many Chinese automakers already have fuel cell vehicles in their products catalogue. As for infrastructure, China now has three FCV hydrogen filling stations – in Beijing, Shanghai, and Zhengzhou, Henan Province, — with a fourth one currently being built in Foshan, Guangdong Province.

Fuel cell vehicles (FCV) in China are expected to develop faster in terms of commercialization following a multilateral project launched by the United Nations Development Programme (UNDP). A project, called "Accelerating the Development and Commercialization of Fuel Cell Vehicles in China," is the third phase of a continuous scheme called Global Environmental Facility Fuel Cell Bus Commercialization. In the first two phases, 12 prototype fuel cell buses manufactured by Daimler-Chrysler, SAIC Motor and Foton completed a combined distance of 262,338 km and served a total of 126,586 passengers during the 2008 Beijing Olympics and the 2010 Shanghai Expo. The 12 buses helped reduce 400 tons of carbon dioxide and significant amount of nitrogen oxides, carbon monoxide and sulfur oxides, according to MOST statistics.

Ballard Power System, one of the leading company in PEM fuel cell system, announced a $17 million order for hydrogen fuel cells for roughly 300 buses. A segment where the fuel cell probably makes a great deal more sense than passenger cars. This largest-ever order comes from an existing partner in China – Guangdong Synergy Hydrogen Power Technology Co. The buses will be used in the cities of Foshan and Yunfu, China.

China's growth has spawned the largest commercial vehicle segment in the world, in terms of production and domestic sales – including 7% year-over-year growth in the manufacture of city buses, to almost 74,000, in 2011. Naturally, this growth has resulted in high levels of automotive emissions, with the International Council on Clean Transportation reporting that auto emissions contribute more than 33% of the air pollution in Beijing, Shanghai and Pearl River Delta Region.

China wants to expand public transit while also reducing the number of vehicles in the city. As a result, it unveiled new measures this month that place tougher restrictions on the number of new vehicles allowed on the roads each year going forward. By the end of 2017 the government will cap the number of cars on the road at 6 million. Beijing also aims to reduce total vehicle fuel consumption by promoting the sale of new energy vehicles – including the use of subsidies – while also encouraging people to drive less frequently.

Based on the great market demand and environmental protection issues, China government looks for fuel cell strategy partner aggressively, which is the same as the developing history of PV, Wind, LED and those renewable technologies. China is seeking for developed technology and provides the domestic market which has strongly demand for field testing. In the meantime, the quantity production can help the new technology reduce its high cost.

6. <u>Conclusions and Recommendations</u>

6.1. Conclusions and information on next steps

China Guodian Corporation is one of the five largest integrated power generation corporations in China, with a total installed generation capacity of up to 135,000 MW, among which the renewable generation accounts for 29.8%. China Guodian also takes an active participation with APEC in order to enhance the communication and collaboration with other economies. Until now, Guodian New Energy Technology Research Institute got funded by APEC program for three years and, the project in this year is about "Progress on novel energy industrial by the development of fuel cell technology".

As a new technique of power generation, fuel cell is playing a more and more important role in the energy area due to its own advances- high efficiency and zero pollution emission. The 2016 APEC Fuel Cell Forum was successfully held on January 18-19 in Beijing. It represents the highest level in the global fuel cell field. More than 400 delegates from major fuel cell associations, well known fuel cell companies and top research organizations in the APEC economies were invited to attend the forum. The tendency of the development of fuel cell technology was discussed and the newest products from global leading research institutes and industrials were shared. The forum not only provided a platform for in-depth discussion on the commercialization pathway of fuel cells, but also to propose solutions to the technical bottlenecks through constructive communications and interactions among engineers, scientists and government leaders. In some ways, it will contribute for promoting the further industrialization of fuel cell technologies.

The literature review and technology interviews were done in this project. A market analysis was conducted to define the current status of the fuel cell market and where fuel cell technology currently stands. The results revealed that fuel cells are nearing the end of the introduction phase product life cycle, ready to penetrate the growth phase. Fuel cells offer a clean and high efficiency features in different applications, especially in mobility and energy segment (distributed power). The major barrier to be accepted into the market is the high price of the product and lack of hydrogen infrastructure. Businesses who are looking to create the fuel cell market must ensure to not only have an innovative product but more importantly offer it with a breakthrough business model or niche product application to reduce the cost concern in early face, or combine with government incentive program. Conclusions for this promotion project as follows,

1. Fuel cell is presently approaching the end of the introduction phase and entering into the growth phase of the product-life cycle.

Although fuel cell currently possesses only a small share in transportation and stationary market, it is becoming increasingly popular. Fuel cell mobility sales are projected to grow at an extremely high rate over the next decade, and a prosperous growth phase is inevitable for fuel cell vehicle in the public transportation market.

2. Fuel Cell CHP products are still relatively new products and they have strong potential for continued technological advancement and innovation moving forward.

Fuel Cell CHP technology has been improved rapidly in recent years due to the successful demonstration program in Japan Ene-Farm Project and Europe Callux Project. Significant advancements in the energy efficiency, product reliability, and durability of fuel cell micro-CHP system are expected to continue to occur for many years to come. These three factors were all identified in most of research report as the three main factors that influence consumers to use fuel cell CHP product. Along with these advancements, the production costs, and therefore the available cost of fuel cell residential system will inevitably decrease over time, as they have since these products were first introduced.

3. Power to Gas (PEMFC Electrolyze) offers variety of benefits compared to traditional battery energy storage and is highly feasible for widespread use in the energy sector.

Power to Gas is a promising system solution on grid level energy storage. The idea behind Power to Gas is to convert renewable electricity to hydrogen, store it in the compressed tank for feed into gas infrastructure and then use it in a variety of consumption areas. Hydrogen and methane from renewable electricity can be used equally in mobility, industrial, heat supply and electricity generation applications. That makes Power to Gas a multi-system solution which supports the integration of renewable energy into the energy system and also contributes to reaching the ambitious goals of reducing emissions of greenhouse gases and the sustainability goals in all areas of consumption.

As an electricity storage method, Power to Gas can also contribute to compensating the increasing fluctuations in electricity generation from wind and solar energy and facilitate long-term use of electricity which could not be integrated directly into the electricity grid at times of particularly high renewable generation.

6.2. Recommendation for next steps

Regulation and certificate in possible first entry market like back-up power system, forklift, micro-CHP and public transportation must be ready in countries and the company can start the business and it can help user to eliminate the hydrogen safety concern.

Hydrogen infrastructure should be built for transportation and other niche market. Most of research shoes the fuel cell commercialization strongly relies on hydrogen infrastructure conditions. Like how to create clean hydrogen, storage and dispensing. The whole hydrogen society concept and design should be built in each economy and then the fuel cell industry or say product and application can be well developed.

Government incentive and demonstration program is key step for start the fuel cell industry. The results revealed that fuel cells technology are ready for market field testing. Since the novel technology with small production quantity always combine with the high product cost issue, the government support in early market entry phase is important. It can help the technology introduce to the customer more easily and help the company get more information from the field testing result.

Annexes

Annex 1：Forum participant list

No	Economy	Organization	Name	Title
1	Australia	Hydrexia	Fang Peijun	China chief representative
2	Canada	Ballard	Randall MacEwen	President/CEO
3	Canada	Canadian Embassy in Beijing	Josiane Simon	Commercial Counsellor
4	Canada	Canadian Embassy in Beijing	Helen Bao	Trade Commissioner
5	Canada	CANADIAN STANDARDS ASSOCIATION	Deng Mingxing	operation manager
6	China	Guodian New Energy Technology Researchy Institute	Hua Guo	Vice President
7	China	Dalian Institute of Chemical Physics (DICP)	Gong-quan Sun	Professor

8	China	National Institute of Clean-and-Low-Carbon Energy	Chang Wei	President
9	China	Tsinghua University	Han Minfang	Professor
10	China	Tongji University	Cun-man Zhang	Professor
11	China	Ningbo SOFCMAN Energy	Wang Weiguo	Chair of the Board and CEO
12	China	China Guodian Corporation	Zhang Shumin	Chief economist
13	China	Dalian Institute of Chemical Physics	Bao-lian Yi	CAE academician/Professor
14	China	Sunrise Power	Pingwen Ming	President/CEO
15	China	Guodian New Energy Technology Research Institute	Liu Congmin	Doctor
16	China	AnHui key laboratory of low-temperature Co-fired materials	Gu Qingwen	Assistant Director
17	China	AnHui key laboratory of low-temperature Co-fired materials	Lu Xiaoyong	Director

18	China	AnHui key laboratory of low-temperature Co-fired materials	Chen Yonghong	Director/Professor
19	China	Earth Magazine	Teng Ling	Reporter
20	China	21st Century Business Herald	Wei Yuping	Reporter
21	China	Proton (China)	He Jiangang	
22	China	Proton (China)	Li Kean	
23	China	Softbank China Capital (SBCVC)	John Guo	Managing Director
24	China	UNDP China	Zhang Weidong	Project Manager
25	China	Verde LLC	Song Jiangtao	Vice general Manager
26	China	Verde LLC	Ye Hongwu	Sales Manager
27	China	Advanced Technology & Materials co., ltd	Wan Jing	Student
28	China	Advanced Technology & Materials co., ltd	Zhang Bao	
29	China	Advanced Technology & Materials co., ltd	Jiang Zan	Student
30	China	Advanced Technology & Materials co., ltd	Li Wei	Master
31	China	APW Milestones	Wu Ziquan	CEO
32	China	BJX.com.cn	Lv Ronghao	Original Leader
33	China	Beijing Benz Automotive Co.,ltd	Zhang Qingli	Senior engineer

34	China	National Institute of Clean and Low-Carbon Energy(NICE)	Liu Qinghua	Lead engineer
35	China	National Institute of Clean and Low-Carbon Energy(NICE)	Hu Jinmin	
36	China	National Institute of Clean and Low-Carbon Energy(NICE)	Miu Ping	
37	China	National Institute of Clean and Low-Carbon Energy(NICE)	He Guangli	Senior engineer
38	China	Beijing Technology and Business University	Shao Zhi	Director
39	China	Beijing Technology and Business University	Shao Jie	Teacher
40	China	Beijing huadian tianren electric power control technology co., LTD	Li Xingyu	Hardware R&D Engineer
41	China	Beijing huadian tianren electric power control technology co., LTD	Wang Kefei	Hardware Engineer
42	China	Beijing huadian tianren electric power control technology co., LTD	Li Zhiqiang	Vice director
43	China	Beijing HuaQing technology co., LTD	Mao Zhiming	General Manager

44	China	Beijing University of Chemical Technology	Han Xiaoshuai	
45	China	Beijing University of Chemical Technology	Wang Yanan	Student
46	China	Beijing University of Chemical Technology	Li Dong	
47	China	Beijing University of Chemical Technology	Li Qifeng	Master
48	China	Beijing University of Chemical Technology	Chu Yuhao	Doctor
49	China	Beijing University of Chemical Technology	Xie Qixian	Master
50	China	Beijing University of Chemical Technology	Chen Yuenan	
51	China	Beijing University of Chemical Technology	Xie Qixian	Master
52	China	Beijing University of Chemical Technology	Zhang Qian	Master
53	China	Beijing University of Chemical Technology	Sun Guohua	
54	China	Beijing University of Chemical Technology	Zhu Hong	Professor
55	China	Beijing University of Chemical Technology	Zhang Libo	Master
56	China	Beijing University of Chemical Technology	Cai Yezheng	Student
57	China	Beijing University of Chemical Technology	Wang Fanghui	Associate professor
58	China	Beijing University of Chemical Technology	Cao Hehuan	Student
59	China	Beijing University of Chemical Technology	Kong Linghan	Doctor
60	China	Beijing University of Chemical Technology	Li Rui	Doctor

61	China	Beijing University of Chemical Technology	Li Ziming	Master
62	China	Beijing University of Chemical Technology	Liu Yang	
63	China	Beijing University of Chemical Technology	Gao Peng	
64	China	Beijing University of Chemical Technology	Li Wenwen	Master
65	China	Beijing University of Chemical Technology	Chen Nanjun	
66	China	Beijing University of Chemical Technology	Sun Zhaonan	Doctor
67	China	Key Innovation	Li Tiejun	Vice President
68	China	Beijing Institute of Technology	Sun Liqing	Associate professor
69	China	Beijing Institute of Technology	Sun Baigang	Professor
70	China	Beijing PERIC Hydrogen Technologies Co.,ltd	Zhang Mingjun	Manager
71	China	Beijing PERIC Hydrogen Technologies Co.,ltd	He Wen	Vice general Manager
72	China	Beijing Sevenstar Electronics Co.,Ltd.	Liu Guolei	
73	China	Beijing Sevenstar Electronics Co.,Ltd.	Wang Zhao	Market vice minister
74	China	Beijing Sevenstar Electronics Co.,Ltd.	Zhang Liqin	General Manager
75	China	Baic Motor	Dong Xiaoling	Senior engineer

76	China	Baic Motor	Zhang Bo	Engineer
77	China	Baic Motor	Zhang Lina	
78	China	Baic Motor	Li Yuan	Director
79	China	Beijing Nowogen Technology Co., ltd	Jiang Haike	overseas department charge
80	China	Beijing Nowogen Technology Co., ltd	Lai Pinghua	Chief Engineer
81	China	Beijing Nowogen Technology Co., ltd	Cheng Yafei	Market Vice GM
82	China	Beijing Nowogen Technology Co., ltd	Ouyang Xun	General Manager
83	China	Beijing Sxieny	Xu Jie	Project Manager
84	China	Beijing Sxieny	Hu Xiaojing	Project Manager
85	China	Beijing Sxieny	Zhang Zhemin	General Manager
86	China	Beijing SMHT technology co., LTD	Zhang Pu	
87	China	Beijing SMHT technology co., LTD	Yang Meng	
88	China	Beijing Hyundai Motor	Fang Kaizheng	Engineer
89	China	Beijing Hyundai Motor	Wang Ting	Section chief
90	China	Beijing Sinohytec Co.,Ltd.	Zhao Depeng	GM assistant
91	China	Beijing Sinohytec Co.,Ltd.	Zhang Yan	Project Manager

92	China	Beijing Sinohytec Co.,Ltd.	Liu Ping	FC R&D
93	China	Beijing Sinohytec Co.,Ltd.	Xie Tian	Minister
94	China	Beijing Sinohytec Co.,Ltd.	Gan Quan	Vice director
95	China	General Research Institute for Nonferrous Metals	Jiang Lijun	President
96	China	General Research Institute for Nonferrous Metals	Wang Shumao	Professor
97	China	General Research Institute for Nonferrous Metals	Zeng Rong	Senior engineer
98	China	Beijing NET technology company	Zhang Xinzhou	Manager
99	China	Beijing ZongBiao network technology co., LTD	Wan Ruyi	CEO
100	China	Beijing ZongBiao network technology co., LTD	Xiong Yun	Market Manger
101	China	Foton Motor	Wang Wenmin	
102	China	Honda	Fukushima Dachiya	Chief Researcher

103	China	Honda	Wang Juan	
104	China	ChaoZhou Three-circle (Group) Co.,Ltd	Chen Shuoshuo	President
105	China	ChaoZhou Three-circle (Group) Co.,Ltd	Dian Huanghong	vice-president
106	China	Truewin Renewables Technology	Xie Fangji	Vice Gm
107	China	Dalian Institute of Chemical Physics, Chinese Academy of Sciences	Gan Haibo	Student
108	China	Dalian Institute of Chemical Physics, Chinese Academy of Sciences	Xu Xinlong	Student
109	China	Dalian Institute of Chemical Physics, Chinese Academy of Sciences	Yu Hongmei	
110	China	Dalian Institute of Chemical Physics, Chinese Academy of Sciences	Hou Ming	
111	China	Dalian university of technology	Song Yujiang	Professor
112	China	Daimler China	Cai Yanxin	Manager
113	China	Daimler China	Qiu Xianlei	Assistant Manager
114	China	TÜV Rheinland	Li Weichun	General Manager
115	China	Northeastern university	Liu Liying	Associate professor
116	China	Northeastern university	Fang Xin	Doctor

117	China	Northeastern university	Wang Yisong	Doctor
118	China	Northeastern university	Song Yanli	Doctor
119	China	Dongfang Electric Corporation	Tao Shiyong	
120	China	Dongfeng Renault	Li Geng	Engineer
121	China	Northeastern university	Tong Guodao	Professor
122	China	Tunghsu Group	Zhao Jun	VP
123	China	Pan Asia Technical Automotive Center	Wang Jayuan	
124	China	FeiChi Bus	Jiang Yong	General Manager
125	China	Guangdong University of Technology	Yi Guobin	Professor
126	China	Guangdong University of Technology	Zu Xihong	
127	China	Guangdong GH hydrogen technology co., LTD	Chen Xiaomin	General Manager
128	China	Guangdong GH hydrogen technology co., LTD	Ma Dongsheng	CEO
129	China	Foshan Development and Reform Commission	Lu Guohan	Secretary
130	China	Guangzhou DX Chemical Co., Ltd	Peng Huayong	Engineer

131	China	Sealand securities	Shi Jinman	Analyst
132	China	State Grid	Shu Bin	Director
133	China	National Development and Reform Commission (NDRC)	Liu Jian	Researcher
134	China	State Grid Smart Grid Research Institute	Yang Cenyu	
135	China	State Grid Smart Grid Research Institute	Jin Yu	
136	China	State Grid Smart Grid Research Institute	Song Pengxiang	
137	China	State Grid Smart Grid Research Institute	Zhao Bo	Director
138	China	State Grid Smart Grid Research Institute	Xiao Yu	
139	China	State Grid Smart Grid Research Institute	Niu Meng	
140	China	State Grid Smart Grid Research Institute	Zhao Pengcheng	
144	China	State Grid Smart Grid Research Institute	Liu Feng	
145	China	State Grid Smart Grid Research Institute	Du Zhaolong	
146	China	Guosen securities	Yang Jingmei	Analyst
147	China	Haima Automobile Group	Wang Hetao	Engineer
148	China	Haima Automobile Group	Qiao Huimin	Engineer

149	China	Haima Automobile Group	Wen Yi	Minister
150	China	Hangzhou Shanhejiang Advanced Energy Technologies Co., Ltd.	Xue Longjun	General Manager
151	China	CASC LANCEL	Zhai Junxiang	topic leader
152	China	CASC LANCEL	Tian Zhonghui	Design Supervisor
153	China	CASC LANCEL	Gu Yan	Project Leader
154	China	CASC LANCEL	Song Yanping	General Manager
155	China	CASC LANCEL	Huang Shuqing	FC R&D engineer
156	China	CASC LANCEL	Jin Yinshi	Vice general Manager
157	China	HCIG Guo Rong Energy Service CO.,LTD.	Xu Ying	R&D Manager
158	China	HCIG Guo Rong Energy Service CO.,LTD.	Deng Yanbin	General Manager
159	China	Heilongjiang Bayi Agricultural University	Yu Haiming	Teacher
160	China	Heilongjiang Bayi Agricultural University	Li Qingda	Director
161	China	North China Electric Power University	Zuo Xiangzhong	Assistant President
162	China	Beijing huadian tianren electric power control technology co., LTD	Duan Xinxin	Product Manager
163	China	Huaneng clean energy research institute	Liu Ruwei	

164	China	Huawei technologies co., LTD	Wang Xingjie	
165	China	Huazhong University of Science and Technology	Pu Jian	Professor
166	China	Huazhong University of Science and Technology	Chi Bo	Professor
167	China	YunXiang technology co., LTD	Feng Ye	Vice general Manager
168	China	YunXiang technology co., LTD	Zhang Weisheng	General Manager
169	China	Mechinery industry BeiJing electrotechnical institute of economic research	Lu Chenyu	Vice President
170	China	Mechinery industry BeiJing electrotechnical institute of economic research	Chen Chen	Engineer
171	China	Jiangsu post & telecommunications planning and designing institute	Wang Jiuhai	Senior project manager
172	China	EVAUTOE	Chen Manman	Editor
174	China	Goldwind Science & Technology Co., Ltd.	Ye Chen	Invest Director
175	China	Jincheng, abondi energy co., LTD	Wan Haiying	GM
176	China	Jincheng, abondi energy co., LTD	Guo Xinxin	Technical vice GM

177	China	JAMG	Fu Junqing	Vice Chief Engineer
178	China	JAMG Coal Chemical Institute	Su Chunsheng	Chief Engineer
179	China	Ke Huang Co.,Ltd.	Lin Jingjia	Derictor
180	China	Shell Group	Wang Chang	Product Manager
181	China	Shell Group	Deng Qun	GM
182	China	Kunming University of Science and Technology	Zhu Yunpeng	Scholar
183	China	TÜV Rheinland	Li Qiang	Senior project manager
184	China	Faculty science	Li Ke	Student
185	China	Narada power source co.,ltd	Chen Dong	Engineer
186	China	South university of science and technology of China	Wang Haijiang	Professor
187	China	Nanjing university innovation research institute	Huang Lin	Assistant President
190	China	Nanjing university innovation research institute	Liu Jianguo	Professor
191	China	Nanjing Tech University	Lv Min	Vice Researcher

192	China	Nanjing Tech University	Wang Qi	Master
193	China	Nanjing Tech University	Xu En	Master
194	China	Nanjing Tech University	Yu Penghui	Master
195	China	Nanjing Tech University	Bu Chao	Master
196	China	Nanjing Tech University	Zhang Longfei	Master
197	China	Nanjing University of Science and Technology	Zhong Qin	Professor
198	China	Nanjing University of Science and Technology	Zhang Shule	Doctor
199	China	Auto magazine official website	Zhang Likun	Editor
200	China	Tsinghua University	Ma Fanhua	Associate professor
201	China	Tsinghua University	**Zhang Jian**	Master
202	China	Tsinghua University	**Xu Shun**	Master
203	China	Tsinghua University	Shi Shaxiang	Associate professor
204	China	Tsinghua University	Cao Tianyu	Assistant Researcher
205	China	Tsinghua University	Lin Xuping	Vice Researcher
206	China	Tsinghua University	Ge Ben	Assistant Researcher

207	China	Tsinghua University	Zhang Wenqiang	Assistant Researcher
208	China	Tsinghua University	Yu BO	Vice Researcher
209	China	Tsinghua University	Liu Shaoming	Doctor
210	China	Tsinghua University	Shi Wangying	Doctor
211	China	Tsinghua University	Fan Hui	Post Doctor
212	China	Tsinghua University	Zhang Yongliang	Student
213	China	Tsinghua University	Han Minfang	Professor
214	China	Tsinghua University	Mao Zongqiang	Professor
215	China	SAC/TC309	Li Yan	
216	China	Rugao economic and technological development zone	Zhao Wei	Vice director
217	China	Rugao economic and technological development zone	Ma Jinhua	Vice director
218	China	Rugao economic and technological development zone	Zhao Hongxiang	Vice director
219	China	Rugao economic and technological development zone	Zhang Weiwei	Vice director

220	China	Xiamen tungsten Co.,Ltd.	Zhu Changfeng	General Manager
221	China	Xiamen tungsten Co.,Ltd.	Yu Yang	Director
222	China	Shandong Tancheng Economic Development Zone	Li Wei	Party committee secretary
223	China	Shandong Tancheng Economic Development Zone	Wang Wenhua	Vice director
224	China	Shanghai Volkswagen	Li Kedi	EV Engineer
225	China	Shanghai Volkswagen	Liu Xupeng	EV Engineer
226	China	Shanghai Gcevolution Information Tech. Co., Ltd	Zhang Xiaolong	Sales Manager
227	China	Shanghai Gcevolution Information Tech. Co., Ltd	Zhu Guoan	Sales Manager
228	China	Shanghai Gcevolution Information Tech. Co., Ltd	Yuan Lei	Sales Manager
229	China	Shanghai Gcevolution Information Tech. Co., Ltd	Wang Tao	Sales Manager
230	China	Shanghai Electric Group	Chen Yuqi	Engineer
231	China	Shanghai Electric Group	Liao Wenjun	Chief Officer

232	China	Shanghai Electric Group	Di Zhigang	Engineer
233	China	Shanghai Electric Group	Ni Leilei	Engineer
234	China	Shanghai Jiaotong University	Shao Meng	Doctor
235	China	Pearl Hydrogen	Dong Hui	General Manager
236	China	Saic Motor Group	Lu Ye	Chief
237	China	Saic Motor Group	Zhai Shuang	FC engineer
238	China	Saic Motor Group	Wu Bing	FC senior manager
239	China	Saic Motor Group	Zhou Hongru	FC engineer
240	China	Saic Motor Group	Tang Houwen	FC chief engineer
241	China	Saic Motor Group	Wang Jin	Engineer
242	China	Horizon Fuel Cell Technologies	Gu Zhijun	CEO
243	China	Horizon Fuel Cell Technologies	Zhang Chi	CFO
244	China	Horizon Fuel Cell Technologies	Zhang Lijun	Sales Director
245	China	Shanghai Shen-li High Tech Co.,Ltd	Zhang He	General Manager
246	China	Shanghai Shen-li High Tech Co.,Ltd	Zhang Ruogu	Vice general Manager
247	China	SUN WISE	Liu Shaojun	

248	China	Iwatani Group	Dong Ding	Technical minister
249	China	Iwatani Group	Jinjuegangzhi	Sales section chief
250	China	Saic Motor Group	Wang Haipeng	Invest Manager
251	China	Extender Energy	Wen Zhaohui	General Manager
252	China	Extender Energy	Song Wenshuai	R&D Engineer
253	China	ZIMT	Cao Zhifeng	Vice GM
254	China	ZIMT	Zhai Wei	Minister
255	China	ShenHua Group	Song Xiaofei	Supervisor
256	China	ShenHua Group	Yue Hui	Supervisor
257	China	ShenHua Group	Zhang Siyi	Supervisor
258	China	ShenHua Group	Nie Xuelei	Supervisor
259	China	DONGFEN PEUGEOT CITROEN AUTOMOBILE COMPANY LTD	Huang Wenxin	Director
260	China	Shenyang trust antai equity investment fund management co., LTD	Zhu Xiaojun	Vice general Manager
261	China	Shenyang Fortune Precision Equipment Co. Ltd.	Li Changzhe	GM

262	China	ShuangDeng Group - nanjing branch	Xian Cunni	Project Manager
263	China	Soochow University	Xu Dan	lecturer
264	China	Foresight Energy	Xiao Zhan	GM assistant
265	China	Foresight Energy	Gu Rongxin	General Manager
266	China	Suzhou Huatsing Jingkun New Energy Technology Co., Ltd.	Dou Yiwen	Market Director
267	China	Suzhou Huatsing Jingkun New Energy Technology Co., Ltd.	Sun Zaihong	General Manager
268	China	Suzhou QingJie power technology co., LTD	Shen Jianyue	CEO
269	China	Suzhou QingJie power technology co., LTD	Chen Gang	GM
270	China	Suzhou QingJie power technology co., LTD	Yang Weihua	Vice GM
271	China	Suzhou QingJie power technology co., LTD	Wen Xiaofeng	strategy consultant
272	China	Tianjin University Of Technology	Wang Guixing	tester
273	China	Tianjin University Of Technology	Li Jian	Student
274	China	Tianjin University Of Technology	Yin Huiming	lecturer
275	China	Tianjin University Of Technology	Ding Yi	Professor

276	China	Tianjin Lishen Battery Joint-Stock Co., Ltd.	Cong Haibo	marketing manager
277	China	Tianzi Environment Protection Investment Holdings Co., Ltd	Zheng Shuai	secretary
278	China	Tianzi Environment Protection Investment Holdings Co., Ltd	Zhang Yongping	VP
279	China	SGS-CSTC Standards Technical Services Co., Ltd	TonyHe	
280	China	Tongji University	Pan Xiangmin	Vice Researcher
281	China	Tongji University	Geng Zhen	
282	China	Troowin Power System Technology Co.,Ltd	Zhao Feng	Vice GM
283	China	Troowin Power System Technology Co.,Ltd	Qi Zhigang	CTO
284	China	Xi'an hua jiang environmental technologies co., LTD	Jiang Naiwu	GM
285	China	Xi'an hua jiang environmental technologies co., LTD	Liu Endong	R&D minister
286	China	Xi'an hua jiang environmental technologies co., LTD	Li Wensi	Director

287	China	GMCC ELECTRONIC TECHNOLOGY WUXI CO.,LTD	Wang Junhua	
288	China	GMCC ELECTRONIC TECHNOLOGY WUXI CO.,LTD	Sun Wei	Director
289	China	ENN energy research institute	Liu Tao	Vice GM
290	China	ENN energy research institute	Wang Guoqing	Vice President
291	China	ENN energy research institute	Zhu Zhenqi	President
292	China	Sun Rise Power	Ji Guancheng	Supervisor
293	China	Sun Rise Power	Liu Changfu	Vice GM
294	China	Sun Rise Power	Fu Yu	Business Department Manager
295	China	Sun Rise Power	Liang Dong	Project Manager
296	China	Sun Rise Power	Du Chao	Business Manager
297	China	Ether Captial	Qing Geer	Investment Manager
298	China	Great Wall Motor	Chen Peng	staff
299	China	Great Wall Motor	Sun Fulong	staff
300	China	Great Wall Motor	Li Ming	staff

301	China	Zhejiang University	Chen Jian	Professor
302	China	Zhejiang University	Liu Zhiyang	Doctor
303	China	Narada power source co.,ltd	Xiang Jiayuan	Senior Engineer
304	China	Zhengzhou Yutong Group Co., Ltd.	Li Jin	Project Manager
305	China	China Fuel Cell Energy	Lv Weisi	President
306	China	China Fuel Cell Energy	Zhang Cong	Chair
307	China	China Fuel Cell Energy	Li Jian	VP
308	China	CRRC Qingdao Sifang Co., Ltd.	Wang Xiaobo	Project senior manager
309	China	CRRC Qingdao Sifang Co., Ltd.	Yang Yanzhi	chief manager
310	China	The Eighteenth Institute of CETC	Li Qingshan	Engineer
311	China	China north vehicle research institute	Wang Yituo	
312	China	China north vehicle research institute	Wang Zidong	Director
313	China	China energy storage application association	Yue Rong	Vice director
314	China	China faw group R&D center	Wang Yupeng	Engineer
315	China	China faw group R&D center	Shen Xia	Engineer
316	China	China faw group R&D center	Zhou Feikun	Engineer

317	China	China faw group R&D center	Sun Huanli	Engineer
318	China	China Electrotechnical Society	Zhang Jiping	Director
319	China	The Eighteenth Institute of CETC	Wang Yuxuan	Engineer
320	China	The Eighteenth Institute of CETC	Wang Songrui	
321	China	The Eighteenth Institute of CETC	Guo Yan	Researcher
322	China	China huadian corporation science and technology institute（CHDI)	Wang Zhen	Engineer
323	China	Huaneng clean energy research institute	Zhang Ruiyun	
324	China	Huaneng clean energy research institute	Cheng Jian	Chief Engineer
325	China	Huaneng clean energy research institute	Wang Pengjie	Engineer
326	China	China Chemical Reporter(CCR)	Wang Lihua	chief editor
327	China	China Industrial Association of Power Sources	Zhou Xiaoqing	Director
328	China	CAS Investment Management Co., Ltd	Feng Chaoqun	Investment Manager

329	China	The Dalian Institute of Chemical Physics (DICP)	Gao Yanyan	Student
330	China	Institute of Chemistry Chinese Academy of Sciences	Jiang Wenjie	Doctor
331	China	Institute of Chemistry Chinese Academy of Sciences	Hu Jinsong	Researcher
332	China	China University of Mining & Technology,Beijing	Zheng Ziwei	Engineer
333	China	China University of Mining & Technology,Beijing	Yang Zhibin	Associate professor
334	China	China automotive news	Guo Chen	Reporter
335	China	China automotive news	Feng Hua	
336	China	China automotive news	Guo Chen	
337	China	China automotive news	Wang Lingfang	Reporter
338	China	China automotive news	Wan Renmei	Editor
339	China	China Automotive Technology & Research Center	Wang Ju	

340	China	Sinopec fushun research institute of petrochemicals	Wang Hongtao	R&D leader
341	China	China University of Petroleum-BeiJing	Xie Jing	Assistant Researcher
342	China	China University of Petroleum-BeiJing	Li Yujing	Associate professor
343	China	China University of Petroleum-BeiJing	Ban Shuai	vice Researcher
344	China	China University of Petroleum-BeiJing	Yu Changchun	Associate professor
345	China	China University of Petroleum-BeiJing	Zhou Hongjun	Professor
346	China	China Quality Certification Centre	Wang Gang	Engineer
347	China	AVIC INTERNATIONAL	Li Peng	Project Manager
348	China	CECEP Wind-power Corporation (CECWPC)	Shen Hongshuai	Project Manager
349	China	CECEP Wind-power Corporation (CECWPC)	Sun Jialiang	Project Manager
350	China	CECEP Wind-power Corporation (CECWPC)	Li Hang	Project Manager
351	China	Shanghai Institute of Ceramics of the Chinese Academy of Sciences (SICCAS)	Wang Shaorong	Vice director
352	China	Shanghai Institute of Ceramics of the Chinese Academy of Sciences (SICCAS)	Liu Zhi	Assistant Engineer

353	China	Chung-Hsin Electric and Machinery Manufacturing Corp. (CHEM)	Zhang Rongui	Vice Director
354	China	Chung-Hsin Electric and Machinery Manufacturing Corp. (CHEM)	Wu Jintiao	chief operating officer
355	China	Power capital	Lv Fei	Invest Director
356	Hong Kong, China	PT TECHKING ENTERPRISES INDONESIA	Huang Shiheng	Derictor
357	Indonesia	PT TECHKING ENTERPRISES INDONESIA	Xu Xianlong	President Commissioner
358	Indonesia	Ministry of Energy, Green Technology and Water	Ivy Yap Lee Lian	
359	Indonesia	Energy Commission	Hadziratul Qudsiah Binti Abdul Aziz	
360	Japan	Iwatani Group	Rkura Takashi	President
361	Japan	Iwatani Group	Kurada Katsuya	Minister

362	Japan	TOSHIBA / ENE Farm	Fumio Ueno	Technology Executive/Chair of IEC TC105
363	Japan	Hyundai Motor Company	Sangho Yoon	Senior Research Engineer
364	Japan	Nissan	Takuya Hasegawa	Senior Innovation Researcher
365	Japan	Honda	Moriya Takashi	Senior Chief Engineer
366	Japan	Toyota	Kawai Taiyo	Project General Manager
367	Korea	Korean Hydrogen Industry Association	Hee-Chun Lim	Vice Chair
368	Korea	Hyundai	Jungik Kim	Senior Research Engineer
369	Korea	Doosan /Fuel cell BG	Meenam Shinn	President
370	Peru	Energy and Mining (Peru)	Manuel Kiyan	Senior Engineer
371	Chinese Taipei	Chung-Hsin Electric and Machinery Manufacturing Corp. (CHEM)	Song Lianyong	operating officer

372	Chinese Taipei	Chinese Taipei Steel	Yang Fengxiang	Doctor
373	Chinese Taipei	Chinese Taipei Steel	Wu Zhanwei	Doctor
374	Chinese Taipei	Chinese Culture University	Shi Guangheng	Assistant professor
375	Chinese Taipei	ASIA PACIFIC FUEL CELL TECHNOLOGIES, LTD.	Huang Linhui	President
376	Chinese Taipei	ASIA PACIFIC FUEL CELL TECHNOLOGIES, LTD.	Huang Boru	Assistant President
377	Chinese Taipei	Chinese Taipei Institute of Economic Research (TIER)	Lin Ruoqin	New energy team leader
378	Chinese Taipei	Hephas Energy co., Ltd	Chen Zhiyuan	Vice GM
379	Chinese Taipei	Hephas Energy co., Ltd	Wu Zhenli	Vice GM
380	Chinese Taipei	Porite Chinese Taipei Co., Ltd	Li Huilong	Manager
381	Chinese Taipei	Porite Chinese Taipei Co., Ltd	Xu Weixun	leader
382	Chinese Taipei	Toplus Energy	Yan Mingyu	General Manager
383	Chinese Taipei	Chinese Taipei Fuel Cell Partnership	Chunto Tso	President/Convener
384	Chinese Taipei	YC Synergy Co.,Ltd	Chen Jianxing	
385	Chinese Taipei	LEATEC Fine Ceramics Co., Ltd	Wang Ruikai	Vice GM
386	Chinese Taipei	Plus Metal Tech., Co. LTD.	Zheng Guizhong	Vice GM

387	Chinese Taipei	Plus Metal Tech., Co. LTD.	Xie Heyan	Director
388	Chinese Taipei	National University of Tainan	Guo Zhenkun	Professor
389	Thailand	Dept. of Alternative Energy Development and Efficiency, Ministry of Energy	Chanyut Thongchinda	
390	Thailand	Dept. of Alternative Energy Development and Efficiency, Ministry of Energy	Pornpan Chanapiwat	
391	USA	Fuel Cell and Hydrogen Energy Association	Morry Markowitz	President
392	USA	Sumitomo Corporation of Americas Business Development Group	Risei Goto	Directot
393	USA	US Hybrid	Don Kang	Vice President, Engineering
394	USA	US Hybrid - US FuelCell (a division of US Hybrid)	Dr Abas Goodarzi	President and CEO
395	USA	Oorja Protonics	Wang Heng	
396	USA	Ballard Power System	Alfred Wong	Sales Director
397	USA	Ballard Power System	Jerry Yu	China Sales Manager
398	USA	H2 PowerTech	Harol Koyama	CEO

399	USA	Georgia Institute of Technology	Zhang Zhe	Doctor
400	USA	Proton OnSite	David T. Bow	Senior Vice President
401	USA	US Hybrid	Abas Goodarzi	President/CEO
402	Belgium	International Partnership for Hydrogen and Fuel Cells in the Economy	Tim Karlsson	Executive Director
403	Germany	BMW China Service Ltd.	Anne Kleczka	Hydrogen project director
404	Germany	BMW China Service Ltd.	Guo Yan	
405	Germany	Daimler	Wolfram Fleck	Manager, RD/EFE Dept
406	Germany	TUV-SUD	Yang Yunxiao	North Sales Manager
407	Germany	Sunfire Gmbh	Carl Berninghausen	CEO
408	England	Intelligent Energy	Fang Shiying	China chief representative
409	French	Air Liqnide Advanced Business & Tednologies	Marc Coekelbrgris	
410	France	Air Liquide	Zhao Yingpeng	Senior Marketing Manager

Annex 2：Experts / consultants list

Bao-lian Yi
Dalian Institute of Chemical Physics, China
CAE Academician/Professor

Speech Topic:

Fuel Cell VehicleTechnology and Development in China

Presentation Outline / Brief:

Status of the research on the key materials for PEMFC in China; Reason and solution for decay of the cell stack operating in vehicles; Status of the research on the critical component in the cell system; Demonstration and application of the cell stack and cell system technologies; Technical problems for the commercialization of the fell cell electric vehicles.

Speaker’s Biography:

Prof. Baolian Yi is mainly engaged in the conversion of chemical energy and electricity. He is one of the academic leaders of fuel cell technologies in China. He is the Chair of national technical committee of standardization administration of China.

Morry Markowitz
Fuel Cell & Hydrogen Energy Association
President

Speech Topic:

U.S Fuel Cell Industry

Presentation Outline / Brief:

Morry will be discussing the state of the U.S. fuel cell and hydrogen energy industry, providing an overview of major activities to date, top market sectors, industry players, trends, and current market status. Morry will also be providing an overview of H2USA, the public-private collaboration to advance FCEVs and hydrogen infrastructure in the United States.

Speaker's Biography:

Morry Markowitz leads FCHEA advocacy programs on Capitol Hill, at DOE, DOD and other government agencies, and outreach programs to target markets and users of fuel cells and hydrogen energy. Morry comes with extensive expertise in the energy field, in addition to sixteen years of association management. Prior to coming to the FCHEA, Morry was the Group Director of External Affairs at the Edison Electric Institute (EEI) for nine years. Before his work at EEI, Morry was the Vice President of Public Affairs with the Association of International Automobile Manufacturers. Morry brings years of government relations, energy policy, and communications experience to the Association. Morry has worked on Capitol Hill, in addition to the Executive Branch of government. Morry graduated with a J.D. from George Mason School of Law.

Fumio Ueno
Toshiba Corp.
Technology Executive

Speech Topic:

Stationary fuel cell market and development in Japan

Presentation Outline / Brief:

Market, development, and products of residential micro-CHP (combined heat and power） and electrical energy storage system using fuel cell technologies will be explained.

Speaker’s Biography: Technology Executive:

Materials and Devices Control Center of Toshiba. Chair of IEC TC105 fuel cell technologies. Convenor of IEC TC21 JWG7 Flow Battery Systems for Stationary applications and system evaluation group of Smart Cities.

Hee Chun Lim
Korea Hydrogen Industry Association
Technical Vice Chair

Speech Topic:

Status and Opportunities for Hydrogen & Fuel Cell Technology in Korea

Presentation Outline / Brief:

Looking at the Fuel Cell industry in Korea at this moment, a number of company related Fuel Cell business are now over ten companies and the incomes of those companies showed over $ 1.170 billion in 2012. Stationary power generation capacity from Fuel cell system in Korea showed over 160 MW even in 2014. In the field of Fuel cell vehicle, Hyundai-Kia motor company declared that it's mass production line that have capability to manufacture more than 1,000 cars per year was established on 2013. Plus, for infrastructure, fourteen hydrogen stations for refueling of FC vehicles were constructed and eight sites are now operating.

Speaker's Biography:

Hee Chun Lim is now the technical vice Chair of Korean Hydrogen Industry Association(KHIA) in Korea(KHES) from 2015. He is also the director of Research Center in Deokyang Ltd. He was the former chief researcher in KEPCO Research Center where he had executed many fuel cell projects something like PAFC, PEMFC and MCFC by that time. Dr Lim is well known person in Korea as the first introducer of the fuel cell technology in Korea in 1988. His contribution in Fuel cell was that he made the basement for the industrialization of fuel cell technology through the projects that he had been carried out in Korea since 1985. Dr Lim graduated from Department of Mechanical Engineering of Sungkyunkwan University and received his Master and PhD degree from Chung Nam National University

Tso, Chunto
Chinese Taipei Fuel Cell Partnership
Convener

Speech Topic:

Fuel Cell Industrial Development in Chinese Taipei

Presentation Outline / Brief:

International commercialization of fuel cell industry; FC Development in Chinese Taipei; Advantages of Chinese Taipei FC Industry.

Speaker's Biography:

Dr Tso received his Ph.D degree in Economics in Texas A&M University. He is now the researcher in Chinese Taipei Institute of Economic Research, director of Research Division I (TIER) and Survey and Statistics Center (TIER). Previously, he worked as Deputy Executive Secretary of Ministry of Economic Affairs in Industrial Development Advisory Council from 1994, Chair of Chinese Taipei Biomass Energy Industry Association, Chair of Chinese Taipei Fuel Cell Partnership, Secretary General of Taipei Fuel Cell Foundation, etc. Additionally, he is also adjunct professor of National University of Chinese Taipei, National Chiao-Tung University and Shih Chien University.

Guo Hua
Guodian New Energy Technology Research Institute
Vice President

Speech Topic:

Low Temperature and High Efficiency Direct Biomass Fuel Cell

Presentation Outline / Brief:

Straw burning on-site is a significant seasonal source of air pollution and the other environmental issues caused by biomass waste that are not improperly treated, is also becoming increasingly serious. This presentation will introduce a novel direct fuel cell technology with biomass such as straw as the fuel and it is totally different from the other traditional fell cell technology. The novel design of the liquid-catalyst fuel cells (LCFC) changes the traditional gas-solid-surface heterogeneous reactions to liquid-catalysis reactions. With this design, raw biomasses, such as cellulose, starch, and even grass or wood powders can be directly converted into electricity. The power densities of the fuel cell as high as 44-51 mW/cm2 has been achieved, which is almost 3,000 times higher than microbial fuel cells. Unlike noble-metal catalysts, POMs are tolerant to most organic and inorganic contaminants. Almost any raw biomass can be used directly to produce electricity by this novel fuel cell technology. In brief, the development of this technology provides a low cost, high efficiency and environmental-friendly way to deal with biomass waste.

Speaker's Biography:

Dr Guo Hua joined the "Recruitment Program of Global Experts" in 2011 and he was nominated as Vice President of Guodian New Energy Technology Institute then. He leads the R&D center and international cooperation department of the institute and in charge of 4 international & national research projects and more than 10 projects of Guodian Corporation. Dr Guo got the fifth session of the Beijing overseas special contribution award of innovation and entrepreneurship.

Gongquan Sun
Dalian Institute of Chemical Physics, Chinese Academy of Sciences
Director/Professor

Speech Topic:
Progress and Perspective of Fuel Cells at DICP

Presentation Outline / Brief:
The recent progress and perspective on fuel cells, especially on the methanol/ethanol fuel cells, metal air fuel cells, will be presented both in fundamental and engineering at DICP. The challenges and strategies ranging from electro catalysts, electrolyte membranes, membrane & electrode assemblies, compact stacks, systems, etc., will be reviewed by means of experimental and demonstrative results.

Speaker's Biography:
Prof. Gongquan Sun received his doctorate from Changchun Institute of Applied Chemistry, Chinese Academy of Sciences (CAS), in 1993. He served for Case Western Reserve University, Georgia Institute of Technology, the University of Notre Dame as a visiting scholar in USA in the duration of 1996-2001, and he is the Director of Division of Fuel Cell & Battery of DICP, the Principle Scientist of the "973 Program". More than 230 peer reviewed papers and 200 patents have been published and pended. He has been awarded several prizes including the National Natural Science Prize of China.

Meenam Shinn
Doosan FuelCell
President

Speech Topic:

Fuel Cell Activities in Doosan & Korea

Presentation Outline / Brief:

For the last 15 years, Korean fuel cell market has evolved in the three major application fields: power generation, residential/commercial buildings and vehicles. In the presentation, the recent activities of the market players will be discussed. The issues and hurdles that the players should solve also will be addressed.

Speaker's Biography:

Dr Shinn received her PhD in Material Science& Engineering from Northwestern University. For last fifteen years, she has initiated the commercialization of fuel cells as President of Doosan Fuel Cell and CEO of Fuel Cell Power Inc. As a member of Presidential Committee on Green Growth, she actively has involved in the national efforts to reduce CO2. Dr Shinn also has served as a member of Presidential Advisory Council on Science and Technology and National Science & Technology Commission. Before joining Fuel Cell Power, she worked at McKinsey & Company as a strategic consultant and at Samsung as a senior researcher.

Carl Berninghausen
Sunfire GmbH
CEO

Speech Topic:

Novel SOC based applications for today challenges in the energy sector

Presentation Outline / Brief:

Sunfire company introduction;
Sunfire SOC technology introduction;
SOFC / SOEC technology in different energy sectors;
Power to fuel concept in future energy network.

Speaker's Biography:

Carl studied business administration at EBS University and economics at the University of Frankfurt am Main before going on to become a successful family businessman and founder of various companies. He is responsible for strategic management at Sunfire. He is a co-founder and shareholder of Sunfire GmbH.

HAN Minfang
Tsinghua University
Yangtse River Scholar, Chief Scientist of 973 program

Speech Topic:

Development of Carbon-based Solid Oxide Fuel Cell

Presentation Outline / Brief:

Solid oxide fuel cell (SOFC) can offer an environmentally friendly technology to convert carbon-based fuels into electricity at high efficiencies, such as coal gas, natural gas and biomass gas. Supported by the national 973 program, the new materials, structures and methods of carbon-based SOFC have been developed. New mechanisms and theories have been presented. The SOFC market will be bright in the near future.

Speaker's Biography:

After graduation from Tsinghua University in 1990, Minfang Han had gotten her Master degree and Ph. D in 1993 and 2002 in China University of Mining & Technology, Beijing (CUMTB). Now she is the Yangtse River Scholar and Chief Scientist of 973 programs. Prof. Han's research interests involve solid oxide fuel cell (SOFC) and solid oxide electrolysis cell (SOEC) materials and power system, oxygen permeation membrane (OPM) and hydrogen refining from coal relative gas, CO_2 separation and capture, ceramic materials.

Weiguo Wang
Ningbo SOFCMAN Energy Technology Co., Ltd.
Chair of the Board and CEO

Speech Topic:

On the Road to Commercialization of SOFC Technology

Presentation Outline / Brief:

The status of SOFC technology and its international market will be briefly presented. The key issues and relevant technical problems concerning SOFC commercialization will be analyzed. The current activities in SOFCMAN towards the development, manufacture, and sales of the large-scale distributed power generation system will be introduced. The installation, maintenance, and operation cost in comparison with gas turbine and coal fire plant will be reported. We believe that the construction, operation, and service of large-scale distributed power generation station in the level of 10MW to 100MW will bring the SOFC business to profitable.

Speaker's Biography:

Dr Weiguo Wang is the Chair of the Board and CEO of Ningbo SOFCMAN Energy Technology Co., Ltd. Before founding the company, he was the Deputy Director of Ningbo Institute of Materials Technology and Engineering (NIMTE), Chinese Academy of Sciences. In the end of 2006, Dr Wang joined NIMTE and established the Fuel Cell and Energy Technology Division at NIMTE.

Taiyo Kawai
Toyota Motor Corporation
Project General Manager

Speech Topic:

Toyota's FCV Developmentand Efforts Toward Sustainable Mobility

Presentation Outline / Brief:

FCV"MIRAI" was introduced into Japanese market on Dec 15, 2014, and into the U.S./Europe market on Oct 2015.Activities of FCV new market creation have been just starting. For FCV popularization "Improvement of FCV Products", "Preparation of H2 station", and "Low price Hydrogen" would be important.

Furthermore CO_2 free H_2 will be required to supply into the Market together with CO_2 free electricity in the future toward sustainable mobility. For China, "Scenario/Roadmap for Hydrogen Society" and "Preparation for FCV market introduction" would be desired.

Speaker's Biography:

Taiyo Kawai joined Toyota Motor Corporation in 1978.He worked as a general manager of Fuel Cell System Development Division from 2001 through 2012 after he was in charge of engine R&D and R&D management. He has been the project general manager of R&D Management Division since 2012. He is in charge of planning, promotion of FCV market introduction, and alliance with other partners.

Wolfram Fleck
Daimler AG
Manager, RD/EFE Dept.

Speech Topic:
Fuel Cell-The Next Step of Daimler

Presentation Outline / Brief:
Introduction
History and current product
Outlook next Generation
Next steps towards market deployment

Speaker's Biography:

Wolfram Fleck is currently leading the Hydrogen storage system- and safety engineering team. In his current role he is also responsible for hydrogen safety concept development, validation testing of such and coordination of codes and standards with respect to hydrogen storage systems for vehicles.
He started his career at Daimler Corporation in 1987 as mechanical engineer and was pioneering fuel cell applications for automotive applications since 1991. He helped to develop various fuel cell demonstrator vehicles as NECAR 1 and NECAR 2 based on PEM fuel Cell technology.
In his function as project manager from 1996 to 2009 he developed three generations of fuel cell power train applications for urban city bus applications. Since 2010 he is in charge of hydrogen storage systems development.

Jungik Kim, Ph.D.
Hyundai Motor Company
Senior Research Engineer

Speech Topic:
Hyundai's FCEV

Presentation Outline / Brief:
Due to the energy and environment issues, a polymer electrolyte membrane fuel cell (PEMFC) is attracting a great attention for automotive application because of its high energy efficiency and power density. A hydrogen fuel cell electric vehicle (FCEV) installed with PEMFC is one of the promising candidate for transportation due to its convenience and zero-emission mobility. Hyundai Motor Company (HMC) has developed FCEV since the end of 1990s and launched the world first mass production ix35 FCEV in 2013.

Speaker's Biography:

1993-1999: B.S., Seoul National University;
1999-2001: M.S., Seoul National University;
2001-2003: Research Engineer, Powertrain Analysis Team, Hyundai Motor Company;
2003-2009: Ph.D., Massachusetts Institute of Technology;
2009-present: Senior Research Engineer, Fuel Cell Technology Development Team, Hyundai Motor Company.

Ming Pingwen
Sunrise Power Co,. Ltd
General manager

Speech Topic:
Fuel cell technology in Sunrise Power

Presentation Outline / Brief:
Presentation summarized the fuel cell rolling development process in sunrise power. Sunrise Power, one of the key players of fuel cell industry in China, transferred 3 generations of fuel cell stacks, and is planning the 4th generation, which would meet the requirement of the stage of fuel cell vehicle market introduction.

Speaker's Biography:

2003.4-2003.12, he was the director of science and technology department in Dalian institute of Chemical Physics (DICP). Manager of "Fuel cell bus commercial demonstration of China" project that was held by MOST/UNDP/GEF. 2004.1-2006.11, Dr Ming took the charge of the Fuel cell engineering center and Fuel cell system and engineering research group in DICP. From November 2006 till now, he play the lead role in both Sunrise Power Co,. Ltd and National Engineering Research Center of Fuel Cell & Hydrogen Generation Technology. He enjoyed special allowance from Dalian city and State Council and was selected as young and middle-aged technological leading talent of national innovation talents plan in 2013.

Takuya Hasegawa
Nissan Motor Co., Ltd.
Manager

Speech Topic:

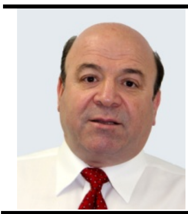
FCEV Commercialization, Social and Economic Studies at Nissan Motor

Presentation Outline / Brief:

Fuel cell electric vehicles (FCEVs) have been attracting increasing attention as one of zero-emission vehicles. However, despite many efforts and investments, the profitable commercialization of FCEVs remains a difficult task. This study focused on the hyper-expectations that prevents reasonable economic growth and proposed a mechanism that displaces the innovations needed for business creation of infrastructure-dependent new products: FCEVs. To take hyper-expectations into account, a new framework of technological innovation system and a set on heuristics were proposed. This study then proposes a multi-step business model including non-automotive FC applications and commercial vehicle applications in parallel with passenger vehicle applications.

Speaker's Biography:

Takuya Hasegawa manages a R&D team in the Nissan Research Center for advanced fuel cell technologies and hydrogen / fuel cell market creations. He was appointed a senior innovation researcher in 2012 as one of three disruptive innovators in Nissan. In 2012, he started his Ph.D. study in hydrogen / fuel cell vehicle market creation at Ritsumeikan University. He is also a visiting professor at Hosei University, Business School of Innovation Management Global MBA program since 2015.



Abas Goodarzi Ph.D., PE
US Hybrid
President & CEO

Speech Topic:

PEMFC technology and product for Medium and heavy duty Vehicles

Presentation Outline / Brief:

This paper presents an integrated fuel cell engine, including power conversion, that reduces the total cost, while increasing power density and reliability, resulting in better diagnostics, service and maintenance. The fuel cell engine is optimized for operation in wide load ranges and operation dynamics.The FC engine design is based on over 15 years of fuel cell engine integration and vehicle operation. It is designed to simplify integration, operation, and service for commercial vehicles, while meeting the robust shock and vibration required with 20,000 hours operation life design. The integrated design provides SAE J1939 control, command and diagnostics with enhanced failure mode protection and prognostics.

Speaker's Biography:

Dr Goodarzi is the founder and President, US Hybrid Corporation, US Fuel Cell, and Magmotor Technologies Inc. With over 30 years of EV and HEV experience, Dr Goodarzi directs the technology and product development at US Hybrid with focus on Fuel Cell, Electric and Hybrid Power train design and manufacturing for medium and heavy duty commercial and military vehicles and Fuel Cell Systems. Dr Goodarzi was formerly a professor at Cal State San Francisco, technical director for General Motors' EV1 program, Senior Scientist at Hughes Aircraft Company, and co-founder Enova System where he served as CTO till 1999. He holds a Ph.D. and MS. from University of Missouri, Columbia in Power Electronics and B.S. from Cal State Sacramento in Power Systems. He has been a registered Professional Engineer since 1985. Dr Goodarzi has various publications, patents and professional awards.

Dr Chang Wei
National Institute of Clean-and- Low-Carbon Energy
President & CEO

Speech Topic:
NICE/Shenhua Perspectives of Hydrogen Energy

Presentation Outline / Brief (within 100 words):
Hydrogen energy is an important part of Shenhua/NICE clean energy strategy. This talk outlines key technologies and processes related to hydrogen energy and its applications, including hydrogen production, transport, storage and downstream applications. Different sources of hydrogen, venues of transporting hydrogen, and types of hydrogen applications as well as related economics will be presented. The major challenges that the energy industry is facing and the potential pathways going forward will also be highlighted and discussed.

Speaker's Biography:
Dr Chang Wei is President and CEO of National Institute of Clean-and-low-carbon Energy (NICE), the corporate research arm for Shenhua Group, one of the world largest energy companies. At NICE, Dr Wei leads about 350 scientists conducting advanced research in energy areas including clean coal, performance materials, water technologies, distributed power and hydrogen energies.
Prior to his current role, Dr Wei was an executive at General Electric Company where he worked for almost 20 years; most recently he was the General Manager responsible for the global water R&D at GE Global Research.
Dr Wei holds a PhD degree in Chemistry with 31 issued US patents and 30+ publications in referred journals.

Tim Karlsson
International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE)
Executive Director

Speech Topic:

Issues Ahead for Deployment of Fuel Cells: A Response to Global and Local Drivers

Presentation Outline / Brief:

Hydrogen and Fuel Cell technologies offer a way to enable clean energy systems, to enhance energy security, to address local environmental goals, and to contribute to economic growth. Economies around the world are taking action to develop, deploy, and use these technologies. This presentation will discuss some of the government related initiatives that are being implemented, some of the issues that remain, and potential opportunities to address them.

Speaker's Biography:

Tim Karlsson is Executive Director of the International Partnership for Hydrogen and Fuel Cells in the Economy (IPHE), a forum for governments to share information and experiences with the goal of integrating hydrogen and fuel cells into energy and transportation systems. Previously, Tim was the Director of Emerging Technologies at the Department of Industry in Canada. He has worked on numerous policy issues related to energy and the environment including domestic and international climate change policy, and, was a member of Canada's delegation to the United Nations Framework Convention on Climate Change for a number of years.

Cunman Zhang
Tongji University
Professor

Speech Topic:

Current Status and Development of Hydrogen Energy Infrastructure Construction in China

Presentation Outline / Brief:

The presentation summarizes construction and operation status of hydrogen refueling station in China, analyzes current status about R&D and industrialization of refueling station key technology and discusses development tendency and challenge of refueling station under new station. In addition, the presentation analyzes necessity and opportunity about pushing energy storage based on hydrogen in China, combining with development tendency and challenge of renewable energy.

Speaker's Biography:

Professor of School of Automotive Studies, Tongji University; Deputy director of Shanghai Engineering Technology Research Center of Hydrogen Energy Utilization; Chief expert of National 863 program about advanced energy; Winner of "Young Leading Talent of Technological Innovation" of MOST, China; Member of China Association for Hydrogen Energy, China Renewable Energy Society; Member of China Association for Hydrogen Energy standardization; Member of China Association for Gas Cylinder standardization.

Randy MacEwen
Ballard Power Systems
President & CEO

Speech Topic:
Ballard Technology & Market Leadership – Putting Fuel Cells to Work

Presentation Outline / Brief:

Over 30 years of experience with significant PEM IP portfolio, Shipped more than 210MW of PEM fuel cell products worldwide, Thousands of backup power systems installed at telecom sites, Millions of kilometers driven by Ballard powered fuel cell buses, Key automotive customers include Volkswagen & Mercedes-Benz

Speaker's Biography:

Mr MacEwen has extensive executive-level experience leading a range of clean energy organizations, including involvement in the hydrogen and fuel cell sector. He possesses strengths in a broad range of key areas, including corporate governance, international B-to-B sales, product development, manufacturing, engineering services, M&A and corporate finance. He provided strategic planning, interim/consultant CEO, corporate finance advisory and M&A advisory services to clean technology companies. Mr MacEwen previously served as President & CEO of Solar Integrated Technologies, Inc., a commercial rooftop solar company, and was Executive Vice President, Corporate

Development of Stuart Energy Systems Corporation, and a supplier of hydrogen generation systems.

Moritani Takashi
Honda R&D Co. Ltd.
Senior Chief Engineer

Speech Topic:

Honda Fuel Cell Vehicle Development and Toward the Hydrogen Society

Presentation Outline / Brief:

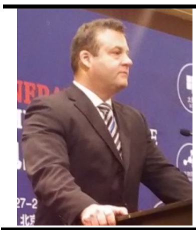
This presentation is not only explanation of Fuel Cell Vehicle (FCV) development status of Honda, but also Smart Hydrogen Station (SHS) development and Power output supply system. Honda has been demonstrated the possibility of Hydrogen Society using these technologies in Japan. Honda's thinking way is described through these activities in this presentation.

Speaker's Biography:

-1981: Join Honda R&D Co., Ltd.

Attached Internal Combustion Engine Design DepartmentEngaged mainly future ICE engine design

-1995: Engaged Fuel Cell Electric Vehicle Development Department, engaged research activities of Fuel Cell Stack and System. Now Senior Chief Engineer after Department manager, Senior Manager and Operating Officer.



David T. Bow
Proton OnSite
Senior Vice President

Speech Topic:

MW-Scale PEM Electrolysis for Energy Storage and Grid Stabilization Applications

Presentation Outline / Brief:

With the ever-increasing addition of wind and solar renewable energy to the traditional electric grid, the need for energy storage also grows. Hydrogen from electrolysis is a promising technology for renewable energy capture as it has the capability to store massive amounts of energy in a relatively small space. In addition, electrolysis can also provide ancillary services to the grid such as frequency regulation and load shifting resulting in multiple value streams. The hydrogen produced can alternatively be injected into the natural gas pipeline (thus making that energy carrier more green), in the production of high value chemicals such as ammonia, in upgrading of methanization-produced biogas, or used as a transportation fuel. With the commercialization of MW-scale PEM-based water electrolysis systems large scale hydrogen energy storage is a solution that is ready today.

Speaker’s Biography:

Mr Bow is the Senior Vice President of Sales, Service & Marketing and Executive Officer responsible for Global Commercial and Business Development. He has extensive expertise in global business development, with a strong operations and engineering foundation. Mr Bow joined Proton OnSite on June 2, 2014. Prior to joining Proton OnSite, Mr Bow provided sales and marketing consulting services through his company, Sales Growth Solutions, from September 2013 through May 2014. From October 2010 to March 2013, he was Senior Vice President - Global Commercial Development of Cosa Instrument Corporation. Prior to working at Cosa, Mr Bow worked at Dionex Corporation as Vice President - Sales, Service and Marketing.

Annex 3：Domestic media coverage links of the forum

http://www.sasac.gov.cn/n86114/n326638/c2185450/content.html
http://dangjian.people.com.cn/gq/n1/2016/0122/c241157-28077360.html
http://www.chinapower.com.cn/fdhyyw/12072.jhtml
http://money.163.com/16/0125/03/BE55477L00253B0H.html
http://chaohusnews.com/a/xinwenzhongxin/guojixinwen/20160126/20959.html
http://www.cgdc.com.cn/mtbd/783541.jhtml
http://www.zgjn365.com/news/show-32506.html
http://www.258.com/news/1145188.html
http://www.autoenv.com/zixun/huizhan/2016/0126/3967.html
http://www.yuncaijing.com/news/view/3659588
http://www.in-en.com/article/html/energy-2244056.shtml
http://hb.people.com.cn/n2/2016/0125/c192237-27617277.html
http://news.xinmin.cn/domestic/2016/01/25/29385994.html
http://news.ifeng.com/a/20160125/47215081_0.shtml
http://www.clii.com.cn/zhhylm/zhhylmHangYeZiXun/201601/t20160126_3886071.htm
http://news.ifeng.com/a/20160125/47215081_0.shtml

http://m.21jingji.com/article/20160121/1ad09986a827b1464f0f60dc95cef5f0.html
http://auto.163.com/16/0122/09/BDU2IC4L0008598H.html
http://auto.sohu.com/20160121/n435420602.shtml
http://www.china-nengyuan.com/news/88733.html
http://news.10jqka.com.cn/comment/587448679.shtml
http://stock.jrj.com.cn/2016/01/21053120454602.shtml
http://news.steelcn.cn/a/114/20160121/83325700BD16D2.html
http://guba.eastmoney.com/news,600192,244375464.html
http://bbs.pinggu.org/k/news/1431122.html
http://www.itdcw.com/m/view.php?aid=56508
http://www.ddqcw.com/bbs/thread-154578-1-1.html

Annex 4：commercial analysis report

Part A: Market Analysis

1. Global Fuel Cell Market

Fuel cell industry, as an emergent technological innovation system, is continuously breaking its record high in market expansion and growth. Fuel cell total shipment hit record high in 2015 with over 70,000 units shipped. Fuel cell innovation system was started by the initiation of government research program as an important technology to solve the environmental issue that we face - ever increasing CO_2 and green house gases (GHGs). In Europe, fuel cell is considered as an innovative technology to change our energy systems to meet the targets of reducing green house gases (GHGs), increasing use of renewable energy, and improving our overall energy efficiency. When talking innovation, there are two forces such as technology push and market pull. In the early stage when the technology is still expensive, governments play an important role by creating a market pull force to attract early technology adopters to get involved until the market reaches sustainable level, when government funding subsidy can vanish. It is important, as a role of government, not to stop supporting funding or discontinue programs base on the status of an innovation technological system. In this chapter, we will review the government fuel cell program globally to analyze the global fuel cell market. The current market driving force is still by government supported program and tax credit incentives to create volume production advantage in order to achieve economy of scale. The two early markets of fuel cell are clearly material handling application in America and stationary power generation in Japan, with a potential latecomer from vehicle application. From the statistical report of Fuel Cell Industry Review 2015 in figure 1: total shipment by megawatt (MW) is nearly 350 MW, which is almost doubled from 2014, among them, 150 MW is contributed from transportation (including material handling application and fuel cell vehicles such as cars and buses). The fuel cell market is full of growing potential, in the area of test equipments, material supply, complementary technologies and components, and finally any niche applications that can revolution the current energy system.

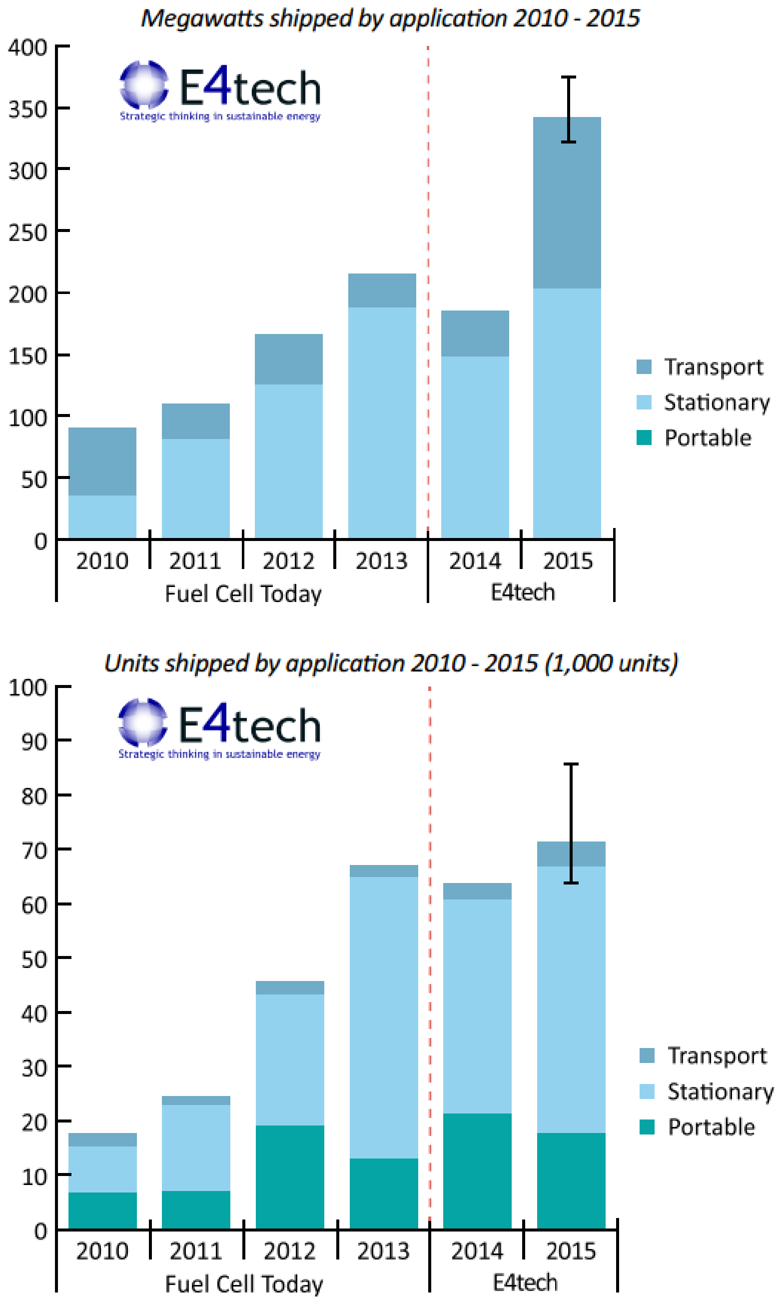
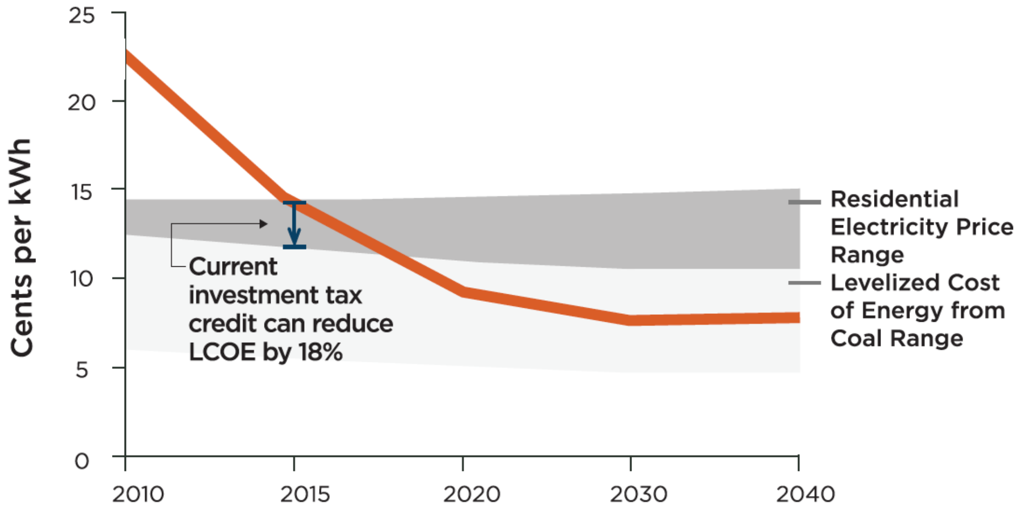


Figure 1: Fuel cell shipment reports by unit and power output.

2. Government Support Program in the USA

In America, many activities of fuel cell pre-commercialization are in place. With the aid of federal business energy investment tax credit (ITC), the incentive has helped growth of fuel cell in material handling and stationary applications across economy. In the USA, federal government encourages business to purchase and utilize fuel cell technology with tax credit, which allows them to reduce tax paying to the government. The credit provides an incentive of 30% of the cost of fuel cell up to $3000 per kW, while the fuel cell system must be greater than 0.5

kW in size and has electric efficiency over 30%. With this incentive, business can taste the benefit of new fuel cell technology and get tax exemption at the same time! This program required fuel cell installation before Dec. 31, 2016 in order to apply for the tax credit.



Assumptions	2010	2015	2020	2030	2040
Total Efficiency (HHV)	72.7%	74.8%	78.0%	84.0%	85.2%
CHP Electrical Efficiency (HHV)	39.7%	42.4%	45.1%	46.9%	48.7%
Capital Costs w/o Stack Replacements ($/kWe)	7,200	4,600	2,000	1,000	960
Fixed O&M Costs ($/kWe-yr)	302	204	108	68	67
Variable O&M Costs ($/MWh)	13.7	8.8	3.8	1.9	1.8

Figure 2: Example of Levelized Cost of Energy from Fuel Cell CHP Systems

Fuel cell technology is becoming well known in the USA, according to the 5th annual Deloitte Resources Study of more than 600 U.S. companies, it found that 55% of the businesses generates a portion of their electricity onsite, and 9% of them are using fuel cell to produce the electricity. Fuel cell customers benefit from the technology by saving money on fuel and labor costs, lowering emissions, and yielding quite a lot energy saving through increased efficiency and reliability.

The total revenue of fuel cell industry has reached $2.2 billion in 2014, and the revenue contribution of the U.S is around 30%, or 660 million dollars. Repeating orders are coming from experienced customers who expand with additional and larger fuel cell systems in the applications of material handling equipment and backup power systems.

Table 1: Summary of USA Demonstration Project in Material Handling.

Company in Demonstration	Project Short Description	Project Budget	Unit Average Cost by Government Support
Federal Express	A two-year demonstration of fuel cell powered cargo tractors, launched at the Federal Express facility at Memphis International Airport in Tennessee. 15 cargo tractors will be tested.	$2.5 million from DOE, 50% of total cost.	$160,000 per unit, tractors and fueling facility
United Parcel Service (UPS)	UPS and Hydrogenics are developing fuel cell hybrid electric walk-in delivery van. They will retrofit 17 UPS delivery vans to test distribution facilities across California.	$3 million from DOE as a four-year project.	$176,000 per truck unit truck and refueling stations.
Sysco	Participated in a DOE funded fuel cell powered refrigeration transport units (TRUs), Plug Power is working with Thermo King and Carrier Transicold by integrating 4 fuel cells to the truck.	$650,000	$162,500 per truck.
H-E-B Grocery	Participated in a DOE funded fuel cell powered refrigeration transport units (TRUs), Nuvera Fuel Cell is doing the same with its fuel cells working with Thermo King.	$650,000	N/A/

The vigorous market did not appear naturally, it was initiated by a large demonstration program, supported by the U.S. Department of Energy (DOE), sparked by the investment of the American Recovery and Reinvestment Act (ARRA) in 2009 funding $41.9 million for deploying of nearly 1300 fuel cells for material handling application and stationary telecommunication backup powers. At that time, 504 fuel cell forklifts were deployed to 8 sites, and 607 stationary backup power units were installed at 203 sites. At an average investment of $32,000 per unit, the industry contributed the other half of the investment, bringing a contribution of $51 million from the industry. Participants and partners from the private sector are H-E-B Grocery, Federal Express, AT&T, Sprint, Sysco (Houston), GENCO, Wegman's Whole Foods, Sysco (Philadelphia), Coca-Cola, and Kimberly-Clark. Since the ARRA funding investment, other DOE-led market transformation projects have brought US government and industry together to demonstrate the feasibility of fuel cell in various real-world settings and gather crucial data needed to move markets forward. After the funding program in 2009, additional purchase of more than 13500 fuel cell system were purchased without DOE funding, a more than eight-time increase.

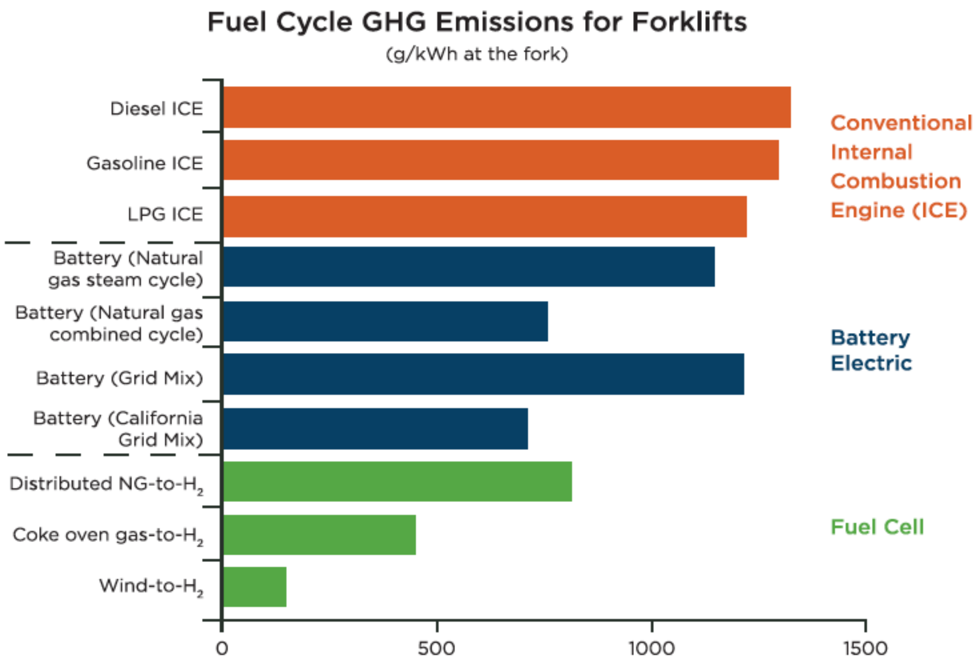


Fig3. Greenhouse Gas Emissions from Forklifts

Based on the secondary document provided by Fuel Cell Hydrogen Energy Association, in this section, we will analyze the average cost of fuel cell demonstration in the USA.

In 2015, Plug Power has shipped 3431 units of GenDrive (fuel cell forklifts) and installed 18 hydrogen refueling infrastructures, generating a revenue of $78 million. On average, the average unit price of GenDrive is $22,700, by not considering price difference among class I, class II, and class III forklifts and the cost of refueling stations. In real case, the price of the forklift should be lowered, roughly at $12,000. Plug Power claims the gross margin of the sales on fuel cell systems and infrastructure is 13%, which means they could make a sell at loss in fuel cell systems, but gain margin back from installing the refueling stations. Even at an average cost price of 22,700 per unit, the price is already competitive comparing to other fuel cell systems.

Table 2: Summary of Plug Power Revenue and Sales

	2015	2014	2013	2012
Sales Revenue	$78 million	$46.4 million	$18.4 million	$20.7 million
Units of Forklift Shipped	3431	2406	918	1136
Hydrogen Refueling Station Site	18	11	0	0
Average Unit Cost	$22,733	$19,285	$20,000	$18,220
Gross Margin	13.2%	10.2%	-10.7%	-21.9%

It is clearly that due the economy of scale and the integrated GenKey service, Plug Power has gained increase in product gross margin since 2014. The calculated average unit cost includes hydrogen refueling stations, which is expensive. The unit cost of an actual fuel cell forklift module - GenDrive is actually lower than the average unit cost. In prediction, it is about $15,000.

Walmart is the most important customer of Plug Power, which contributes 56.7% of the consolidated revenue, the rest of the customers did not exceed 10% consolidated revenue. It is important for Plug Power to work out second and third largest customers in case if they lose orders from Walmart.

3. Government Support Program in Europe

In Europe, the European Union (EU) has set itself ambitious long-term targets for its energy system. Fuel cell technology is part of the Strategic Energy Technology Plan (SET-Plan) among the eight sets of technologies with a role to play in a future sustainable European energy system. European Council concluded their targets for 2030 which comprise of three targets: 1) an increase in the share of renewable energy to 27%, 2) improvements in energy efficiency by 27%, and 3) dramatic reduction in greenhouse gas (GHG) emissions by 40%

EU considers fuel cell and hydrogen technologies are in a unique position because they can be used in both energy storage and transportation systems, while the hydrogen is produced through renewable energies by electrolysis, fuel cell technology can provide zero-emission solutions to a range of challenges. In addition, hydrogen provides a means of short-term and long-term energy storage, as an energy vector, it is an energy carrier that enables shift of energy from transportation to power production, which can replace conventional gasoline. As a result, fuel cell technology provides a bridge for intermittent renewable resources such as wind and solar power.

In the first phase of the Fuel Cell and Hydrogen Joint Undertaking (FCH JU), the budget for 2008 - 2013 amounted to around 940 Euro million, jointly funded by the European Commission and Europe's fuel cell and hydrogen research communities. Following the success of the first phase program, the FCH JU was renewed in June 2014 under Council Regulation (EC) 559/2014 as part of the Horizon 2020 plan. The new budget is now set at 1.33 Euro billion with activities focusing on the two innovation pillars: transportation and refueling infrastructure and energy, supported by cross-cutting activities. The two innovation pillars continue to support the range of application area, but with greater focus on those that can be widely deployed with the 2020 time frame.

Under the Multi-Annual Work Programme (MAWP), a list of activities for two pillars is listed in the figure shown below.

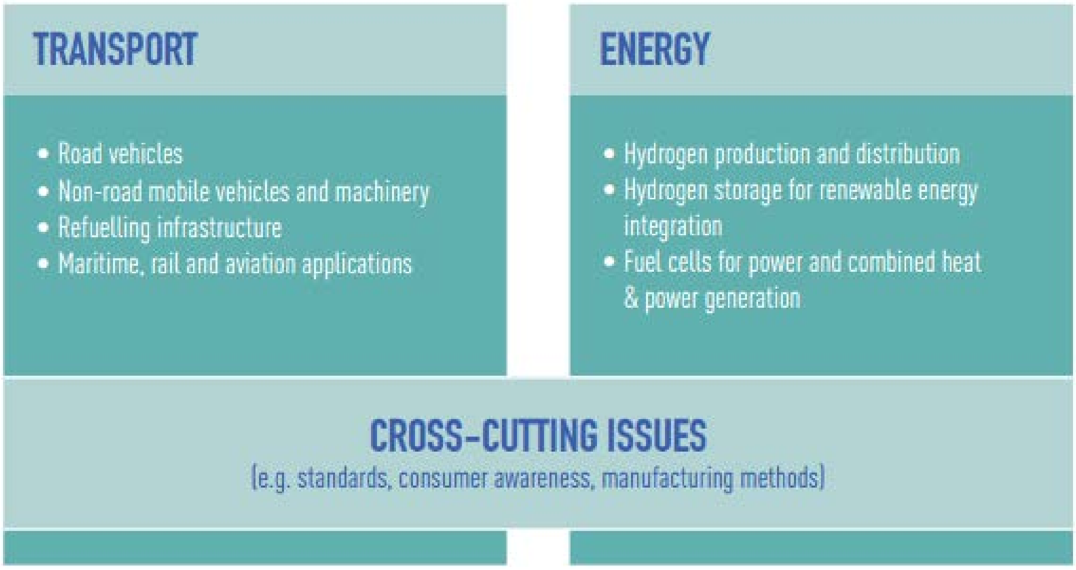


Figure 2: List of activities for transportation and energy pillars of FCH JU program.

In the transport pillar, FCH-JU sets to focus on road vehicles, non-road mobile vehicles and machinery, refueling infrastructure, and maritime, rail, and aviation applications. In the energy pillar, FCH-JU sets to focus on hydrogen production and distribution, hydrogen storage for renewable energy integration, and fuel cells for power and combined heat & power generation. Each pillar accounts for about 47.5% of the 1.33 Euro billion budget.

3.1 Transportation Pillars

The objective of the transportation pillar is the acceleration of the commercialization of FCH technologies for use in a range of transport applications, primarily road transport. The budget for all transportation pillar projects between 2014 and 2020 accounts for 631.7 million Euros, and the major projects are for demonstration of fuel cell cars and buses. Table 3 summarizes the projects of transportation demonstration.

Table 3: The projects of transportation demonstration supported by FCH JU

Project Code	Number of Vehicles	Short Description
H2MsovesScandinavia	15 cars	10 sedans and 5 city EV with hydrogen fuel cell range extender, and one HRS installed. Completed in 2012.
HYFIVE	110 cars	Deployment of 110 FCEVs and 6 HRSs in three European regions
HyTEC	30 cars	Demonstration of up to 30 new H2 vehicles in Denmark and the UK, in three classes: taxis, passenger cars and scooters.
H2ME	300 cars	300 cars to be deployed for large scale demonstration, begin in 2015
SWARM	100 cars	Delivery and operation of a critical mass of passenger and delivery vehicles. Build 3 HRS infrastructures.
CHIC	53 buses	53 fuel cell buses are on the road in day-to-day passenger service.
High V.LO-CITY	14 buses	Delivered 14 FC buses and demonstrated in 3 regional sites: Sanremo, Antwerp, and Aberdeen. Each kW cost is less than 2500 Euro.
HYTRANSIT	6 buses	Developing six A330 hybrid fuel cell buses specially for long suburban routes. Constructing and operating a hydrogen refueling station to serve the bus fleet.
3EMOTION	21 buses	Deploying 21 new fuel cell buses in 5 European cities: Rotterdam, London, Antwerp, Cherbourg, Rome.
HyLift Europe	200 material handling vehicles (MHVs)	Plan to deploy 123 fuel cell forklifts and 67 airport fuel cell tugs for material handling operation.
MobyPost	10 MHVs	10 fuel cell vehicles built and homologated for post service.

HAWL	200 MHVs	Aiming to deploy 200 fuel cell forklift trucks on 2 or 3 logistics warehouses and demonstrating competitiveness.

In total, the FCH-JU program supports around 94 fuel cell buses, 410 fuel cell MHVs, and 555 fuel cell cars in large scale demonstration. These demonstration units help stakeholders to collect necessary data and reduce overall costs toward next commercialization step. The total budget for different categories of transportation is summarized in the table below.

Table 4: The total budget by different categories of fuel cell transportation demonstration pillar.

TRANSPORT ACTIVITY	SEGMENT	FCH JU MAX CONTRIBUTION (MILLION EUR)	NUMBER OF PROJECTS
Transport demonstration	Car	76.5	5
	Bus	61.4	4
	MHV	23.1	5
	APU (including UAV systems)	22.2	8

The target cost in this demonstration program ranges from 2500 to 3500 Euro per kilowatt fuel cell system. In the project of 3Emotion, they have committed to a total cost of fuel cell bus vehicle reduction from 1.2 million Euros in 2012 to 1 million Euros at current.

3.2 Energy Pillar

In energy pillar, its objective is to accelerate the commercialization of FCH technologies for stationary fuel cells and the production of green and low-carbon hydrogen as an energy vector in Europe. The widespread deployment of competitive technologies will deliver substantial benefits in terms of energy efficiencies, emissions, and security, together with maximizing the integration of renewable energy source (RES) into energy system.

Programs of energy pillar include stationary fuel cells (power and heat) demonstration and proof of concept (PoC) activities to prove technology capability and readiness, stationary fuel cell (power and heat) research and innovation for performance, durability, and cost improvements, as well as hydrogen production pathways from renewable energy source, handling, distribution, and storage technologies to enable hydrogen to become a major energy vector in Europe.

The total budget for the energy pillar under FCH JU is also set at 47.5% of the 1.33 billion Euros between 2014 and 2020. In the field of demonstration, the budget distribution is listed in table 5 shown below:

Table 5: The total budget by different categories of fuel cell energy pillar.

ACTIVITY AREA	SEGMENT	FCH JU MAX. CONTRIBUTION (MILLION EUR)	NUMBER OF PROJECTS
Stationary heat and power demonstration	- Field demonstration	50.5	6
	- System PoC	16.8	8
	- Improvement of components and their interaction	20.8	10
	- Portable generators, back-up and UPS power systems	13.9	4

The program aims to demonstrate and deploy SOFC and PEMFC combined heat and power (CHP) systems for up to 1000 units in total, with a target to reduce CAPEX to 2000 Euro/kWe for each micro-CHP by year 2020, and around 3000 to 4000 Euro/KWe for large-scale units. The lifetime of stationary fuel cell is expected to reach 40,000 hours.

Figure 3: Europe Callux Program CHP unit

4. Government Support Programs in Asia

The development of Fuel cell technology is also very active in Asia, especially in Japan, Korea, and China. Fuel cell development started early in Chinese Taipei since early 2000, as a result, Chinese Taipei also plays a key role in fuel cell technology development in Asia. However, due to the limitation of small internal market, Chinese Taipei fuel cell companies have to extend their business activities outside of Chinese Taipei, mostly to China.

4.1 Status in Japan

Japan's Ene-Farm program is the most successful and well know fuel cell pre-commercialization demonstration program. In fact, more than 150,000 residential fuel cell combined heat and power (CHP) systems have been deployed in Japan. Participants in the Ene-Farm program are Pasanosic and Toshiba, which offer PEMFC systems, and Aisin and Seiki, which offer SOFC systems. The PEMFC system has achieved 60,000 hours lifetime with daily cycling operation.

Table 6: Ene-Farm Program Unit and Performance Comparison

	TOSHIBA	Panasonic	JX	Aishin
type	PEFC	PEFC	SOFC	SOFC
fuel	city gas / LPG	city gas	city gas / LPG	city gas
Electric power output	250W - 700W	200W - 700W	200W - 700W	50W - 700W
Electrical efficiency	39%	39%	45%	46.5%
Total efficiency	95%	95%	87%	90%
Hot water reserve	60℃, 200L	60℃, 140L	70℃, 90L	70℃, 90L
Operation	Learning control	Learning control	Non stop	Non stop
	life 80,000 hrs			

	PEFC (TOSHIBA)	SOFC (JX)
operational mode	熱主運転 hot water demand driven	電主運転 electrical power output demand driven
	learning control*	continuous operation is mandatory
low electric power demand condition	learning control (stop operation)	generating 200W & wasting power**
Electrical efficiency	39%	45%
Total efficiency	95%	87%
Hot water reserve	60℃, 200L	70℃, 90L do not cover typical hot water demand
Start-up time	> 60 min	10 ~ 16 hours after shut down

*high hot water demand; 24 / 7 operation. low hot water demand; daily start & stop operation

**Reverse power flow from FC to Grid isn't allowed in Japan

Japan showed a great example of large scale demonstration which led the market to grow. The project started in 2005 with a 3,300 units residential fuel cell demonstration with deep government subsidy. In 2009, the Japanese government agreed to support 1.4 million Yen per unit (around 12,700 US dollar), or up to half the unit cost. The Japanese Ene-Farm program is an example model of public-private partnership. Each year, the subsidy was declined per unit, but the total funding budget for the program steadily increase to support more units, resulting the Ene-Farm to improve on cost reduction and durability while market demand also increased. In 2015, the subsidy per unit has declined to about 300,000 Yen (around 2720 US dollar), which is similar to the subsidy of US fuel cell program (cf. $3000/kW). Yet these models initiate the growth of the fuel cell market. Since 2012, the sales of Ene-Farm doubled every year. The budget of Ene-Farm subsidy in 2015 is 22.2 billion Yen. (around 2 billion US dollars). Japan has set a central role for hydrogen economy which includes targets of 1.4 million residential fuel cell units by 2020 and 5.3 million by 2030 (about 10% of Japan's homes). Japan is also exploring hydrogen pipelines to support the Ene-Farm units, to build hybrid and micro-grid systems to transform petroleum economy to hydrogen economy.

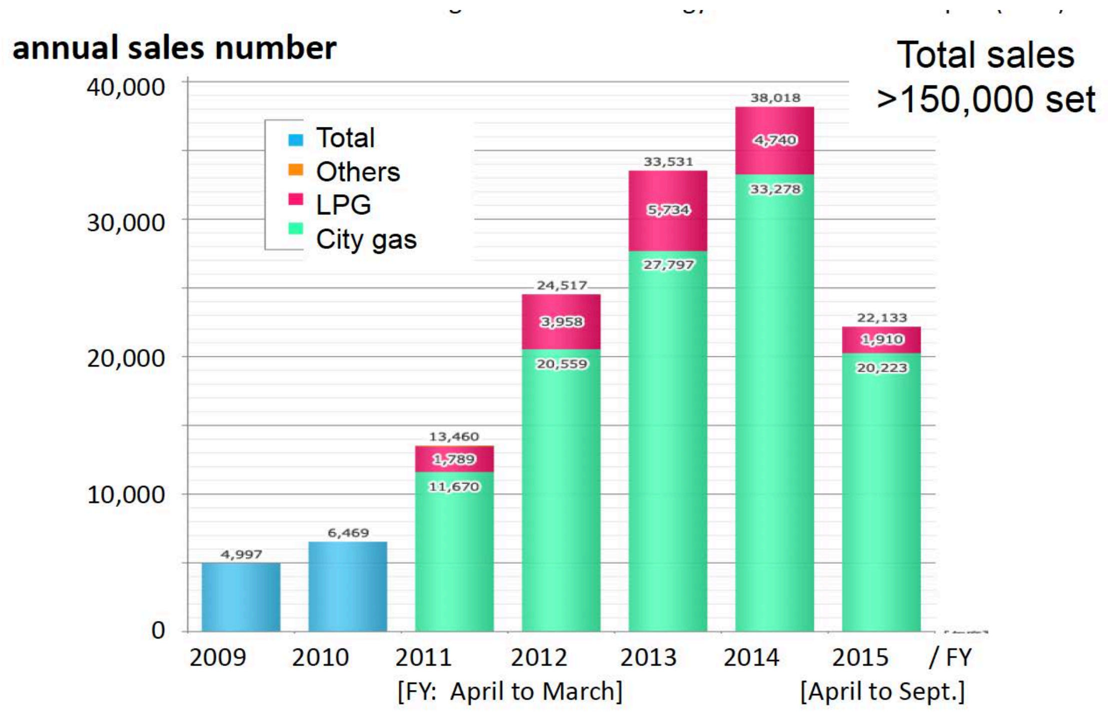


Figure 4: Sales Unit in Ene-Farm Program

Another leading fuel cell activity in Japan is the development fuel cell electric vehicles (FCEV) by Honda and Toyota and the established 81 hydrogen refueling infrastructures. In total, Japanese government set a eager plan to build 100 hydrogen refueling stations (HRSs) and to spend 40 billion Yen (330 million US dollars) by 2020 Tokyo Olympic Grams to build a Hydrogen Village to promote hydrogen economy.

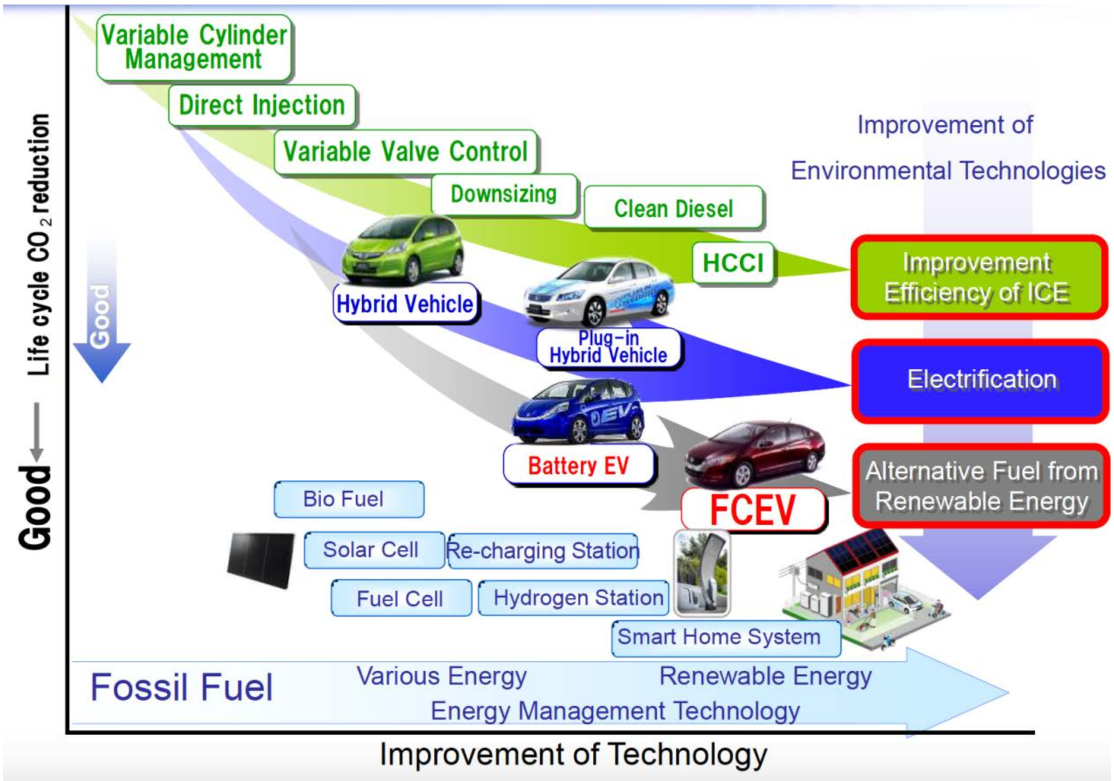


Figure5: Fuel cell Vehicle Development Strategy (Honda)

Tokyo Governor Yoichi Masuzoe wants to use the Olympics as an opportunity to build and showcase new hydrogen infrastructure. "Hydrogen society" is a term that has been used by Japanese Prime Minister Shinzo Abe to describe a more expensive deployment of fuel cells, which aims to powering the buildings and vehicles with hydrogen. At current, Toyota plans to make 700 Mirai fuel cell vehicles with a selling price of 7.23 million Yen (around 65,600 US dollar). By 2017, the production will reach 3,000 cars a year.

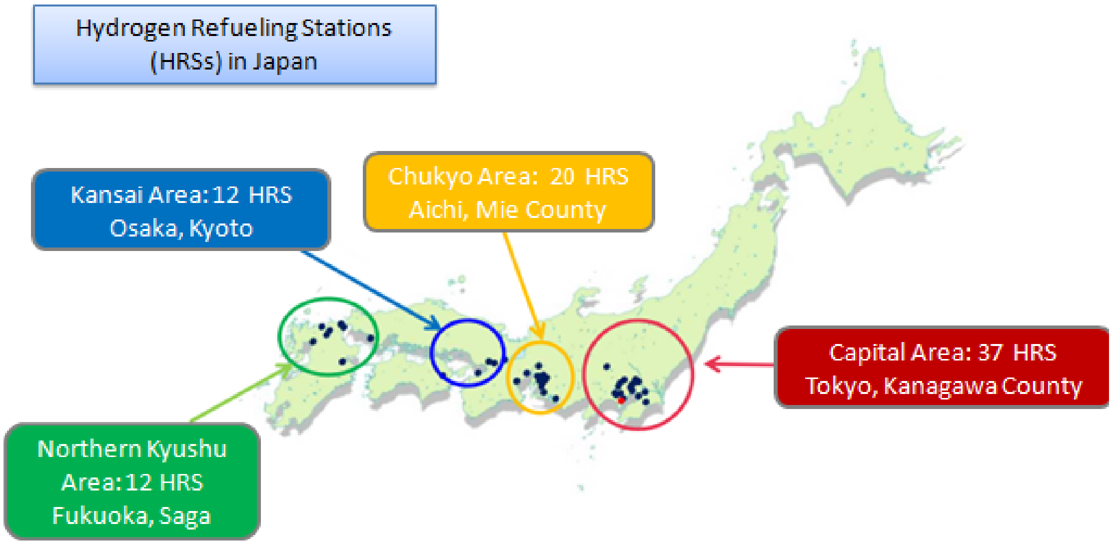
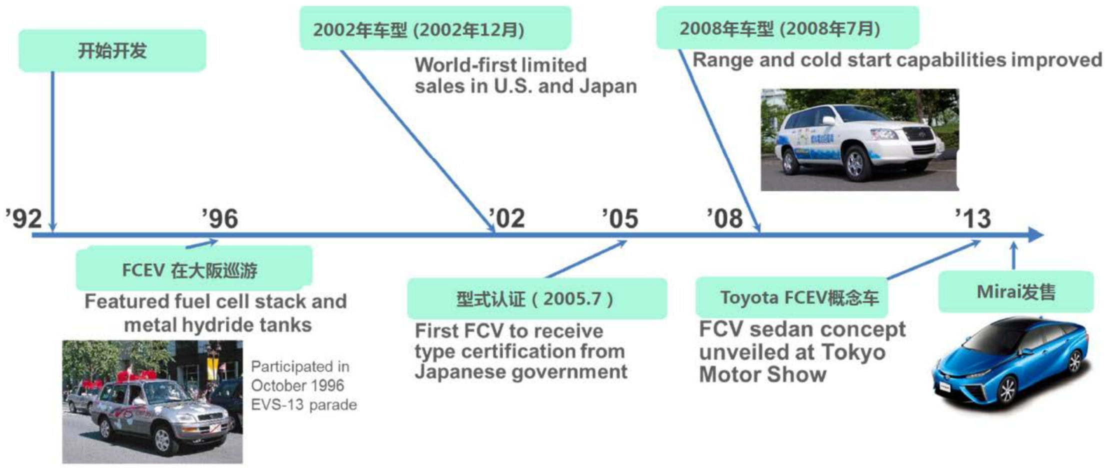


Figure 6: The current status of hydrogen refueling stations installed across Japan**.**

The Japanese government aims to have thousands of fuel cell cars on Japanese roads by 2020, and at least 100 fuel cell buses that primarily serve the Tokyo Olympic Village. They are also considering building a pipeline to supply the Olympic Village with hydrogen, and fuel cells will be used to power certain buildings such as media center and athlete dormitories. Japan is the most promising economy in Asia for fuel cell technology to become widely spread nationwide.



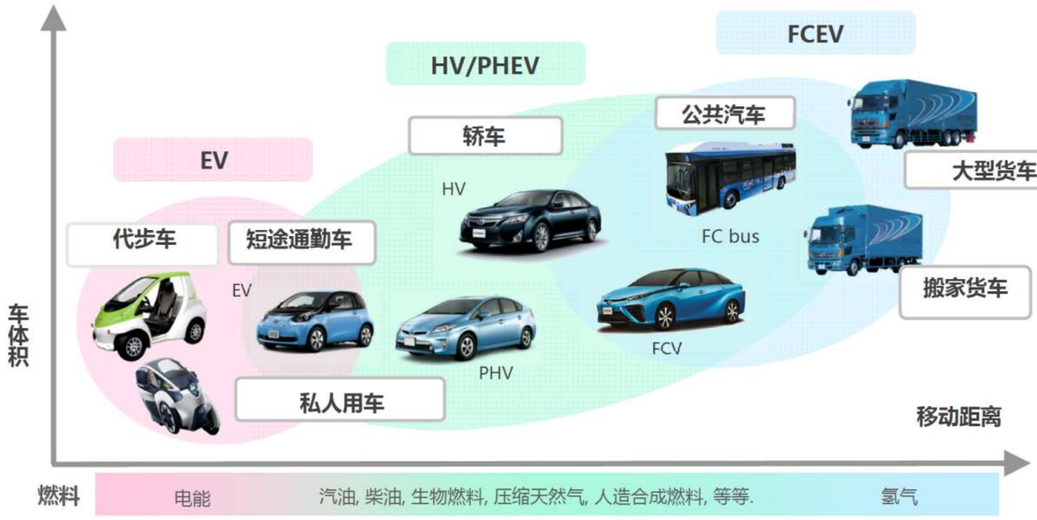


Figure 7: FCV developing Strategy in Tokyo

4.2 Status in Korea

Korea has one of the most supportive government policy for fuel cell in comparison with Japan. There are a number of government programs to increase energy efficiency and new renewable energy, and promote economic growth. Specifically, there is a 80% government subsidies for small stationary fuel cell installations, and up to 10% from local government to support micro-CHP demonstration.

Table 7: Stationary Unit Installation in Korea

Fuel-Cells supply status :A total of 22 places, capacity 123.8MW

No.	Date of Operation (yy.mm)	Installed Place	Capacity
1	'06.11, '13.04	KOSEP(Korea South East Power CO.) / Gyeonggi	3.38MW
2	'08.03	POSCO ICT /Pohang	300KW
3	'08.09	HS ENP / Jeonju	2.4MW
4	'08.09	Natura Power / Gunsan	2.4MW
5	'08.09	KOMIPO(Korea Midland Power CO.) / Boryeong	300KW
6	'08.10	POSCO ENERGY /Pohang	2.4MW
7	'09.05	SH Corporation / Seoul	2.4MW
8	'09.10	MPC Youl Chon Power / Yeosu	4.8MW
9	'09.10	GS EPS / Dangjin	2.4MW
10	'09.10, '13.02	KOSEP(Korea South East Power CO.) / Il-san	5.2MW(2.4MW+2.8MW)
11	'10.01	POSCO POWER / Inchoen	2.4MW
12	'10.05	Byuck San Engineering & Construction / Pusan	1.2MW
13	'10.08	GS Power /An-yang	4.8MW
14	'10.09, '11.06	TCS1 / Deagu	11.2MW(5.6MW*2)
15	'10.10	POSCO ENERGY / Sangam	2.4MW
16	'11.04	KOSEP(Korea South East Power CO.) / Il-san	2.8MW
17	'11.10	The Cobalt sky / Pusan	5.6MW
18	'12.01	MPC Youl Chon Power /Yeosu	5.6MW
19	'12.02	Seoul (For building, Hospital)	100kW
20	'12.02	Seoul (For building, Seoul Children's Grand Park)	100kW
21	'13.08	KOSEP(Korea South East Power CO.) / Ulsan	2.8MW
22	'13.12	Gyeonggi Green Energy / Gyeonggi	58.8MW

Korean president had affirmed his commitment to green growth through the establishment of the Global Green Growth Institute, a base for the development of green technology in the international community in June 2010. The motivation for government intervention in green technology, particularly fuel cells, was to create conditions for future economic growth by establishing a domestic supply chain for green manufacturing and to adopt clean energy technologies in Korea while building a market for future exports. Korean government activities in the area of fuel cells consisted of a mixture of incentives and regulations. Specifically, incentives like generous funding for fuel cell R&D, demonstration and deployment. Regulation like strict rules through the Renewable Portfolio Standard (RPS) set target with 2% energy needed to be new and renewable by 2012.

In 2014, Korean Hydrogen Industry Association (KHIA) was established, which gathered approximately 180 members from academy, research and development centers, and industry in the field of fuel cell and hydrogen to build a strong network. KHIA facilitated strong networking internationally with other fuel cell association, and allow knowledge and idea to gather and exchange. KHIA also hosted international forum, workshop, and symposium in the field of hydrogen and fuel cell.

The subsidy for Korean small stationary fuel cell was between 1 and 2 kW is $34,000/kW in 2012. The target is to install 1 million homes with green energy plan by 2020, including 100,000 fuel cell residential power generators (RPGs).

Figure 8: CHP Unit (Doosan)

The development of fuel cell vehicles is also active in Korea, Hyundai has announced its first production line for fuel cell cars at 1000 units a year. In fact, Hyundai has provided over 1000 fuel cell vehicles, Tucson iX35, to large scale demonstration in Europe and North American since 2014. At current, there are 9 hydrogen refueling stations in service in Korea. In fact, Hyundai has provided the most fuel cell vehicles to demonstrate the new technology to public.

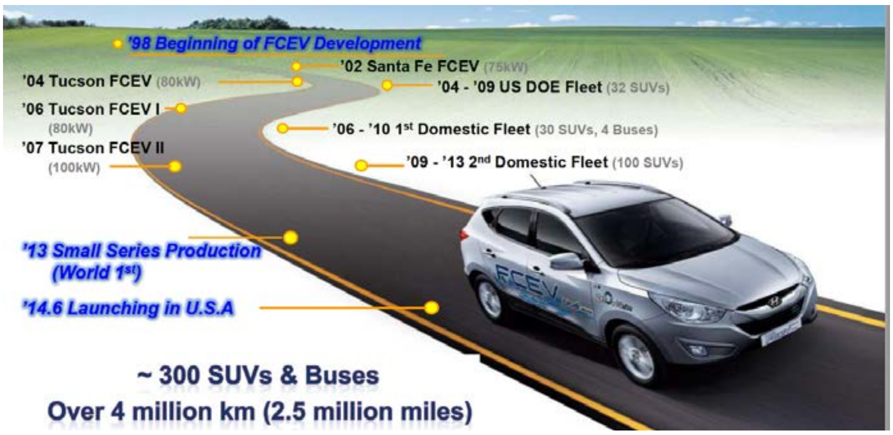


Figure 9: Fuel Cell Vehicle Developing Strategy (Hyndai Motor)

In Korea, due to the strict RPS, utilities over 500MW need to provide at least 2.5% from new and renewable energy, demonstration program in the area large stationary fuel cell generator became critical. Korea has build the largest stationary fuel cell power generators using MCFC (molten carbonate fuel cell) by acquiring technology from Fuel Cell Energy in the USA. LG also bought 51% Rolls-Royces SOFC technology. In 2014, formal ClearEdge was bought by Doosan Group, a Korean company. Doosan Fuel Cell America's technology is a continuity of UTC's phosphoric acid fuel cell (PAFC).

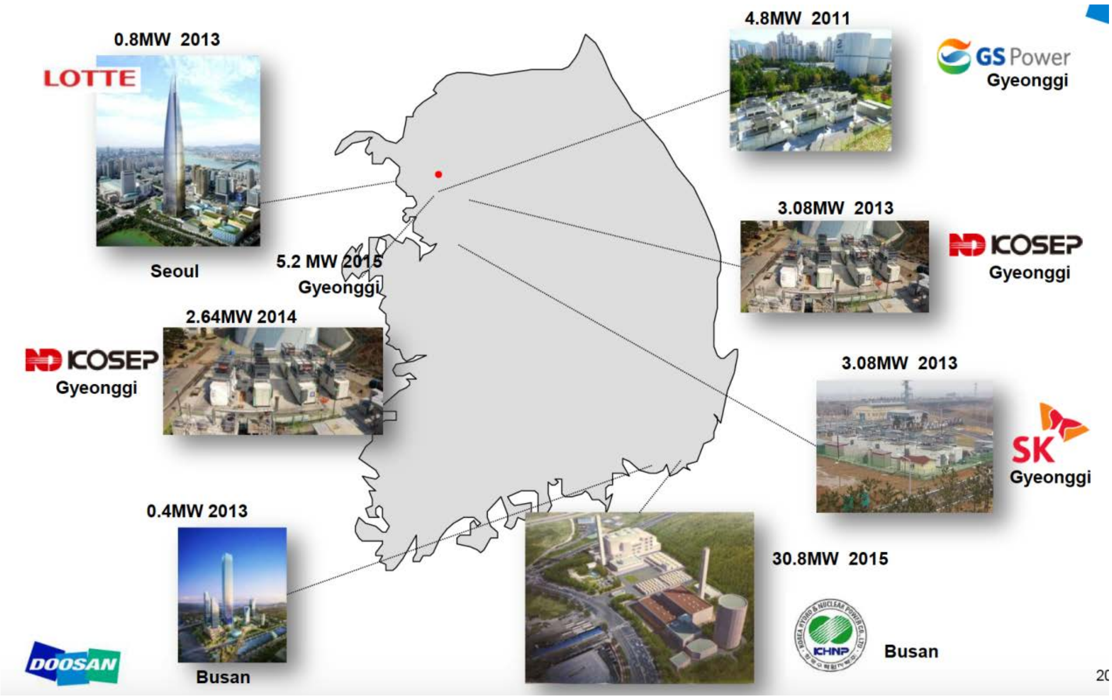


Figure 10: Fuel Cell Stationary in Korea

By forecast, the domestic market for fuel cell in Korea will reach 1450MW by 2020 (8.1% of new and renewable energy, NRE), and 9000 fuel cell vehicles by 2020. Korea will continue their research and development activities on core materials and components.

4.3 Status in China

As economy grows and the demand for transportation rises, bad air quality and smug are very important issues in China. As a result, Chinese government needs solutions such as electric vehicles and hydrogen fuel cell technology to solve the issues. Government has been putting subsidy and R&D funding to support the development of hydrogen and fuel cell technology. Financial support from the Chinese government is strong with fuel cells identified as a key future technology and funded accordingly. Chinese companies throughout the supply chain from catalysts to membranes and system integrators to end users are all driving fuel cell adoption leading China to become an international competitor.

Ministry of Science and Technology (MOST) has launched a R&D program "Fuel cell power system for industrialization" since in June, 2015. The total budget is 69.2 million RMB (around 10.8 million USD), in which government funding is 37.4 million RMB (5.9 million USD).

In the area of pre-commercialization, CRRC Qingdao Sifang Company and Tandshan Railway Vehicle Company, two leading train manufactures in China, signed agreements with Ballard respectively in September and November in 2015, to develop fuel cell powered tram in China. An initial deployment of 8 fuel cell powered trams is planned by CRRC Sifang and the City of Foshan on the Gaoming Line starting in 2017.

Local government of China, the City of Foshan, also announced a deployment plan of approximately 300 fuel cell buses equipped with 90kW HD-7 module through 2016 to 2017. Three hydrogen refueling stations are under plan and design now. The fuel cell technology will be provided from Canadian fuel cell pioneer, Ballard Power System, including technology licensing and a localization of fuel cell module assembly line established in China.

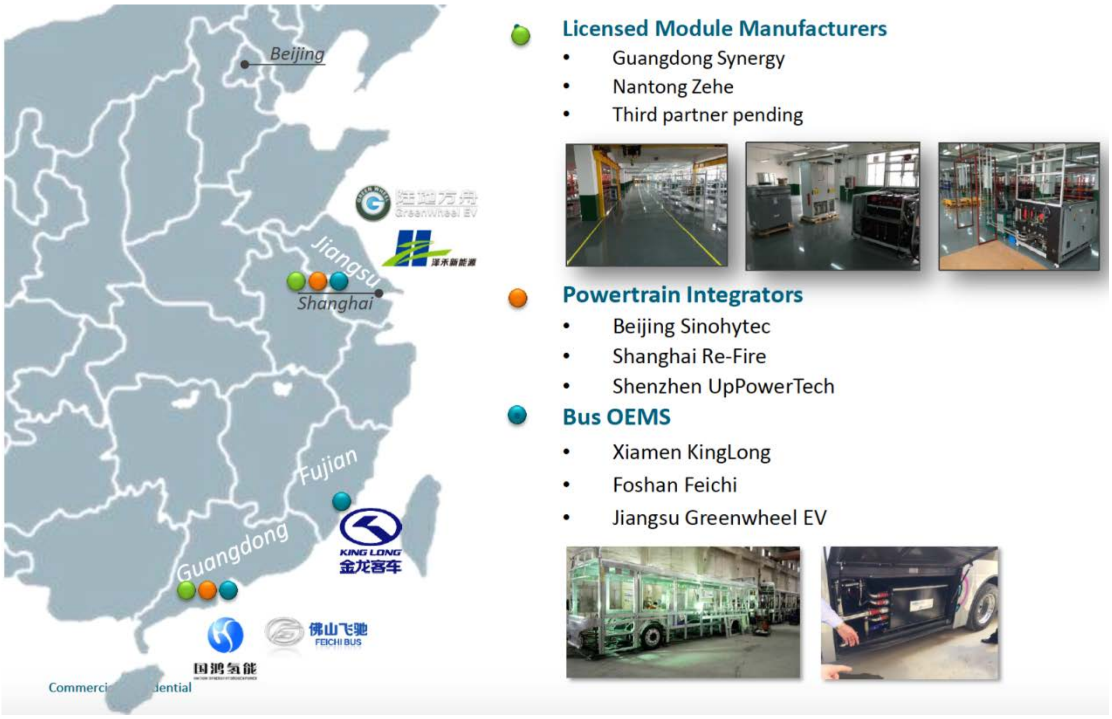


Figure 10: Ballard Power System Technology Partnerships with China OEM maker

The first fuel cell power plant will be installed in the Liaoning province of China. It was reported that Dutch fuel cell technology company Nedstack has signed a contract to deliver a 2 MW PEM fuel cell power plant for Ynnovate Sanzheng (Yingkou) Fine Chemicals Co Ltd in Yingkou, Liaoning Province, China. This chemical facility produces 'waste' hydrogen as a by-product in the chlor-alkali process, which will in future be utilized onsite for the generation of 2 MW of electric power. Nedstack is working with Akzo Nobel Industrial Chemicals and industrial integrator MTSA Technopower in this project, with support from the European Union's Fuel Cells and Hydrogen Joint Undertaking (FCH JU).

The first pilot project of Wind to Hydrogen is carried out in Hebei province. In June 2015, Hebei Construction and Investment Group Co., Ltd signed a €6.4 million contract with McPhy Energy, which will supply a 2 MW Electrolyzer for the recovery of surplus energy generated by a 200 MW wind farm site currently under construction in the Hebei province of China.

4.4 Status in Chinese Taipei

Chinese Taipei's fuel cell development started in 2000. At the six National Science and Technology Conference, a recommendation was made to urge the government to setup guideline and roadmap for fuel cell development in Chinese Taipei. Since 2000, Chinese Taipei has developed a strong, mature and high quality supply chain of experienced manufacturers in the fuel cell sector, including MEA manufacturing, stack assembly, and product and system integration. Chinese Taipei is rapidly moving ahead with demonstration projects nationwide, R&D activities toward cost reduction initiatives, pre-commercialization, and international co-operation efforts.

Currently, Chinese Taipei's fuel cell promotion office is tracking more than 200 demonstration projects across Chinese Taipei involving stationary power, and transportation (vehicle and marine) application, including a large fleet of 80 fuel cell power motor scooters. The economy has invested more than $71 million new Chinese Taipei dollars (around 2.2 million US dollars) in projects so far, and has more than 50 companies involved in the upstream, midstream and downstream hydrogen and fuel cell supply chain. With strong institutional research capability and interest, and a well maturing fuel cell supply chain, arising in part from the flexibility and high tech manufacturing experience of an SME dominated business culture, Chinese Taipei has some nimbleness advantages in comparison to Korea and Japan. The fuel cell companies in Chinese Taipei are often SMEs with flexibility. Although these SMEs do not have much resources, they often response to innovation and market demand much more quickly, and are willing to cooperate with international partners.

	Chung Hsin Electric & Machinery	Toplus Energy	M-Field	Kaori
				
ISC	CE, AMSI/CSA FC-1 Telcordia GR-63-CORE seismic Zone4	ISO 9001:2008 ITRI TAF ukac-MRA UL	CSA, UL	UL
Fuel Source	Methanol	Hydrogen	Hydrogen, Sodium Borohydride	Methanol, Natural Gas

Figure 11: Chinese Taipei Fuel Cell Backup Power System Maker

Although the fundings from Chinese Taipei government is limited, the companies form Chinese Taipei have strong experience in integrating mechanical and electrical products, these resources helps the fuel cell companies to absorb the required knowledge integrate fuel cell system in a shorter time frame. Demonstration projects in Chinese Taipei are often small but unique, including fuel cell scooters and forklifts, fuel cell powered boat, fuel cell CHP and backup power, portable power, etc. Technologies in the R&D are focused on PEMFC, SOFC, and DMFC.

Figure 12: DMFC Portable Power (Chinese Taipei ITRI)

In summary, the current world market of fuel cell is distributed in three regions, among Asia, North American, and Europe. In figure 4, it clearly shows the major market is in Asia, with strong government supporting programs and incentives from Japan, Korea, and China. The next big pie is in North America with the government of USA giving tax credit for enterprises adopting fuel cell technology.

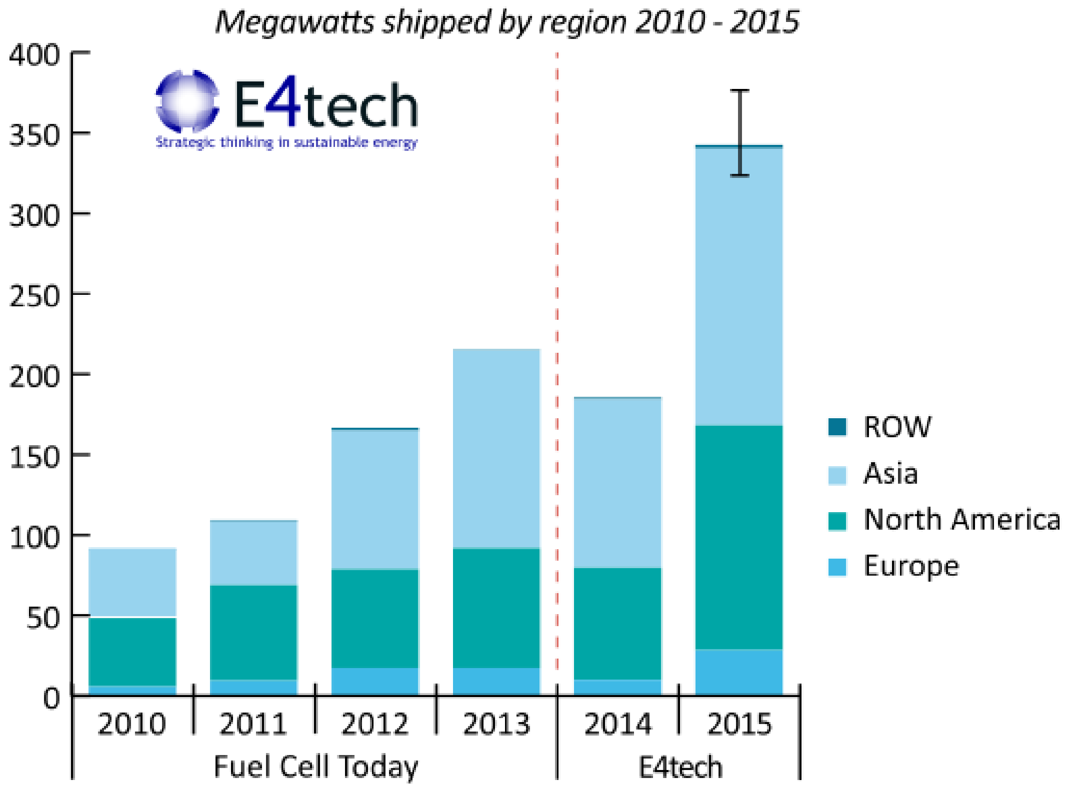


Figure 13: World fuel cell market distribution by shipment of power (megawatt)

5. Fuel Cell Market Analysis by Applications

Fuel cell market is segmented into three major applications, namely transportation, stationary, and portable. Transportation includes automotive and special vehicle like material handling, post service delivery, etc. Stationary includes distributed power generation, and backup power, and combined heat and power (CHP), etc. Portable power includes small power charger and high mobility power generator like APU (auxiliary power unit).

Table 8: Example and definition of fuel cell by applications.

Application type	Portable	Stationary	Transport
Definition	Units that are built into, or charge up, products that are designed to be moved, including auxiliary power units (APU)	Units that provide electricity (and sometimes heat) but are not designed to be moved	Units that provide propulsive power or range extension to a vehicle
Typical power range	1 W to 20 kW	0.5 kW to 400 kW	1 kW to 100 kW
Typical technology	PEMFC DMFC	PEMFC SOFC MCFC PAFC AFC	PEMFC DMFC
Examples	• Non-motive APU (campervans, boats, lighting) • Military applications (portable soldier-borne power, skid mounted generators) • Portable products (torches, battery chargers), small personal electronics (mp3 player, cameras)	• Large stationary combined heat and power (CHP) • Small stationary micro-CHP • Uninterruptible power supplies (UPS)	• Materials handling vehicles • Fuel cell electric vehicles (FCEV) • Trucks and buses

5.1 Transportation Market

Light duty passenger vehicles will be the promising and exciting category in the transportation market, yet, the deployment of fuel cell buses are actively rolling out. Buses usually have a routine route and can gain more public awareness of the new technology, as a result, should be the first niche market in the transportation application. The deployment of fuel cell passenger vehicles is limited by two factors: high capital cost and fueling infrastructures. Toyota has announced to build 350 to 700 fuel cell passenger vehicles - Mirai, with a target to build 3000 in 2017, and 30000 in 2020, with a growth rate of 300% annually. Honda rolled out its fuel cell vehicles to local government and businesses in Japan, and later will also deploy some to California and European nations. Hyundai already produced its first generation fuel cell vehicles - iX35 and is developing its next generation aiming for 500 miles per fueling cycle.

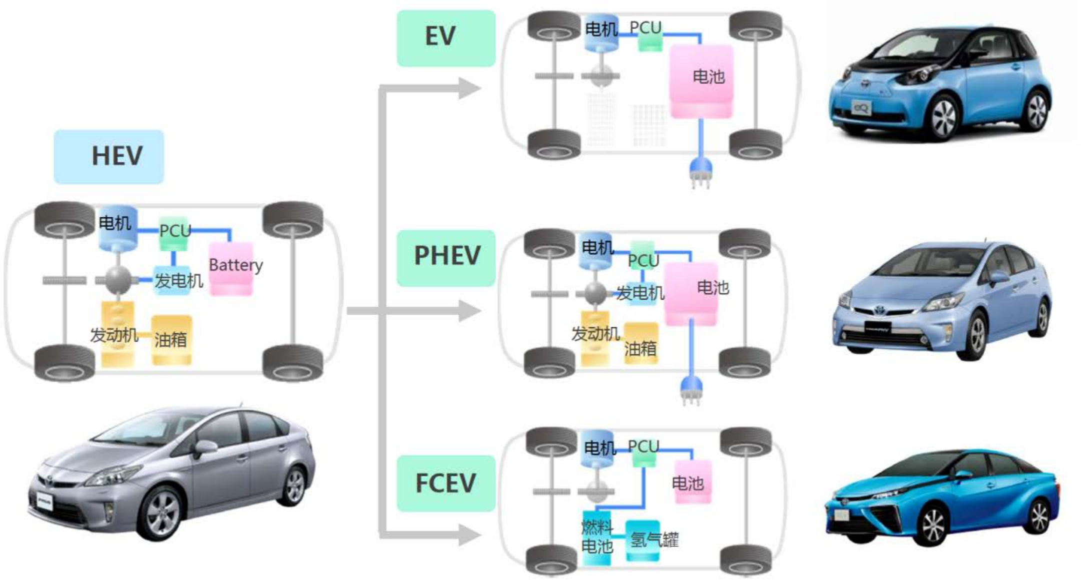


Figure 14: EV, PHEV, and FCEV Comparison

In the application of fuel cell buses, Europe will contribute about 100 buses, and there will be 300 fuel cell buses being deployed in China. In the USA, Hydrogen fuel cell technology for buses is a good range extender solution. It helps the electric bus to have more power by hybridizing both fuel cell and batteries during acceleration. Typically, when batteries are deeply discharged, the lifetime shortens, so fuel cell can aid the performance of the battery as range extender and also protect the batteries of the electric buses.

Forklifts and special vehicles are also promising market for fuel cell application to replace battery-run forklift. Plug Power has dominated the market of fuel cell forklift by annually manufacturing around 4000 fuel cell power modules. The followers such as Nuvera and H2Logic were bought by NACCO Materials Handling Group (Hyster-Yale) and M-Field shows the potential growth of the fuel cell forklift sector. HyPulsion in Europe is currently 100% owned by Plug Power shows its determination to enter the European market. With demonstration projects in HyLift and HAWL of European FCH JU program, the fuel cell forklift power module business seems an early niche market with the potential to become sustainable business without government subsidy.

5.2 Stationary Market

Stationary fuel cells are mainly large hundreds of kW to MW distributed power generators, small 1kW micro-CHP for residential use, and around 5kW size for backup or off-grid power application.

World shipments of small 5kW fuel cell for backup and off-grid applications continue to be the main deployment into the more exotic markets such as India, South East Asia, China, the Middle East and Africa where grid power is not stable. Micro-CHP fuel cell market is the major dominant of stationary application. The Ene-Farm program in Japan provides the markets for Panasonic, Toshiba, and Aisin, with a growth rate of 20% in 2015; and the accumulated installation has reached 140,000 units. In Europe, similar micro-CHP program - Ene.Field, also contributes to the market of stationary application.

Large scale stationary fuel cells of the 100kW to MW scale are dominating the stationary application sector by power output size. Fuel Cell Energy has provided its MCFC technology to POSCO Energy in Korea, built about 270 MW fuel cell power generators in Korea, which is the largest stationary fuel cell project worldwide. Another Korean company, Doosan, has acquired ClearEdge and UTC's PAFC technology and building fuel cell generators in Korea. On the other side of the world, Bloom Energy is doing well by shipping hundreds of 100kW SOFC to its neighbors like Yahoo, Microsoft, Google, etc to take the advantage of government subsidy.

5.3 Portable Market

In the portable application, fuel cell shipments reached thousands of units, but the power output size is small. Starting from 5 W fuel cell chargers like Horizon in Singapore and Intelligent Energy in UK, the chargers provide power in case of emergency and extend the battery power of electronic devices. More significant application is the 50 to 100 W auxiliary power units used for leisure or off-grid application, like construction sites, sensors in transport, and oil and gas infrastructures. These applications have a market growth potential due to higher added value of power use. Lastly, there is also military applications includes the power output from 10W to several hundred Watts. Protonex is the star in the military application using fuel cell technology. Due to the needs of ever increasing small scale power electronics, the portable market is a potential niche. Often, military will assist with the development of products it wants. Take the case of US Department of Defense (DoD), which has supported many projects and prototypes in many US-based businesses. Companies beside Protonex, such as Acumentrics and UltraCell in the USA, and SFC in Germany, had sold fuel cell chargers for soldier power battery packs and power for small equipment such as communications and sensors.

In summary, the following table reported by Fuel Cell Today and E4tech shows the recently growth of fuel cell market by three different applications. Stationary and portable continue to take the big pie, while transportation will soon catch up with the mass deployment of fuel cell cars, buses, and material handling vehicles. In Table 8, a summary of fuel cell market with reporting number based on power output is shown in comparison to table 7. A calculation on average fuel cell power output by different applications in each year is shown in table 9. The big jump in 2015 of transportation application indicates the deployment of fuel cell cars.

Table 8: A summary of fuel cell shipment units worldwide by different applications.

Shipments by application						
	Fuel Cell Today				E4tech	
1,000 Units	2010	2011	2012	2013	2014	2015
Portable	6.8	6.9	18.9	13.0	21.2	17.6
Stationary	8.3	16.1	24.1	51.8	39.5	49.0
Transport	2.6	1.6	2.7	2.0	2.9	4.9
Total	**17.7**	**24.6**	**45.7**	**66.8**	**63.6**	**71.5**

Table 9: A summary of fuel cell shipment power output worldwide by different applications.

Megawatts by application						
	Fuel Cell Today				E4tech	
Megawatts	2010	2011	2012	2013	2014	2015
Portable	0.4	0.4	0.5	0.3	0.4	0.7
Stationary	35.0	81.4	124.9	186.9	147.8	203.2
Transport	55.8	27.6	41.3	28.1	37.2	138.7
Total	**91.2**	**109.4**	**166.7**	**215.3**	**185.4**	**342.6**

Table 10: A table of summary showing the average power output by different application in each year.

Average Fuel Cell Output Power by Different Application						
	2010	2011	2012	2013	2014	2015
Portable	58 W	58 W	26	23 W	18 W	40 W
Stationary	4.126 kW	5.055 kW	5.182 kW	3.608 kW	3.741 kW	4.142 kW
Transportation	21.461 kW	17.250 kW	15.296 kW	14.05 kW	12.827 kW	28.306 kW

6. Hydrogen Refueling Infrastructure

Global wide, based on the public data from North America, Europe, and Asia, the number of hydrogen refueling stations (HRSs) will approach to 200 by 2016. Japan is leading the way with a goal to establish 100 HRSs by the end of 2015. Right now, Japan already had 81 HRS. In California, USA, it has a plan to build 58 HRS, and there will be about 50 HRS in Germany. Toyota has further pledged financial support for 10 to 12 HRS in the Northeaster US to expand the market option. In Korea, there are about 13 HRS in operation and 10 more will be built by 2020. The ''Hydrogen Mobility Europe' project announced in September 2015 planning to bring 29 operational HRS in ten economies by 2019. Scandinavia has 9 operation stations and one under construction. UK will have 5 public stations soon by onsite water electrolysis from ITM. At present, typical HRSs can refuel 50 kg hydrogen per day, with a target to provide up to 200 kg hydrogen per day, which can provide fuel up to 50 cars a day.

In the early stage, the operation of HRSs requires fuel cell passenger cars. Since the stations have been built, it is now for the fuel cell vehicle manufacturers to provide enough cars to the market to bring up the demand of hydrogen refueling service in order to keep the financing balanced. In Japan, the price of hydrogen has been set to be about 1000 Yen per kilogram of hydrogen, which is equivalent to 9 US dollar/kg H_2. In Europe, FCH JU supported demonstration program shows the OPEX of a HRS can be 5.6 Euro/kg H_2, with a CAPEX less than 1 million Euro at a design targeting 200kg/day. The retail price of hydrogen at pump is about 8 to 9 Euro/kg H_2.

Part B Novel Direct Flow Fuel Cell Economical Analysis

1. INTRODUCTION

The world energy demand is growing at a rate of 1.8% per year. Both developed and developing economies are faced with the big challenges of energy security and environmental problems. Today, fossil fuels still dominate the energy market, accounting for over 80% of global energy consumption. Biomass is all biologically-produced matter based in carbon, hydrogen and oxygen. The estimated biomass production in the world is 104.9 petagrams ($104.9 * 10^{15}$ g - about 105 billion metric tons) of carbon per year, about half in the ocean and half on land[3]. Biomass energy is a kind of important sustainable energy sources, which is called “Zero Carbon Energy”. Therefore, production of electricity to power from biomass can reduce the dependence on fossil fuels.

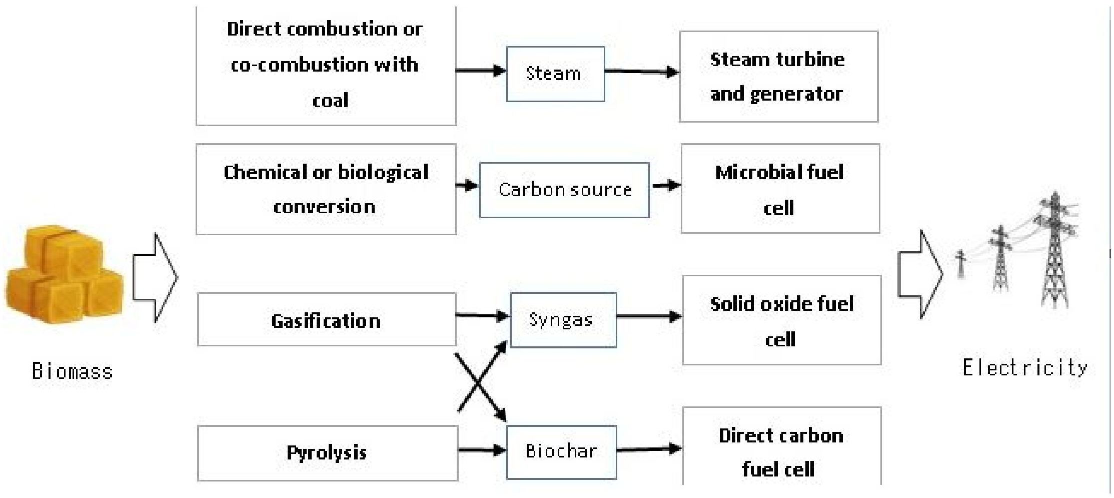


Fig. 1 Different pathways for electricity production from biomass

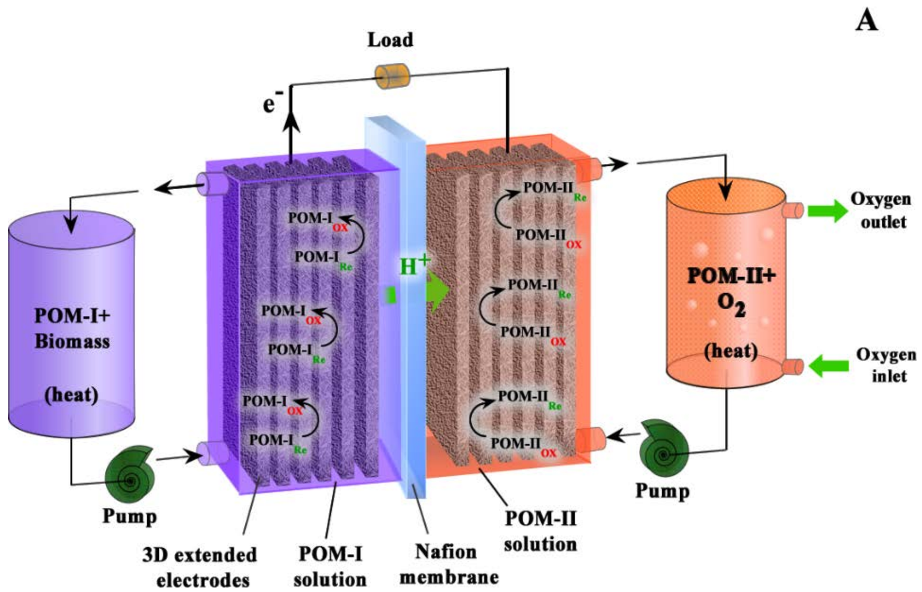
General speaking, combustion, gasification, solid oxide fuel cell (SOFC), microbial fuel cell (MFC) ,and direct carbon fuel cell (DCFC) are technologies using biomass as feedstock to generate electricity (Fig. 1). These technologies have their own advantages and disadvantages naturally. Electricity generation from biomass has already been in commercial practice using combustion or gasification together with a steam turbine. However, distributed operation at relatively small scale is preferred due to the low energy density of biomass. Air pollution is another problem should be concern here. Biomass-energized fuel cells can be classified into two groups: indirect biomass fuel cell and direct biomass fuel cell. Indirect biomass fuel cell, which has been intensively studies in recent years, refers to converting biomass to various fuel sources such as sugars (e.g., glucose and xylose), syngas, biogas, or biochar, followed by generating electricity in fuel cells. However, those technologies have a number of disadvantages. SOFCs can require very high working temperatures (e.g., 500°Cto 1000°C) to gassify biomass. MFCs can work at low temperatures, but very low electric power output, rigorous reaction conditions, and limited lifetime can seriously hinder their applications.

The polymer exchange membrane fuel cell (PEMFC) is another most promising fuel cell technology. Although highly effective PEMFCs powered by hydrogen or low molecular weight alcohols have been successfully commercialized, polymeric biomass such as starch, lignin, and cellulose have not been directly used in PEMFC because the C-C bonds cannot be completely electro-oxidized to CO_2 at low temperatures with a noble metal catalyst. Even for the simplest C-C molecules such as ethanol, it was reported that the fuel could only be converted to acetaldehyde ($-2e^-$) or acetic acid ($-4e^-$) with a noble metal anode, suggesting that only 16.7% and 33.3% of the total 12 electrons can be actually converted to electric power. Therefore, cleavage of C-C bonds in biomass fuels is a major challenge in developing high efficiency PEMFCs. Furthermore, it is well known that noble metals like Pt, Au, Ru etc., are easily poisoned by impurities in the biomass. Accordingly, improved methods and apparatuses to, for instance, produce electricity from sustainable energy sources are desirable.

The liquid catalyst fuel cell (FFC) is a new technology that uses biomass directly to generate electricity. FFC can directly convert polymeric natural biomass, such as trees, grasses, agricultural residue, algae, and other biological material, to electricity. At ideal conditions, the natural biomass could be directly used as the fuel in fuel cells without purification or chemical pretreatment. There are several major breakthroughs in our technology: a) use raw biomasses directly (no purification is needed); b) high power density (comparable to pure alcohol fuel cell, and 3,000 times higher than microbial cellulose based fuel cells); c) completely noble-metal-free; d) The catalyst is extremely stable which will not be contaminated; e) fuel cells are extremely low cost (using raw biomasses and no noble metal); f) can be used in both small power unit as well as large power plant; g) completely sustainable.

2. Principles of FFC

FFC developed in our previous study is completely noble metal free. Two polyoxometalate (POM) solutions with different redox potentials are utilized in this fuel cell: one oxidizes biomass either under sunlight or heating in an anode tank and the other reacts with the oxygen at the cathode. The cell is schematically shown in Figure 2. It is constructed using a Nafion 115 membrane sandwiched between two 3D graphite electrodes with no metal loading. The POM-**I** ($H_3PW_{11}MoO_{40}$) solution, along with the biomass, is stored in the anode electrolyte tank. The oxidation of biomass fuel occurred in the anode electrolyte solution under either sunlight irradiation or directly heating. The reduced POM solution cyclically flows through the anode by a pump. As shown on the right side of Figure 2A, a non-keggin-type $H_{12}P_3Mo_{18}V_7O_{85}$ aqueous solution (noted as POM-**II**) is stored in the cathode tank. The regeneration of POM-**II** is realized by redox oxidation of oxygen in an oxygen-mixing tank.



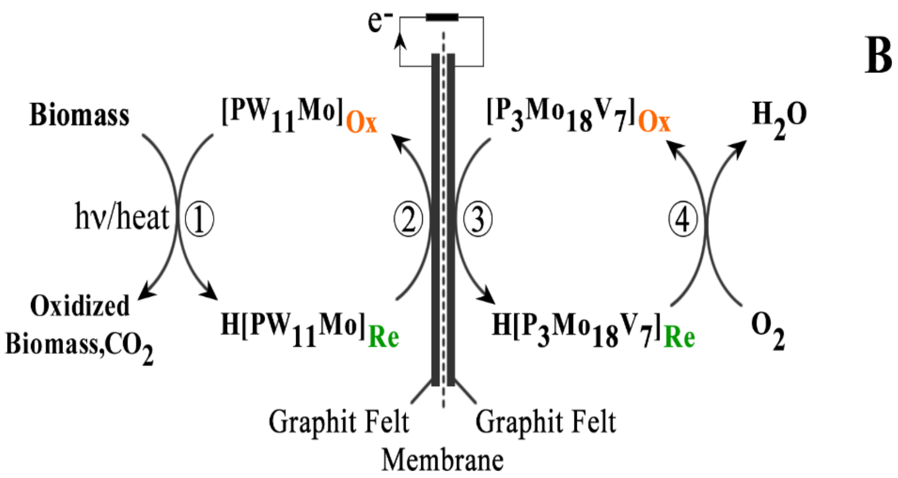


Figure 2.(A) Schematic illustration of direct biomass fuel cell coupled with biomass-POM-I solution anode tank and POM-II-oxygen cathode tank. (B) General pathway of redox reactions in this fuel cell. The subscript Re refers to the reduced form of POM and Ox refers to the oxidation state of POM.

The above novel fuel cell is designed based on the principle that polyoxometalates are very effective photo- or heat- catalyst. The general principle of our solar-induced fuel cell is that PMo_{12} can oxidize biomass or biowaste under solar irradiation while being reduced from Mo^{6+} to Mo^{5+}, and then Mo^{5+} can be oxidized to Mo^{6+} again by vanadium-containing POM through a catalytic electrochemical reaction. Then, the vanadium-containing POM can be regenerated by oxygen without any noble-metal catalyst, as illustrated in Figure 2B.

The PMo_{12} has the well-known Keggin structure consisting of a central tetrahedral [PO_4] surrounded by twelve [MoO_6] octahedrons which are photo-sensitive[22]. Under short wavelength light irradiation, the commonly known O→Mo ligand-to-metal charge transfer (O→M LMCT) occurs, which means the 2p electron in the oxygen of [MoO_6] is excited to the empty d orbital in Mo, changing the electron configurations of Mo from d^0 to d^1, and leaving a hole at the oxygen atom of the POM lattice. This hole interacts with one electron on the oxygen atom of a hydroxyl group of starch. Meanwhile, the hydrogen atom of the hydroxyl group shifts to the POM lattice to interact with the d^1 electron, which is a thermally activated delocalization within the polyanion molecule. Thus, the intermolecular charge transfer (CT) complex is formed, leading to the separation of photo-excited electrons and holes and thus stabilizing the reduced state of PMo_{12}.

It should be noted that although one Mo is reduced from VI to V valence by forming a biomass-POM complex, the total charge of the polyanion (-$[HPMo^{VI}_{11}Mo^{V}O_{40}]^{3-}$) will not change because a proton is also transferred from starch to the POM complex at the same time. Because the standard redox potential of vanadium-containing POM (~1.1 V, vs. Normal Hydrogen Electrode, NHE) is higher than that of the reduced POM (~0.4 V, Vs. NHE), the Mo^{5+} in the reduced PMo_{12} can be oxidized at the anode by connecting to the cathode through an external circuit to produce electricity. As a result, the reduced polyoxometalate (Mo^{5+}) gives one electron to the carbon anode and simultaneously releases a proton to the solution. The electron passes through the external circuit and is captured by vandium-containing POM at the cathode. Simultaneously, the vanadium-containing POM is regenerated by oxidation of oxygen via a spontaneous reaction. During the series of chemical reactions, the biowaste molecules associated with PMo_{12} are released into solution. The net effect of the above reaction is that Mo^{5+} is oxidized back to Mo^{6+} at the anode, and the starch is oxidized through dehydrogenation by POM catalysis. Finally, the proton diffuses to the cathode side through the proton exchange membrane. The entire discharge process is represented by reactions (1) ~ (3).

$$\text{Biomass-O-}[HPMo^{VI}_{11}Mo^{V}O_{40}]^{3-} + [HPMo^{VI}_{11}\,Mo^{V}O_{40}]^{3-} \xrightarrow{anode} 2[PMo^{VI}_{12}O_{40}]^{3-} + \text{Oxidized biomass oligmers} + 2e^{-} + 2H^{+} \quad (1)$$

$$\text{Andode: Starch-O-}[HPMo^{VI}_{11}Mo^{V}O_{40}]^{3-} + [HPMo^{VI}_{11}\,Mo^{V}O_{40}]^{3-} \xrightarrow{anode} 2[PMo^{VI}_{12}O_{40}]^{3-} + \text{Oxidized starch oligmers} + 2e^{-} + 2H^{+} (2)$$

$$\text{Cathode: } 1/2\ O_2 + 2e^{-} + 2H^{+} \xrightarrow{cathode} H_2O \quad (3)$$

The FFC designed in our previous study is a combination of solar cells, fuel cells, and redox flow batteries, but has distinct differences from each. For a traditional solar cell, light energy is converted to electricity directly via the photovoltaic effect when the semiconductor or dye on the semiconductor is exposed to light. However, for our fuel cell, short-wave light excites POMs to the excited state in the presence of biomass and is stored in the form of the reduced POMs (i.e., chemical energy) via the photochromic reaction. Moreover, visible and near-infrared lights are absorbed by the solution and converted to heat, which can also promote the redox reaction between biomass and POM. The cell reported in this study also has a similar feature to redox flow batteries_ENREF_37 in that electrolyte solution with different valence states are used in the electrode cells. It is still different from redox flow batteries because organic fuel is consumed in our fuel cell but no organic fuel is used in a traditional redox flow battery. The overall reaction, as discussed above, is the oxidation of organic biomass by oxygen, which is the fundamental basis of traditional fuel cells but not redox flow batteries. However, this cell is different from a traditional fuel cell where catalytic reactions happen on the precious metal loaded anode. The POM functions as a photo and thermal catalyst and charge carrier, which takes electrons from biomass while reducing its own valence state to Mo^{5+} under light irradiation and thermal degradation. The electrons in the POM are then transferred through the external circuit and the POM reverts to its original Mo^{6+} valence state.

3. Performance of FFC

The performances of fuel cell powered by various biomasses are shown in Fig3. Experimentally, 0.3mol/L POM-I solution was mixed with in the anode tank and 0.3mol/L POM-II solution was filled in the cathode tank. As shown in Fig.3, the power densities were 22 and 34mW/cm^2 respectively when cellulose and starch were used as fuels. Dry switch grass powder and freshly collected plants (bush allamanda) were also used as fuels. The power densities even reached 43 and 51mW/cm2 respectively, which are close to noble metal catalyzed alcohol fuel cell reported in literature. The continueous operation of starch directly fueled cell was also conducted under constant discharge current of 100mA/cm^2, 80mA/cm^2 and 40mA/cm^2, as shown in Fig. 4. The starch-POM-I solution was preheated to 100C to ensure thermals reduction of POM-I before the discharge test. For the cathode, POM-II was oxidatively regenerated by mixing with O2 in the cathode tank. A homogenizer was used to enhance gas-liquid mixing. The cell worked continuously for more than 40hours under 100C and the powder density was stabilized at 30mW/cm^2 with the discharge current of 80mA/cm^2, which suggests both POM-I and POM-II are re-generable under this experimental condition, and the biomass fuel cell can continuously provide electricity by directly consuming starch.

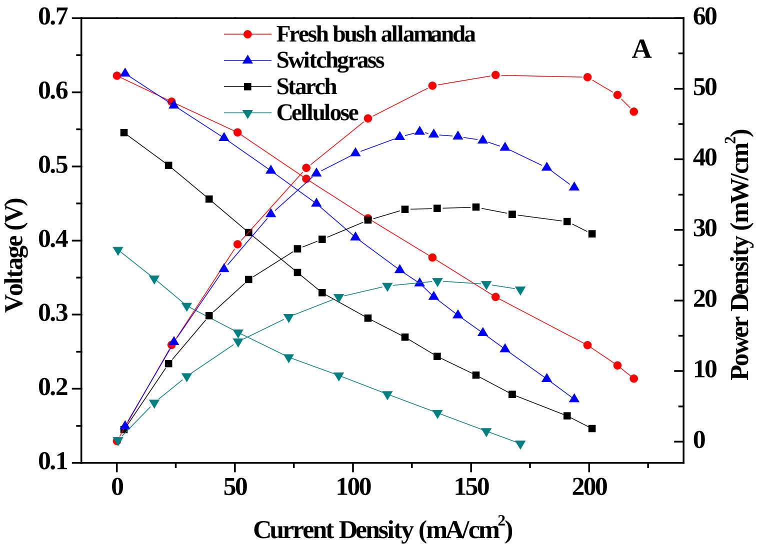


Fig.3. Voltage-current density and power-current density curves for different biomasses at 80C.The initial reduction degree of POM-II was 1.4 for all biomass-POM solutions.

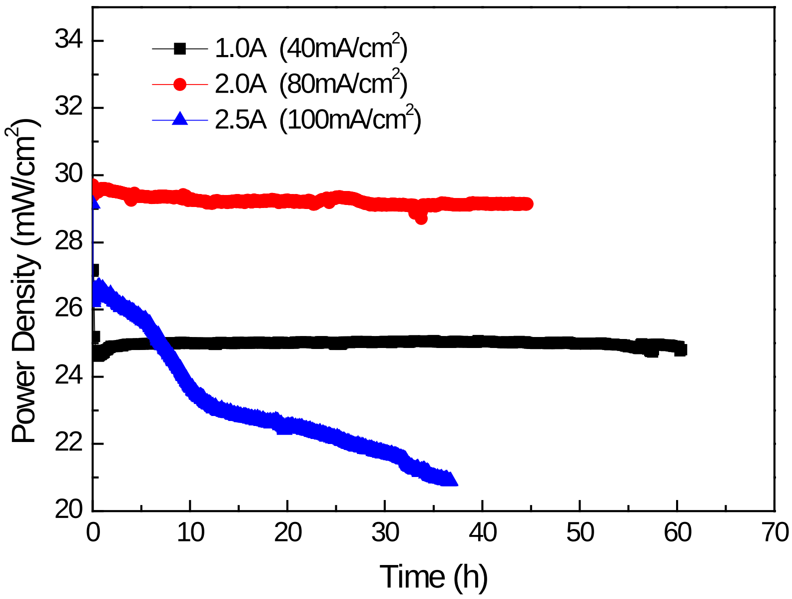


Fig.4. Power density curve in continuous operation of this direct biomass flow fuel cell at 100C. Anode is 500ml starch-POM-I solution with POM-I concentration 0.3mol/L; cathode is 1500ml is 1 Na substituted POM-II solution with concentration of 0.3 mol/L.

4. Economical Analysis of FFC

4.1 System Design Concept

Based on the single cell testing result, a basic 1kW stack module can be achieved by following specification design. As shown in the table, a 1kW single stack will be a basic power generator unit and two stack with share balance of plant components will be a single power unit design. The power unit can increase the stack module to large kW system depends on future BoP components.

Specification Design	Unit	Value
Single Cell Performance		
Open Circuit Voltage	V	0.6
Single Cell Nominal Voltage	V	0.3
Protection Voltage	V	0.1
Nominal Current Density	mA/cm^2	150
Maximum Current	mA/cm^2	300
Rated Power	mW/cm^2	45
Stack Module Performance		
Cell Number	Cells	32
Cell Active Area	cm^2	700
Stack OCV	V	19.2
Rated Voltage	V	9.6
Protection Voltage	V	3.2
Rated Current	A	105
Maximum Current	A	210
Rated Power	W	1008
Single Module Performance		
Module	stacks	2
Module OCV	V	38.4
Rated Voltage	V	19.2
Protection Voltage	V	6.4
Rated Current	A	105
Maximum Current	A	210
Module Power	W	2016

A bottom-up cost structure analysis was developed to review the power unit design. The analysis examined the capital costs of DFFC system. As state of art and above specification concept design we pick up a 2kW power unit as a standard manufacturing module as an first approach and assume it has 2000 power units be produced in a year. A list of materials, components, and manufactured components is developed for the technology.

4.2 Capital Cost Analysis

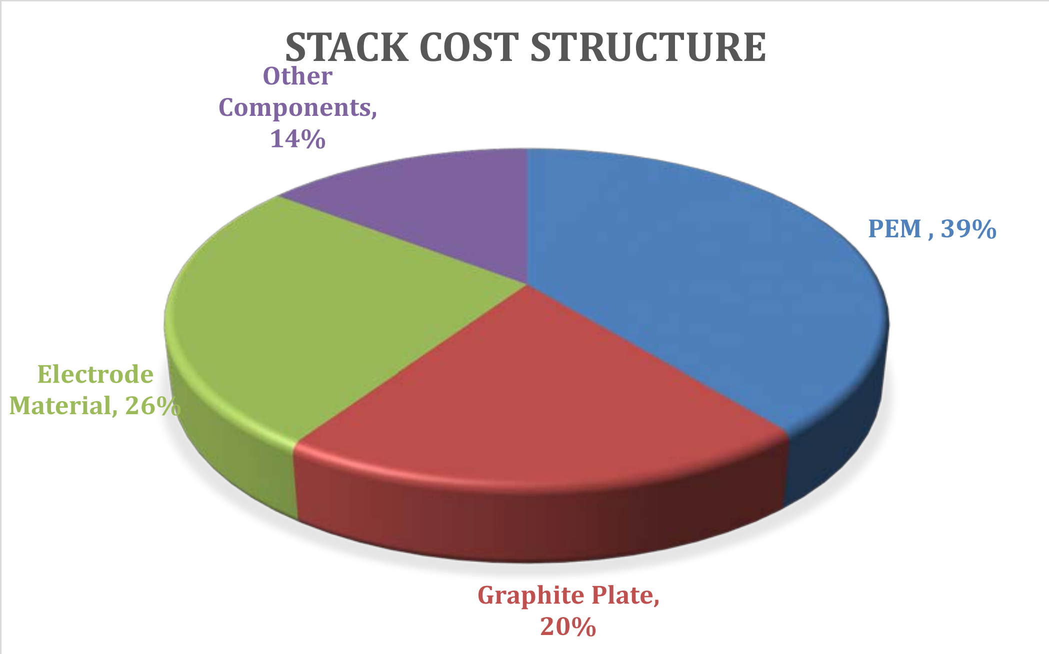
Capital Cost for DFFC Stack consist of following major components

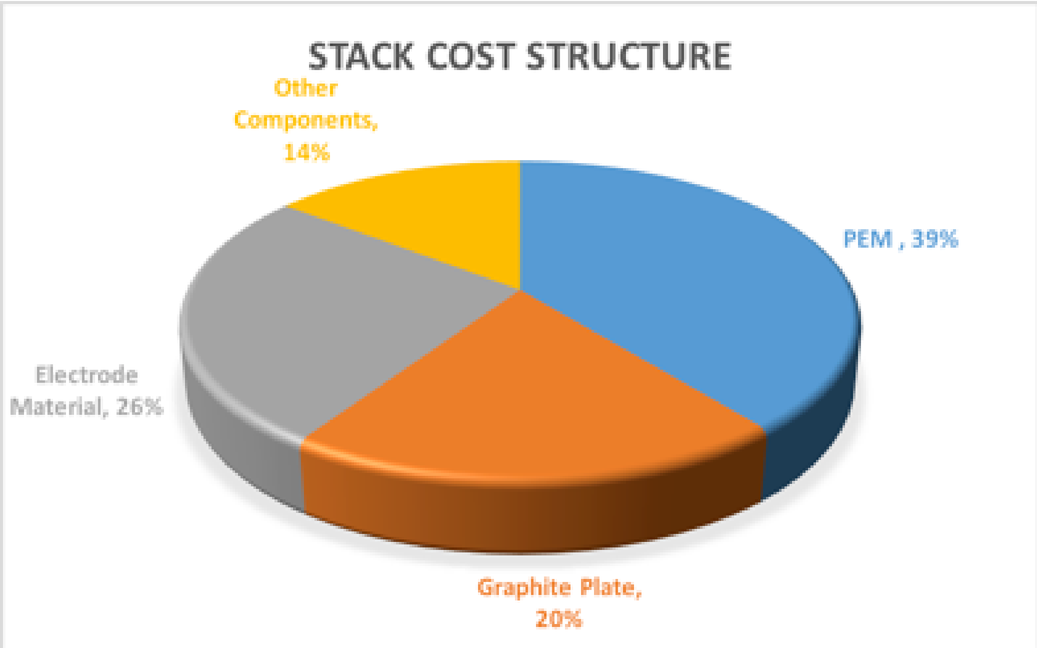
Ionmer Membrane：Dupont Nafion, with thickness of 5 mil, is used as the membrane. Prices for the membrane are assumed to range from $110 to $130 per square meter.

1. Graphite Bipolar Plate: The graphite bipolar plate is made from conductive plastic composites that have high electrical conductivity and can also tolerate the corrosive environment within the cell. The prices range from about $90 to $110 per square meter.
2. Electrode: Electrode usually made from carbon felt or paper with special pretreatment process. Carbon material is an industrial product used in applications where very high surface area is desirable. Felt materials are made from rayon or polyacrylonitrile yarn, which is carbonized through pyrolysis and then converted into cloth using conventional felting processes. It was assumed that felt costs range from $40 to $60 per square meter with treatment in large quantities.
3. Additional Components: the physical frame used to keep the stack together, the manifolds that allow entry and exit of electrolytes, and the electrical connections that allow electrical current to pass through the stack. These additional components are estimated to comprise 10% of the stack.
4. Cell Stack Assembling are consisting of above four major components, electrodes and membranes are placed in frames and assembled into cell stacks. A 32-cell stack is composed of 33 conductive current collectors, 64 carbon felt electrodes, and 32 ion exchange membranes, which form the bulk of the cost of the stack.

Based on the 4,000 stacks (2,000 systems) production capacity per year, a prediction cost target shown as follows:

Per kW Stack Material Cost (USD)		
PEM	270	39%
Graphite Plate	140	20%
Electrode Material	180	26%
Other Components	100	14%
Total	690	100%





In system scales, following key components are major consideration,

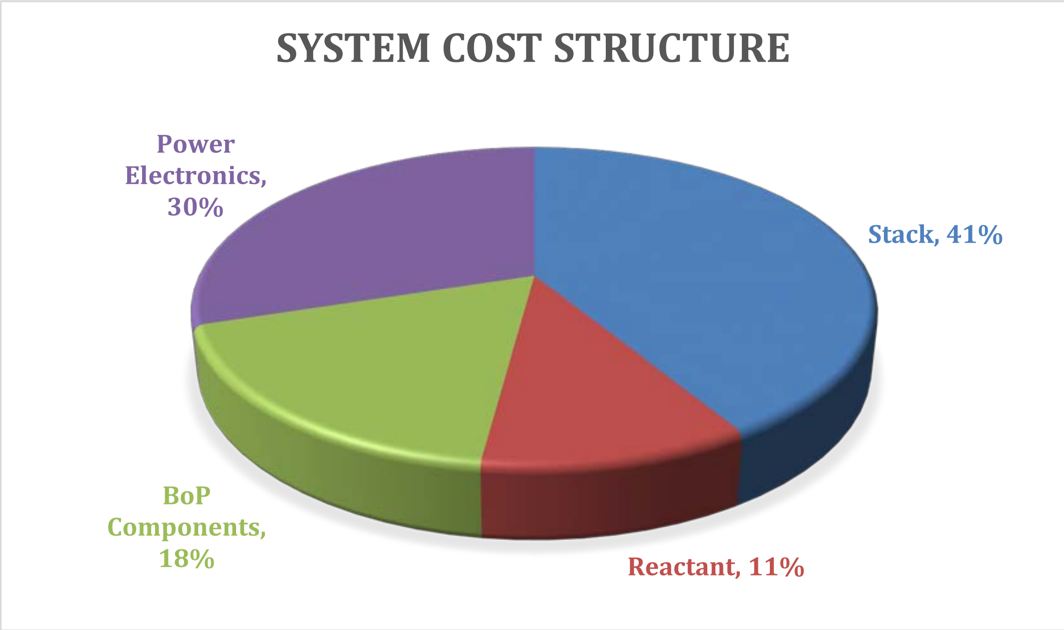
1. Reactant: The direct flow cell use poly acid as reactant to convert the biomass to energy. The poly acid is chemical industry available product, the reactant are 0.3M concentration and the cost around 18USD/L. In the system calculation, we assume 10L reactant need to be used for 1kW stack.
2. Balance of Plant Components

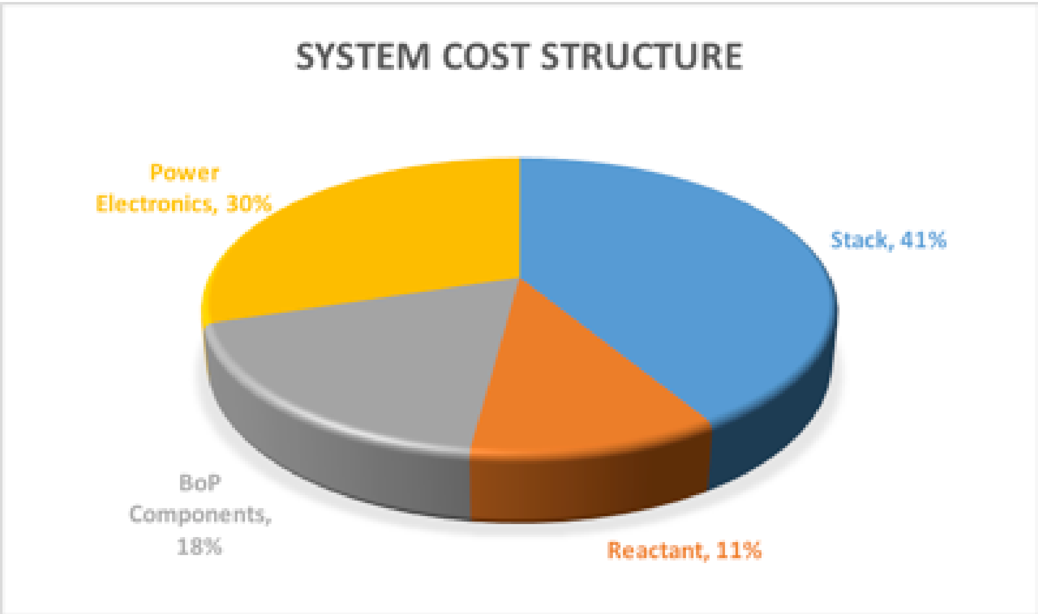
A high temperature anti corrosion pump is designed to handle process fluids similar to the reactant. Piping costs were estimated assuming market prices for PVC piping. Auxiliary equipment costs cover items such as reactant storage tanks, valves, thermal couples and other equipment as may be necessary for the reactant loops.

3. The electrical power system includes the PCS, the transformer, and the cabling and interconnects connecting the components to each other. The power electronics is estimated to around 500 USD/kW for smaller systems.

The cost estimate for complete power system around 1670 USD/kW based on 2,000 units production volume per year, and the cost structure as shown in the following Figure.

Per kW System Cost (USD)		
Stack	690	41%
Reactant	180	11%
BoP Components	300	18%
Power Electronics	500	30%
Total	1,670	100%





Based on China electricity cost (0.1 USD/kWhr), the system invest will return after 20,000 hours operation. The system lifetime and reliability with continuous system performance improvement will be developing focus.

Annex 5：Fuel cell Technical Progress review report

1. Introduction

As the world's population keeps growing, our energy demands continue to increase. It is a big challenge to maintain the standard of living as everyone of the world wants to keep cars, homes, and business running like usual without destroying our environment due to the increasing amount of greenhouse gas emission produced by people, who are so used to the usage of fossil fuel. Moreover, our energy system is much tied-up with fossil fuel that our economy growth is heavily influenced by the unstable price of crude oil. It is crucial and necessary to slowly change from fossil fuel energy carriers to renewable energy fluxes in this century. A hydrogen economy is one of a number of alternatives that offers solutions to the above mentioned issue.

Hydrogen can be a renewable resource when it is produced from water electrolysis using renewable energy or from synthesis of biogas. As hydrogen is reacted with oxygen from the air in a fuel cell system, they produce electricity and the only byproduct is water. As result, fuel cell technologies and hydrogen have the potential to address two essential energy challenges we face in the world today: CO_2 emission reduction and fossil fuel independence if the technologies are used in a comprehensive and balanced portfolio.

Fuel cell technologies are considered as important core technologies of the hydrogen economy that revolutionize the way we power our world. It offers cleaner and more efficient in comparison to the internal combustion engine (ICE) in vehicles and gas turbine or coal fired boiler at distributed power generation stations. Fuel cell technologies are one step short towards commercialization.

We have seen many fuel cell demonstrations in transportation sector such as the Whistler hydrogen fuel cell buses, CUTE (Clean Urban Transport for Europe), CaFCP (California Fuel Cell Parnership), CEP (Clear Energy Partnership in Germany), etc. Announcements of Toyota, Honda, and Hyundai ready to bring fuel cell vehicles to the market in 2015 shows the readiness of the fuel cell technology. In Europe, EU has launched Horizon 2020 framework program, which allocated 1.33 billion Europe to further develop fuel cell and hydrogen technologies, with activities focusing on two innovation pillars: transportation and refueling infrastructure, and energy. Transportation pillar represents road and non-road vehicles and machinery, while energy pillar represents combined heat and power (CHP) generation and hydrogen production and storage from power to gas.

In stationary sector, Bloom Energy , based in California, USA, stated that in 2011 they deployed over 200 solid-oxide fuel cell (SOFC) Energy Server to its customers include eBay, Yahoo, and Google. Until 2015, Bloom Energy has installed over 150 MW of SOFC power generators. For home application, Japan leads the world by reaching 100,000 micro -CHP units accumulated installation in 2014. Small incremental improvements in fuel cell performance and reliability progressed in the past decade bring our attention to review the status quo of the fuel cell technologies. This overview is aimed to build a summary of the state of art fuel cell technologies for readers to gain better understanding of the pivotal technologies in this century.

1.1 The Development of Fuel Cell

Fuel cell was first invented by Welsh scientist Sir William Robert Grove in 1839, but there has been no significant technological breakthrough ever since. Until 1932, Francis Bancon of Cambridge University in England incorporated previous research results and came up with a more advanced fuel cell design, which set a foundation for fuel cell applications in spacecraft in late 1960’s. At that time, fuel cell was still bulky and heavy due to its aqueous or solid electrolyte; although the power density of a fuel cell was better than that of a battery, the cost and weight were still high. As a result, fuel cell was still far away from commercialization.

The invention of Nafion by DuPont in the 1960’s is another major breakthrough for fuel cell technology. Nafion, a synthetic polymer made of polytetrafluoroethylene with ionic properties, was originally developed for chlor-alkali industry. General Electric soon developed a new prototype fuel cell by replacing the aqueous electrolyte with a membrane similar to Nafion; this was the first debut for the Solid Polymer Electrolyte (SPE) fuel cell, also known as Proton Exchange Membrane Fuel Cell (PEMFC).

PEMFC, however, was only limited to spacecraft application in the 1960’s due to its expensive membrane and platinum electrode, low carbon monoxide tolerance, and low power density. Not until 1980’s, with government funding support and research achievements from university and national laboratories, PEMFC drew attention from the world again. Ballard Power System, a Canadian company funded by Geoffery Ballard, developed a 2kW PEMFC, with a size of a car engine, combining with an onboard methanol reformer; the portable prototype engine was tested on submarines of UK Royal Navy.

Despite of its original intention use for special application (such as battle field and space mission), fuel cells nowadays are used in transportation, stationary, and portable application. In transportation application, incumbent automaker like Honda, Toyota, Hyundai, Volkswagen Group, Daimler continues their investment in fuel cell vehicles development. With the competing technology from battery-electric vehicle, the challenging question is how to make fuel cell vehicle more affordable. Toyota, Honda, and Hyundai made the first move to offer lease program to early adaptors in California, USA. Challenger like Plug Power in New York, USA, has built over 8000 units of GenDrives, which ranges from 1.8 to 10kW, that power material handling vehicles such as lift truck and pallet trucks in large warehouses of Walmart, Sysco, P&G, and BMW, etc.

In stationary application, smaller Proton Exchange Membrane Fuel Cell (PEMFC) is deployed to telecommunication sites as backup power and houses for CHP application. Until 2014, Ballard Power has accumulated with over 2600 fuel cell backup units, mostly in the USA and Europe. In Korea, POSCO and Fuel Cell Energy (FCT) strategically worked together to build fuel cell sites those are capable of generating over 150 MW using Molten Carbonate Fuel Cell technologies (MFFC).

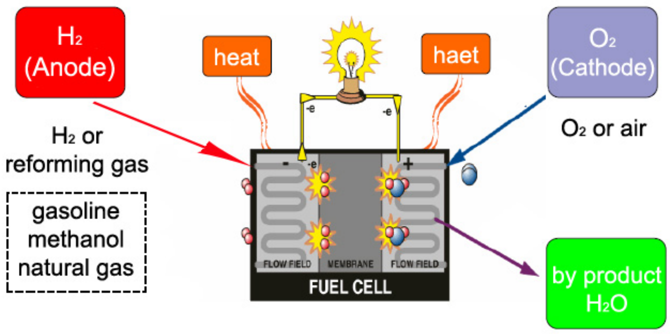
For the portable application, despite of slow technology improvement in fuel crossover issue, the very special niche application such as remote power, off-grid monitoring, and leisure use are gaining momentum and attention with EFOY, a small Direct Methanol Fuel Cell (DMFC) system that powers from 25W to 500W, its special characteristics is the high energy density in the methanol fuel in comparison with hydrogen gas, which allows easy refill and maintenance. Until 2014, several thousands of EFOY has been shipped, which shows that fuel cell technologies are ready and only one step short toward large-scale commercialization. The critical question is how to make the technologies more affordable and reliable. We therefore, will review the four important fuel cell technologies in the following chapters. Table 1 below represents the major milestones of fuel cell development.

Table 1: The milestones of fuel cell development

Year(s)	Milestone
1839	W.R. Grove and CF. Schonbein separately demonstrate the principals of a hydrogen fuel cell
1889	L Mond and C. Langer develop porous electrodes, identify carbon monoxide poisoning, and generate hydrogen from coal
1893	F.W. Ostwald describes the functions of different components and explains the fundamental electrochemistry of fuel cells
1896	W.W. Jacques builds the first fuel cell with a practical application
1933-1959	F.T. Bacon develops AFC technology
1937-1939	E. Baur and H. Preis develop SOFC technology
1950	Teflon is used with platinum/acid and carbon/alkaline fuel cells
1955-1958	T. Grubb and L. Niedrach develop PEMFC technology at General Electric
1958-1961	G.H.J. Broers and J.A.A. Ketelaar develop MCFC technology
1960	NASA uses AFC technology based on Bacon's work in its Apollo space program
1961	G.V. Elmore and H.A. Tanner experiment with and develop PAFC technology
1962-1966	The PEMFC developed by General Electric is used in NASA's Gemini space program
1968	DuPont introduces Nafion®
1992	Jet Propulsion Laboratory develops DMFC technology
1990s	Worldwide extensive research on all fuel cell types with a focus on PEMFCs
2000s	Early commercialization of fuel cells
2008	Fuel cell buses operating during 2008 Beijing Olympic and 2010 Vancouver Olympic Games supported by Ballard Power fuel cell technology.
2011	Bloom Energy started deployment of SOFC power generation in California to IT customers.
2014	Japan leads the world by accumulating 100,000 units of 1kW micro-CHP installation for home application.
2015	Announced of Toyota, Honda, and Hyundai to offer commercial fuel cell vehicles for lease to public users.

1.2 The Fundamental of Fuel Cell

Similar to battery, fuel cell is composed of three key components: anode, cathode, and electrolyze. In contrast to battery, a fuel cell is an open battery system that as long as enough fuel and oxidant are supplied to the cell, the chemical reaction will never stop like traditional battery resulting low voltage. The electrodes consist of a porous material that offers great surface area and is covered with catalyst (typically platinum for PEMFC technology) to accelerate the chemical reaction of hydrogen and oxygen, as shown in the equation of figure 1. The working principle of PEMFC is shown in figure 1. As hydrogen is fed to the anode stream, the molecule reacts with Pt catalyst and decomposes into protons and electrons. The electrons travel through the external circuit to power up the light bulb while the protons penetrate through a selective membrane electrolyte – Nafion® and recombine with oxygen and electrons to produce water. The reacting gas can be pure hydrogen or hydrogen reach gas produced from a reformer, as indicated in figure 1. However, if hydrogen comes from a reforming gas, the carbon monoxide (CO) impurity in the gas mixture can be a poison to the Pt catalyst in the cell, which will drastically reduce the performance of a fuel cell. In high temperature proton exchange membrane fuel cell (HT-PEMFC) and SOFC, the catalyst has higher tolerance to CO concentration of fuel stream, in comparison to low temperature PEMFC (LT-PEMFC). Yet, operating at higher temperature encounters issues such as thermal expansion and heat insulation to deal with, making the overall system more complex somehow. We will explain the differences in technologies and their merits and cons later in the following chapters.



Anode: $H_2 \rightarrow 2H^+ + 2e^-$ $E^o = 0.000$ V

Cathode: $1/2\ O_2 + 2H^+ + 2e^- \rightarrow H_2O$ $E^o = 1.234$ V

Overall: $H_2 + 1/2\ O_2 \rightarrow H_2O$ + power + heat

Figure 1: Working principle of PEMFC.

In order to maximize the performance of PEFMC system, it is important to know the impact of each variable, such as temperature, pressure, and gas constituents, on fuel cell performance. Fuel cell converts chemical energy into useful electrical energy, and the obtainable electrical work is given by the change of Gibb's free energy, ΔG, of the electrochemical reaction:

$$W_{el} = \Delta G = -nFE \qquad (1\text{-}1)$$

Where n is the number of electrons participating in the cell reaction, F is Faraday's constant (96487 coulomb/g-mole e^-), and E is the ideal potential of the cell. Eq. (1-1) can be re-written as:

$$E = \frac{-\Delta G}{nF} \qquad (1\text{-}2)$$

The ideal potential of the cell is therefore related to the change of Gibb's free energy. ΔG is a function of temperature, as shown below:

$$\Delta G = \Delta H - T\Delta S \qquad (1\text{-}3)$$

For the general cell reaction,

$$aA + bB \rightarrow cC + dD \qquad (1\text{-}4)$$

the free energy change can be expressed by the equation:

$$\Delta G = \Delta G^o + \mathrm{RT}\ln\frac{[C]^c[D]^d}{[A]^a[B]^b} \qquad (1\text{-}5)$$

By substituting Eq. (1-1) into Eq. (1-5),

$$\mathrm{E} = \mathrm{E}^o + \frac{\mathrm{RT}}{\mathrm{n}F}\ln\frac{[\mathrm{A}]^a[\mathrm{B}]^b}{[\mathrm{C}]^c[\mathrm{D}]^d} = \mathrm{E}^o + \frac{\mathrm{RT}}{\mathrm{n}F}\ln\frac{\Pi\,[\text{reactant activity}]}{\Pi\,[\text{product activity}]} \qquad (1\text{-}6)$$

Eq. (1-6) is a general form of Nernst equation, the cell potential increases with increase in the activity of reactants.

1.2.1 Fuel Cell Efficiently

When fuel reacts with an oxidant, the cell efficiency is defined as the amount of useful energy produced over the change in stored chemical energy (or known as thermal energy). In the ideal case of an electrochemical converter, such as a fuel cell, the value of useful energy could be the useful electrical energy (ΔG).

$$\eta = \frac{\text{useful energy}}{\Delta H} = \frac{\Delta G}{\Delta H} \qquad (1\text{-}7)$$

At standard conditions, (T = 25°C and P = 1 atm), the thermal energy in a hydrogen/oxygen reaction is 285.8 kJ/mole, and the free energy change is 237.1 kJ/mole. Thus, the ideal thermal efficiency of a fuel cell can be calculated as follow:

$$\eta_{ideal} = \frac{237.1}{285.8} = 0.83 \qquad (1\text{-}8)$$

The actual cell efficiency can be expressed as the operating cell voltage over the ideal cell voltage. The actually voltage is lower due to the losses associated with cell polarization and IR loss, as a result, the thermal efficiency can be re-expressed as:

$$\eta = \frac{\text{useful energy}}{\Delta H} = \frac{\text{useful power}}{\Delta G / 0.83} = \frac{\mathrm{V_{actual}} \times I}{\mathrm{V_{ideal}} \times I \big/ 0.83} = \frac{0.83 \times \mathrm{V_{actual}}}{1.229} = 0.675 \times \mathrm{V_{actual}}$$

Based on the equation above, we can quickly estimate the fuel cell theoretical efficiency by determining the average operating cell voltage. The efficiency of a fuel cell can vary depending on the cell voltage and current of the stack. Higher cell voltage gives higher fuel efficiency but the current density is lowered. The trade-off is that if current density is increased, the cell voltage will drop and the cell efficiency will fall. Thus, it is important to consider both parameters when comes to design a fuel cell system.

1.2.2 Kinetics of Fuel Cell

Due to the kinetic limitation of the electrode, the actual cell potential is always lower than the idea reversible cell potential. For PEMFC as an example, the loss of cell voltage is contributed from (1) activation polarization, (2) ohmic (IR) polarization, and (3) concentration polarization. A mathematical equation [15] is shown below:

$$E_{cell} = E_{ideal(P_{H_2}, P_{O_2}, T)} - \eta_{ORR} - IR - \eta_{conc} \quad (1\text{-}9)$$

Where η_{ORR} is the oxygen reduction reaction (ORR) voltage loss, IR is the ohmic loss, and η_{conc} is the mass transport voltage loss. A sample I-V plot that shows the ideal and actual PEMFC voltage and current relationship is presented in Figure 2.

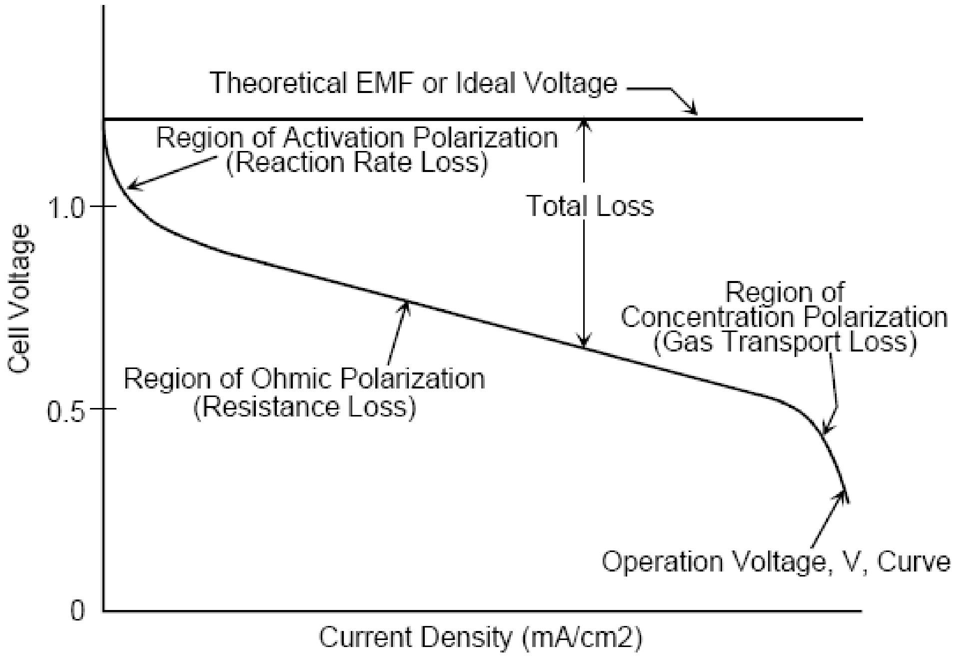


Figure 2: Ideal and actual fuel cell voltage/current characteristics.

The ORR voltage loss is known as the activation polarization; it is directly related to the rate of electrochemical reactions. At low current densities, the rate of electrochemical reaction is mostly controlled by the sluggish O_2 electrode kinetics. The degree of Pt activity inside the catalyst layer will affect the rate the electrochemical reaction, and is responsible to the ORR voltage loss.

The IR loss is mainly due to the resistances of the cell. The resistances include the flow resistance of protons in the electrolyte and the flow of electrons from anode to cathode. The contact resistance between bipolar plates and electrodes is also a consideration. With a higher current flow, the IR loss will become significant; as a result, the IR loss of PEMFC performance is dominated in the middle region of the IV curve.

The mass transport loss is mainly due to the concentration gradient surrounds the electrode. The rate of transporting reaction material to the electrode cannot keep up with the rate of reaction on the electrode surface. This is known as concentration polarization. In PEMFC, the factors such as slow diffusion of oxygen to the catalyst inside the electrode pore, slow transportation of protons from Nafion® path, and slow removal of product water account for concentration polarization.

1.2.3 Characteristics of Fuel Cell

Fuel cell is an electrochemical device, but when cells are combined into a stack, it involves with thermodynamics and mechanical engineering. When it comes to system design, the technology requires extensive knowledge in system level integration and electrical and power electronic design. Due to the complexity of the fuel cell technology is related with electrochemistry, thermodynamics, mechanical engineer, material science and engineering, electrical engineering, and system integration, which makes the research and development an interdisciplinary science. Often, people mismatched fuel cell technology with solar cell and wind energy, considering they are the same renewable technologies. Therefore, we summarized the special characteristics of fuel cell technology in Figure 3 to provide its principle of operation and features as the fundamental for readers to better understand the fuel cell technology.

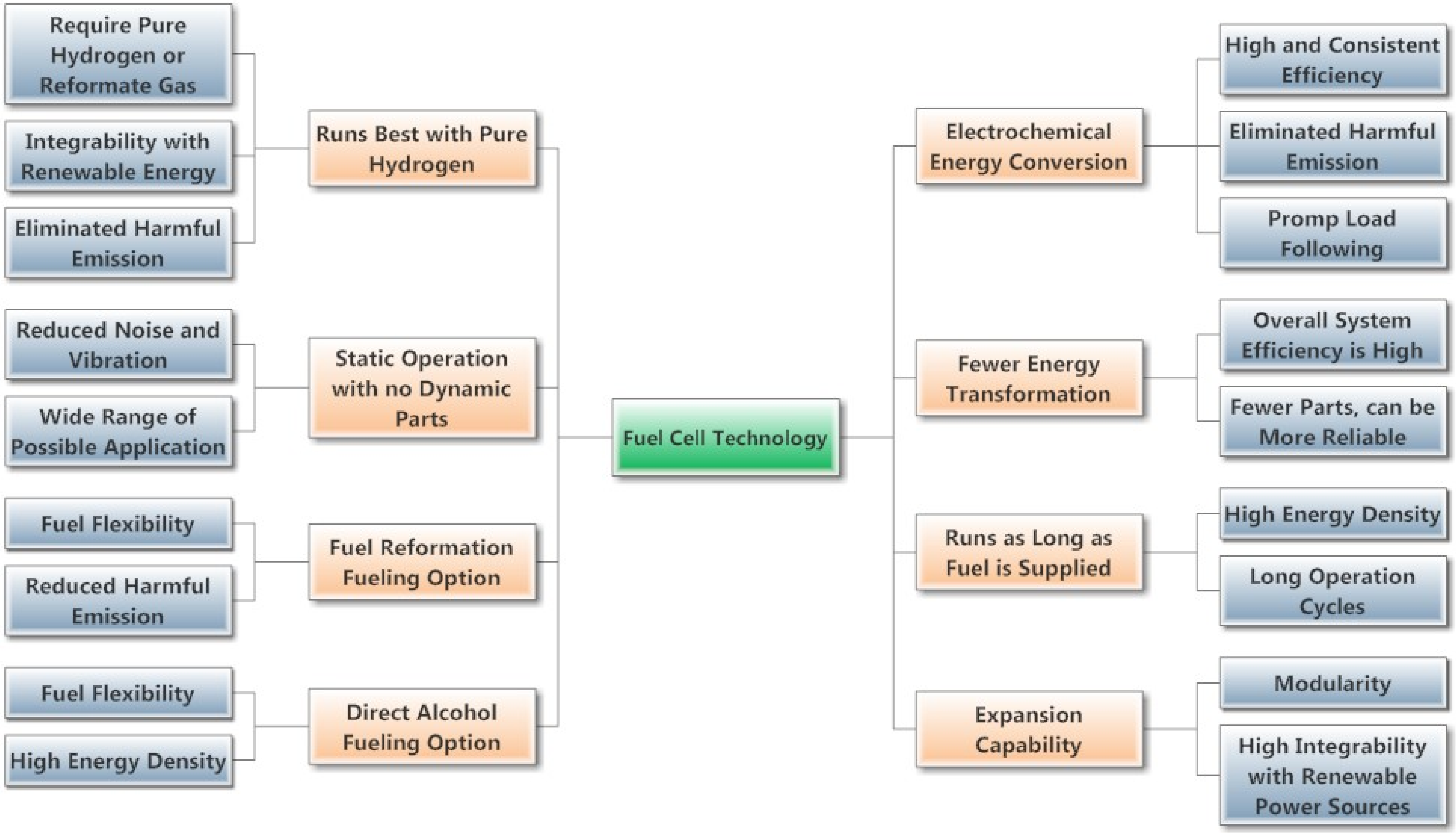


Figure 3: Principle of Operation and Features of Fuel Cell Technology

Comparing with conventional combustion-based system, fuel cells have many inherent merits, which make them one of the strongest candidates to be the future energy conversion device. They also have some inherent demerits that require further research and development to overcome. In Figure 3, the advantages of fuel cells are already shown. Later in Section 1.3, we will go over their merits and demerits in more detail.

1.3 The Types of Fuel Cells and Their Typical Applications

Even though PEMFC has drawn much of the attention and is the most popular one for lab research and pre-commercial application, there are four other types of fuel cell, categorized by different electrolyte. These fuel cells differ in their power output ranges, operating temperature, electrical efficiencies, and typical applications. They are Alkaline Fuel Cell (AFC), Phosphoric Acid Fuel Cell (PAFC), Molten Carbonate Fuel Cell (MCFC), and Solid Oxide Fuel Cell (SOFC). Table 2 shows a summary of the major differences of these fuel cells.

AFCs have the best performance when operating on pure hydrogen and pure oxygen, yet AFCs are intolerant to impurities such as COx and have shorter lifetime. AFCs are predominantly used for extraterrestrial purposes. PAFCs are possibly the most commercially-developed fuel cells operating at intermediate temperatures. They are used for CHP applications with high energy efficiencies. MCFCs and SOFCs are high-temperature fuel cells appropriate for cogeneration and combined cycle systems. MCFCs have the highest energy efficiency attainable from methane-to-electricity conversion in the size range of 250 kW to 20 MW. SOFCs are best suitable for base-load utility application by converting natural gas to electricity. The merit of these cells is that they can quietly generate power at a very high efficiency while not producing much harmful emission such as carbon dioxide and nitrogen oxides.

Fuel cells have promising potential to become competitive plays in a number of markets due to their broad range of applications. As a result of their high modularity, wide power output range, and variation of properties among different types of fuel cells, their applications range from small portable power source to large cogeneration power plants. We will disclose the types of applications and power range of fuel cells by three market sectors: portable, stationary, and transportation.

Table 2: Summary of five fuel cells

	Electrolyte	Operating temperature	Charge carrier	Merits	Prime cell components	Catalyst	Major Contaminants	Cell Efficiency
PEMFC	Ion exchange membrane - Nafion	40 - 80°C	H^+	Rapid start-up due to low temperature	Carbon-based⁻	Platinum	CO, H_2S	35 – 45%
AFC	Mobilized or immobilized potassium hydroxide (KOH)	65 – 220°C	OH^-	Inexpensive catalyst, higher efficiency due to fast reduction kinetics	Carbon-based⁻	Nickel / Silver	CO_2	35 – 55%
PAFC	Immobilized liquid phosphoric acid	205°C	H^+	High grade heat, simple water management	Carbon-based⁻	Platinum	CO, H_2S	40%
MCFC	Immobilized liquid molten carbonate	650°C	CO_3^{2-}	Fuel flexibility, High grade heat	Stainless-based	Nickel	Sulfides, Halides	>50%
SOFC	Ceramic (YSZ)	600 – 1000°C	O^{2-}	Inexpensive catalyst, High grade heat	Ceramic	Nickel-YSZ / LSM	Sulfides	>50%

1. 3.1 Portable Applications

Portable applications for fuel cell technologies are mainly in two market categories: 1) portable power generator for leisure outdoor activities, surveillance, and emergency relief; and 2) power source for consumer electronic devices such as laptops, cell phone, radios, camcorders. The typical power range is between 2 and 500W. Portable fuel cells need to be light so they can be carried easily by individual to use in various scenarios. In contrast to stationary application, fuel cells of portable application require high energy density base on volume and weight. Direct Methanol Fuel Cell (DMFC), a branching technology from PEMFC, and Reformed Methanol Fuel Cell (RMFCs), a PEMFC feeds by reformate methanol, as well as PEMFC are suitable technologies for portable application market. This is due to the characteristics of silent operation, low weight, and quick start-up. In competing with traditional battery, fuel cells offer higher power density and longer cycle life time, in theory. In reality, the challenge remains in system level integration because immature system design requires too much parasitic load which reduces overall system efficiency; and bulky system design decreases overall power and energy density. Additional challenges include technical issue such as heat dissipation, emission dissipation, fuel storage and delivery, shock and vibration endurance; most importantly, cost reduction and durability enhancement as competing technology - battery also improves continuously.

1.3.2 Stationary Applications

Stationary applications for fuel cell technologies are mainly in three market categories: 1) Emergency uninterrupted backup power supply (UPS), 2) Remote-area power supply (RAPS), and 3) Distributed power and CHP generation. The market of stationary fuel cell application accounts for about 70% of the annual fuel cell shipments on a MW-level in 2011, this could be because the entry barrier of the stationary fuel cell technology and its overall system level design is lower in comparison with portable and transportation application. In the early phase, stationary application is considered as market, and it also benefit more from government-assisted large scale demonstration program.

In the application of UPS use, PEMFCs and DMFCs have gained much attention in the early stage of technology development. The incumbent technology, lead acid battery, is bulky and unreliable sometimes due to bad storage condition. In contrast, fuel cells offer compact size and stable operation under harsh ambient conditions. For UPS backup operation requirement, operational lifetime is not necessary the important issue, but availability needs to be close to 100%. As a result, PEMFCs and DMFCs are suitable technology to replace traditional battery in hospitals, data centers, banks, telecommunication sites, and government agencies in early stage. In these applications, power range requirement is between 2 and 10kW.

As the technology of stationary fuel cell system continuous to improve and cost drops down by mass production, one possible niche market is the remote-area power supply (RAPS). Still, many places on earth such as islands, deserts, forests, remote research facilities, and holiday retreats, are grid-isolated locations. Usually, providing power to rural and urban off-grid locations by RAPS is more economical than extending the electricity grid power line. Issues such as high transmission loses, high cost infrastructure, and low utilization due to low load density prohibit the extension of grid power line to rural area. The current RAPS solutions include use of hydrocarbon fuel, renewable solar and wind energy, or two in combinations. Fuel cell technology can play important role in this category by extending the RAPS operation time, eliminating the use of hydrocarbon fuel, and reducing noise. Traditional diesel engines have been widely used as RAPS solution, but its problems are noisy and high carbon footprint. In some national parks and area, diesel is prohibited. Fuel cell could serve as an alternative to replace diesel engines. In fact, DMFCs which is capable providing between 25W and 500W has great potential to compete with diesel engine in this power range. For power requirement larger than 500W, PEMFCs with integrated methanol reformer, or compressed hydrogen storage are commercially available for this market category, however, initial high capital cost of fuel cell and fuel storage make them less favorable than traditional diesel generators. In developing economies such as India, China, and nations in South East Asia, renewable energy like PV-based RAPS systems are rapidly deployed. A fuel cell system coupled with PV-based RAPS system that includes water electrolyzer (a reverse of fuel cell reaction) and hydrogen storage device could compensate for the intermittency problem of PV and wind systems, making the renewable RAPS system more reliable and sustainable. In this category, fuel cell and water electrolyzer technology is directly competing with energy storage device like lead-acid and lithium batteries. To compete, fuel cell technology needs to improve on cost reduction and operation run time extension, so the target cost to compete with battery is from 200 to 300 USD/kWh, which is the price of the lithium ion battery.

Fuel cells could serve as the means to realize the shift from current centralized power generation layout to decentralized distributed power generation scheme. By providing the base load, fuel cell could be used for residential electric power or CHP distributed generation either for houses or large residential zone. It is estimated that by 202, fuel cells could penetrate 50% of the world distributed generation market if cost and durability targets are met (*). Japan is leading this market where over 100,000 fuel cell CHP systems have been installed nationwide, which provide power and heating together. Fuel cell technologies used in CHP systems are mostly SOFC and LT-PEMFC; in addition, PAFCs and HT-PEMFC are also suitable technology, but not commonly applied. Fuel cell systems used for CHP generation could be designed to either grid-independent or grid-assisted; yet system complexity and cost will be increased for grid-independent design since the fuel cell system have to meet dynamic load fluctuation for household appliances. We will discuss the possible solutions in the later chapters of each fuel cell technologies in detail. With continue effort in material research, fuel cell life time keeps improving. It is a common target for fuel cell technologies applied to distributed/CHP generation to reach a lifetime of 80,000 hours in order to compete with the incumbent technologies.

1.3.3 Transportation Applications

Fuel cells offer the transportation industry near-zero harmful emissions without having to compromise the efficiency of the vehicle's propulsion system. In fact, back in the 2000s, putting fuel cell system in vehicle is a dream to reduce greenhouse gas emission and be independent from fossil fuel. At that time, majority of the fuel cell research and development activities was radical and focused on transportation applications such as auxiliary power units (APUs), light traction vehicles (LTVs), light duty fuel cell electric vehicles (L-FCEVs), heavy-duty fuel cell vehicles (H-FCEVs), aerial propulsions, and marine propulsion. However, in order to place fuel cell technology in transportation use, the power and energy density must be able to compete with the incumbent internal combustion engine (ICE). With incremental innovation and performance improvement on fuel cell stack and balance of plant (BoP) , starting in 2008, fuel cells started pre-commercialization in buses, forklift, and passenger vehicles. In 2014, European Fuel Cells and Hydrogen Joint Undertaking (FCH-JU), a program under Horizon 2020, continuing supporting on R&D and large scale demonstration activities of fuel cell technologies in transportation and refueling with 37% funding, the largest portion among all.

Light tracking vehicles (LTVs) are considered as early market of fuel cell technologies, including applications in scooters, personal wheel chairs, electrical bicycles, airport tugs, golf carts, and the shining start - material handling vehicles and equipments (MHV & MHE). Forklifts have been the most successful demonstration of fuel cells in the transportation category. Nowadays, Plug Power continues its development of General Hydrogen, a company formed by Geoffrey Ballard, has successfully deployed over 8000 fuel cell material handling vehicles for indoor warehouses in the USA. Fuel cell in MHV application has advantage over batteries on operation efficiency and cost due to the performance of battery powered vehicles often flat out half way and require. Even though the initial capital cost is three times higher than the incumbent technology, fuel cells can eliminate large number of battery storage and this niche application is very promising.

Light-duty fuel cell electric vehicles (L-FCEVs) provide quiet operation, efficient energy conversion, and less harmful gas emission than the traditional ICE vehicles. As a result, the ultimate target is to replace ICE with fuel cell as a solution to control air pollution. If hydrogen is produced from renewable energy, air pollution problem in urban area can be solved. In February 2013, small Korean automaker Hyundai announced its completion of mass production line of first fuel cell vehicle, the ix35, which delivered first 17 FCEVs to demonstrate in Europe. Later Honda and Toyota also announced commercial lease package of FCEV to potential customers with attractive selling price. In competing with battery electric vehicles (BEVs), FCEV offers longer cruise range, which doubled the range of typical BEVs. The challenges remain in the transportation categories are the cost of on-board hydrogen storage and establishment of fueling infrastructure. We will discuss more later in the technology trend of PEMFC section.

Heavy-duty fuel cell electric vehicles (H-FCEVs) include buses, heavy-duty trucks, locomotives, vans, utility trucks, service fleets, etc. These vehicles can utilize the power from fuel cell to drive the motor system. Until 2012, there are more than 30 fuel cell buses demonstrated in Western Europe and 25 in the USA. These buses provide exposure to public people to demonstrate the new technology and help R&D to collect data of operation for further technology improvement. Fuel cell buses are one of the most appealing applications for fuel cell technology in order to progress towards clean public transportation. Recently in China, national policy sets goals that local government and bus companies plan to launch over 300 fuel cell buses each in the three major cities of China, showing their ambition to relief air pollution stress in the urban area.

In summary, we present in table 3 a summary of fuel cell technologies and its potential applications.

Table 3: A summary of fuel cell technologies and its potential application

Fuel Cell Types	Power Range	Applications and Activities	Representing Companies
PEMFC	5W - 200kW	Stationary, distributed power generator	Ballard Power, ClearEdge Power,
		Stationary, CHP - EneFarm	Panasonic, Toshiba, ENEOS CellTech
		Stationary, UPS, Backup Power	Altergy, Dantherm Power, Idatech (Ballard)
			First Element, ReliOn, Hydrogenics
			M-FIELD, Heliocentris, PowerCell
		Transportation, LTV	Plug Power, Hydrogenics, M-FIELD, Nuvera,
		Transportation, L-FCEV	Toyota, Honda, Hyundai, Volkswagen, Daimler, Nissan
		Transportation, H-FCEV	Vision, US Hybrid, Hydrogenics, Ballard Power
		Transportation, Marine Propulsion	Proton Motor, YC Synergy
		Portable power	Horizon, myFC, Intelligent Energy
SOFC	1kW - 200kW	Stationary, distributed power generator	Bloom Energy, Ceramic Fuel Cell, Hephas Energy
		Distributed power/CHP generator	LG, Topsoe Fuel Cell, Sunfire
DMFC	5W - 500W	Portable	Neah Power, SFC Energy LG, Samsung, MeOH Power (MTI)
		Transportation , L-FCEV	Oorja, Jülich
		Stationary, RAPS or UPS	SFC Energy
HT-PEMFC	300W - 5kW	Stationary, distributed generator	Elcore GmbH, EnerFuell, Serenergy
		Transportation, L-FCEV	Serenergy

Chapter 2 -Fuel Cell Technologies

In this section, we will individually examine the technologies in table 3 for readers to have more understanding of the technologies.

2.1 Proton Exchange Membrane Fuel Cell

Proton exchange membrane fuel cells (PEMFCs) are branched into three similar categories: low-temperature, high temperature, and direct methanol. These three share similar stack structure and system layout, only a small difference in the layout of system components and fuel selection. In this section, we will mainly focus on the technology of low temperature PEMFCs (LT-PEMFCs).

The major applications of PEMFCs focus on transportation mainly due to their potential impact on the environment. PEMFC operated vehicles can control and reduce the emission of the green house gases (GHG) and polluted air, which is a major problem in urban area. This market need draws attention of government to create incentives for technology R&D and product demonstration. Many entrepreneurship innovations of PEMFCs thus are created as niche applications. Such application includes fuel cell buses, fuel cell forklift, fuel cell boat, fuel cell airport ground transportation, etc. Recently, Toyota, Honda, and Hyundai all announced their readiness to produce commercial fuel cell sedan, is another important milestone for the PEMFC technology. Other application of PEMFC includes stationary power generator systems and portable power devices. Stationary power generator systems include decentralized power generator from 50 to 250kW, backup power generator from 3 to 10kW, and residential combined heat and power (CHP) around 1kW output. Portable PEMFC devices utilize metal hydride or chemical hydride with a power output around 2W to 5W.

2.1.1 Fundamental of PEMFC

Categorized by different electrolyte, PEMFC consists of a famous proton exchange membrane as its solid electrolyte - Nafion, which is developed by Du Pont. Nafion is fabricated with chemically stabilized perfluorosulfonic acid copolymer. The solid electrolyte allows PEMFC to operate in any spatial position. The operation of PEMFCs takes pure hydrogen and oxygen from air to generate electricity, the electrode of the PEMFC stack is made of highly dispersed Platinum on carbon support, which allows high gas permeability. As a result, PEMFC has a relatively fast response start-up time compare with the rest of fuel cell technologies. The operating temperature of PEMFC is also low, typically around 60 to 80 ^{o}C, therefore, PEMFC is suitable for quick start power generator application in transportation, stationary backup, and portable use.

Advantage of PEMFC

The main advantage of PEMFCs is their high efficiency and instant dynamic power output characteristics. Unlike the internal combustion engine (ICE) where the efficiency is the maximum with the highest load, the fuel cell efficiency is also high at partial load. As a result, PEMFC is suitable for transportation and stationary power application where load is often low or predictable. Another advantage of PEMFC is its low operating temperature (below 80^oC), allowing it to reach the optimum operation condition relatively quicker than PAFC and SOFC.

Disadvantage of PEMFC

The major disadvantage of PEMFC is its requirement of pure hydrogen gas as reactant and its high cost of catalyst. PEMFCs often requires more pure hydrogen as fuel input and the catalyst is relatively more expensive than other fuel cell technologies. Since hydrogen is not a primary fuel, it is a energy carrier, one of the barriers that prohibits the full scale commercialization of PEMFC is the supply system of hydrogen gas for stationary and fueling infrastructure for transportation application.

In a standard PEMFC stack, explained in figure 4, the operation takes the following steps: 1) hydrogen gas and air are forced (by pumping or diffusion) to flow down the anode and cathode gas flow channels (GFCs), respectively; 2) H2 and air flow through the respective porous gas diffusion layers (GDLs), and diffuse into the respective catalyst layers (CLs); 3) H2 is oxidized at the anode CK, forming protons and electrons; 4) protons migrate and water is transported through the membrane; 5) electrons are conducted via carbon support to the anode current collector, and then to the cathode current collector via an external circuit; 6) O2 is reduced with protons and electrons at the cathode CL to form water; 7) product water is transported out of the cathode CK, through cathode GDL, and eventually come out of the cathode GFC by air purge; and 8) heat is generated and conducted out via carbon support to bipolar plates, being removed by cooling water or air through heat exchanger.

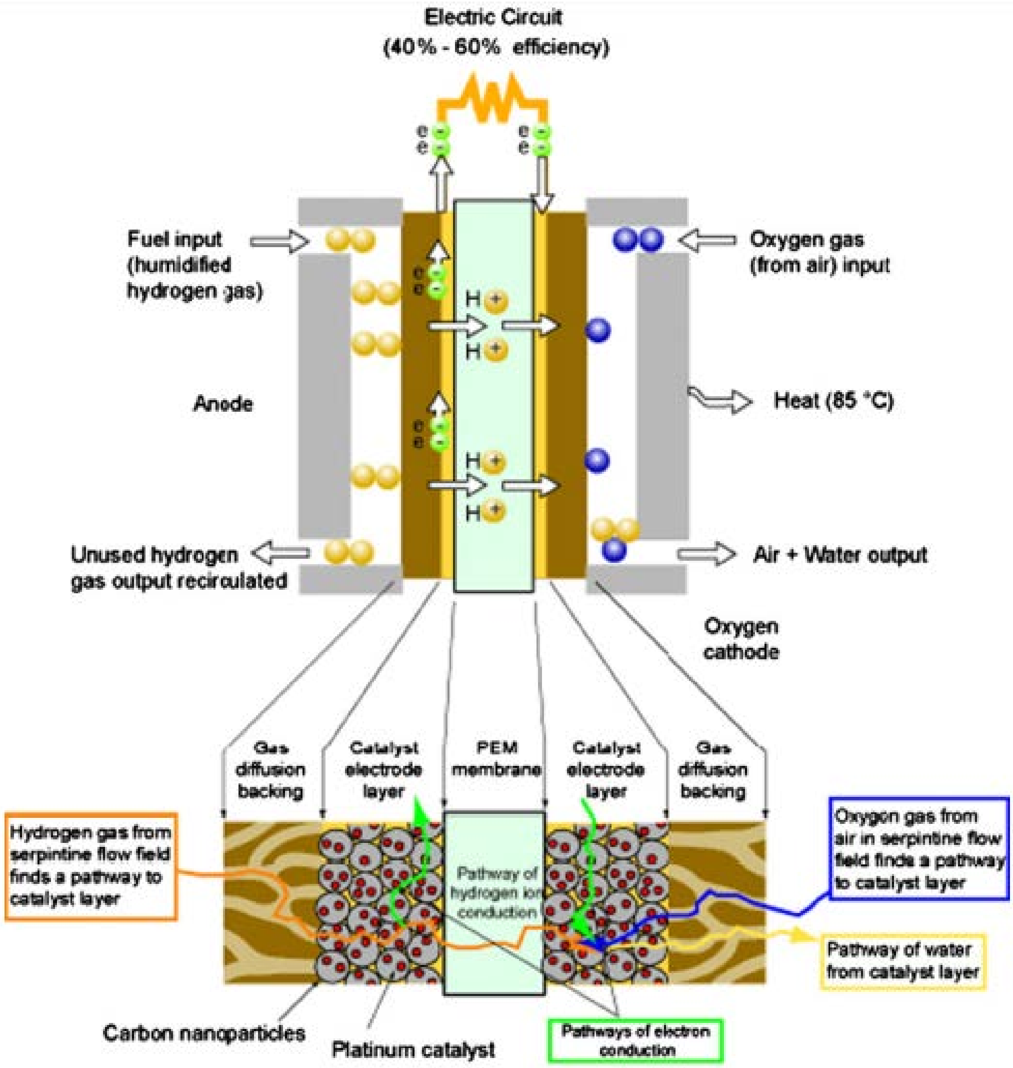


Figure 4: A schematic of a conventional PEMFC stack and its explanation on fuel cell operation.

2.1.2 System Layout

The complexity of PEMFC systems depend on the design of the fuel cell stacks. When the stack is designed with low power density and air cooling, the overall system is simple. When the stack is designed with high power density and water cooling, the overall system will be more complex.

An air cooled PEMFC system requires a cooling unit, a fuel supply unit, a power conversion unit, and a controlling unit. In figure 5, it shows a schematic of the conventional air cooled PEMFC system.

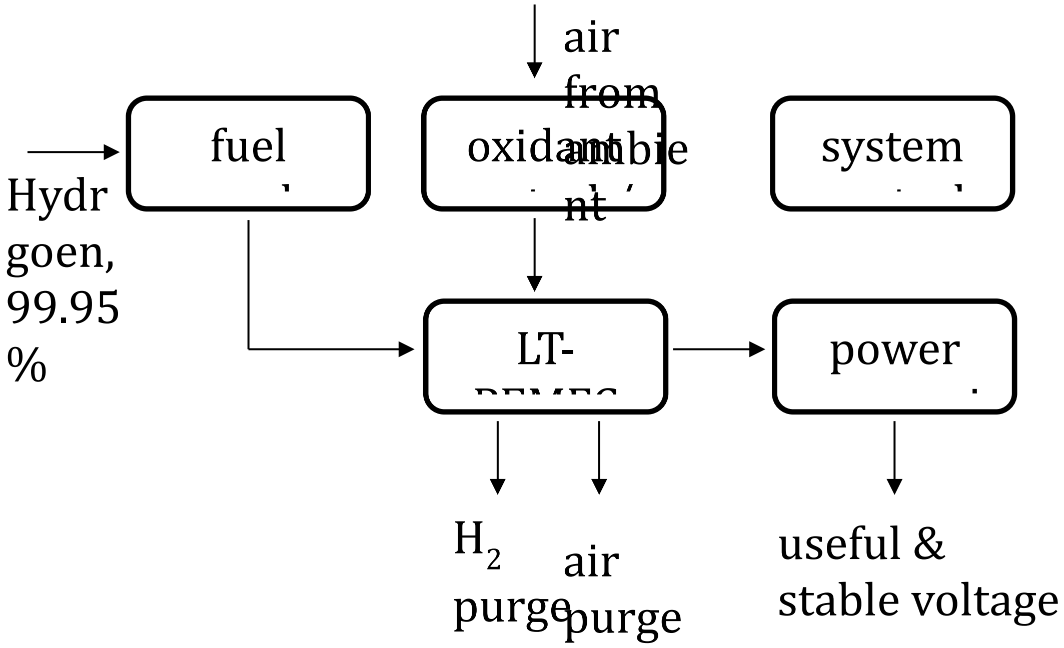


Figure 5: A schematic drawing of conventional PEMFC air-cooling system

A liquid cooled PEMFC system requires a additional oxidant supply unit such as an air blower or air compressor, depending on the air pressure drop specification of the stacks. Additionally, water cooling will require high efficiency heat exchanger such as a radiator or plate heat exchanger. Since the power density of the water cooled stack is much higher, the stack will also require a higher fuel stoic ratio, which means additional hydrogen recirculation pump is needed. Figure 6 shows a schematic of the conventional liquid cooled PEMFC system.

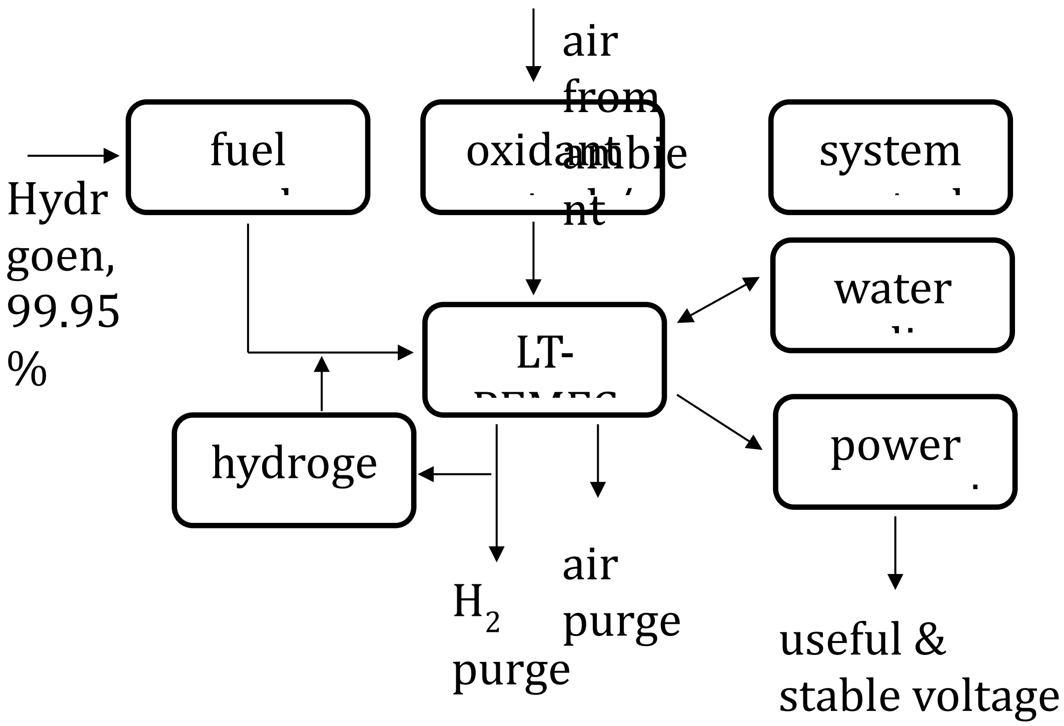


Figure 6: A schematic drawing of conventional PEMFC liquid-cooling system

A typical very compact and state of art liquid cooled PEMFC integrated power module is shown in figure 7, a courtesy from Hydrogenics.

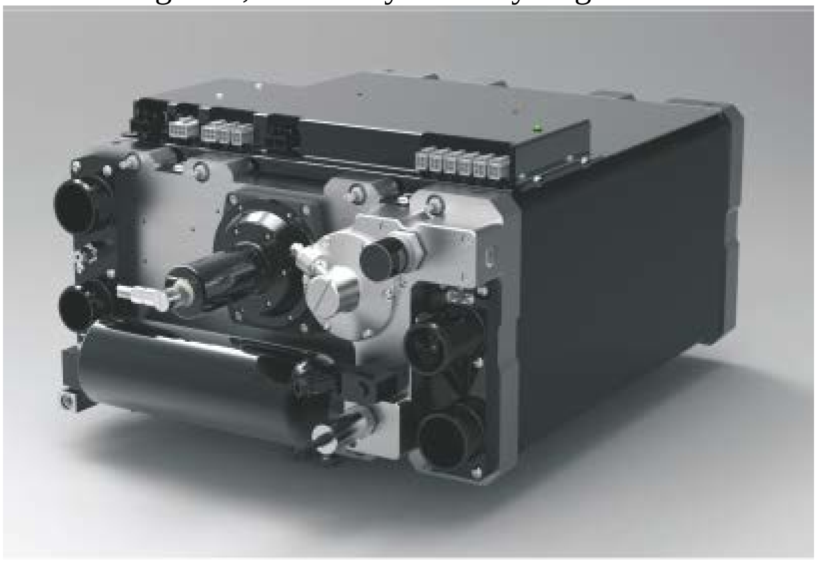


Figure 7: A compact liquid-cooling PEMFC stack module.

2.1.3 Stack Structure

PEMFC is the technology that has been widely developed and used in fuel cell related prototypes and products. As a result, there are many kinds of dimensions and stack designs today, which means there is no standard modular design, making fuel cell system integration difficult in components selection and mechanical design. However, no matter how stack outline has been changed, the structure of the stack remains unchanged, which is composed of bipolar plates, gas flow channel, gas diffusion layer, and membrane electrode assembly. In figure 8, we give an example of conventional PEMFC stack structure from Ballard Power System.

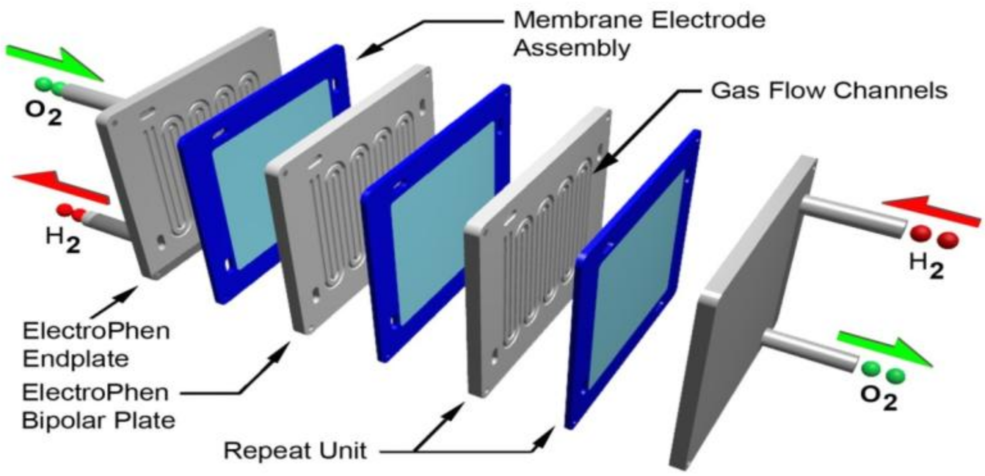


Figure 8: Example of Ballard PEMFC stack module, shows the illustration of the stack structure.

2.1.4 Key developing technologies and components

PEMFC is one of the most promising fuel cell technology, its applications on buses, forklift, stationary backup power, as well as CHP are continuously being developed. Importantly, to increase power density, bipolar plates will go from traditional graphite to metallic. Volkswagen groups, Dana, PowerCell, Elcore, and Japanese automakers are all involved in the development of metallic bipolar plates.

In addition, complementary technologies such as high efficiency air compressor and blower, renewable hydrogen generation technology, compact and inexpensive high pressure gas regulators, low cost onboard hydrogen storage with composite fiber are quite important to lower down the whole system cost. MEAs of PEMFC are very durable already, a breaking through technology will be exploring non-noble metal catalyst with high catalytic performance, but platinum is already not the major cost at this time. The cost of balance of plant needs to be lowered by scaling up the volume, which requires a killing application to create new market need.

2.1.5 Major Players and Suppliers

As summarized in table 3, there are many players involved in the development of PEMFC. Ballard Power System and Hydrogenics are the two leading stack manufacturers. Plug Power is the leading end product manufacturer which manufactures over 4000 fuel cell forklift in a year. Ballard has installed over 3000 units stationary backup systems in accumulation, while there are over 8500 fuel cell forklift manufactured by Plug Power in accumulation. Plug Power acquired ReliOn in 2014; as a result, Plug Power is also capable of producing fuel cell stacks very soon.
In a table shown below, we list the current active members who are in the area of PEMFC.

Table 4: A list of companies, which actively involved worldwide in the area of PEMFC technology

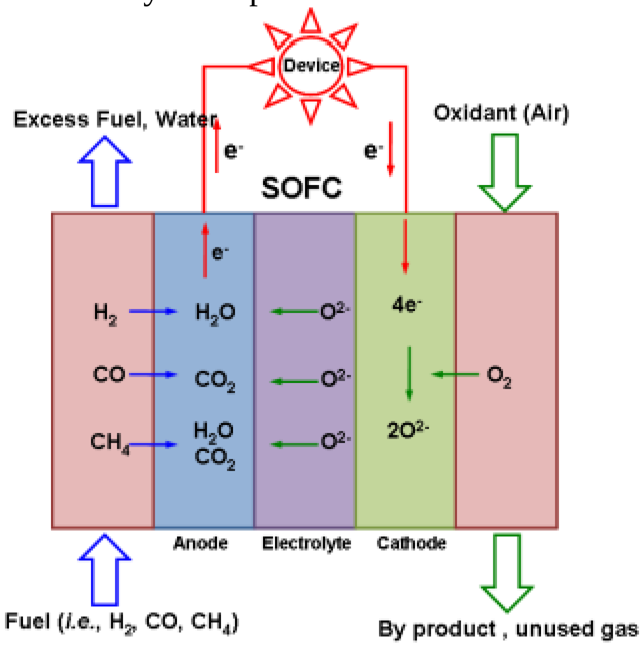
Company Name	Components and technology
AEG Power Solutions GmbH	Fuel cell inverter
Air Squared Inc.	Air compressor for liquid cooling fuel cell stack
Ballard Power Systems Inc.	Fuel cell stack, fuel cell systems
Baltic FuelCells GmbH	Testing equipment, and fuel cell system
Borit NV	Metallic bipolar plates, flow plates for stacks
Dana Holding Corporation	Stack components
Dantherm Power	PEMFC stationary power system, CHP
FuelCon AG	PEMFC test equipment
Greenlight Innovation Corp.	PEMFC test equipment
Hydrogenics	PEMFC stack, and PEMFC system, electrolyzer
Hephas Energy Corp.	PEMFC test equipment
Heliocentris	PEMFC fuel cell, alkaline electrolyzer
Intelligent Energy	PEMFC stack, portable PEMFC system
M-FIELD Ltd.	PEMFC stationary fuel cell
Nuvera	PEMFC fuel cell forklift, Orion stack
PowerCell Sweden AB	PEMFC stack, system
Proton Motor	PEMFC power module
Plug Power	PEMFC fuel cell forklift
YC Synergy	PEMFC fuel cell marine power module
VAIREX air system	Air blower for PEMFC stack

2.2 Solid Oxide Fuel Cell

Solid oxide fuel cells (SOFCs) as being one of the high temperature fuel cells provide a relatively high efficiency due to enhanced reaction kinetics at high operating temperatures. These characteristics also enable internal reforming of the most hydrocarbons and can tolerate small quantities of impurities in the fuel. SOFCs have been demonstrated as electricity provider and heat source with little emission compared to traditional natural gas power generator. However, due to the requirement of operating at high temperature (>600^{o}C), this limits the SOFC application areas to stationary continuous operation because of a long start-up period of time.

2.2.1Fundamental of SOFC

Solid oxide fuel cells (SOFCs), in its working principle, are much different than other three types of fuel cells. Its electrolyte is made of ceramic material and the flow of anion from cathode to anode is also an opposite direction when it is compared with PEMFC family. The following schematic in figure 9 shows the operation of a conventional SOFC. SOFC has several advantages, it is able to convert carbon monoxide as well as hydrogen, and the high operating temperature allows internal reforming of gaseous fuel and promotes rapid kinetics to produce high quality heat for energy conversion. In terms of disadvantages, there are several requirements on its ceramic materials: such as the stability in oxidizing and reducing conditions, chemical compatibility with various ceramics employed, thermal expansion compatibility of various components over the large temperature range, and adequate ionic conductivity of the membrane. Additionally, due to high operating temperature, long waiting times for heat up and cool down cycles are required in order to minimize the structural stresses caused by the expansion and contraction of material in the cell.



Anode: $H_2 + O^{2-} \rightarrow H_2O + 2e^-$

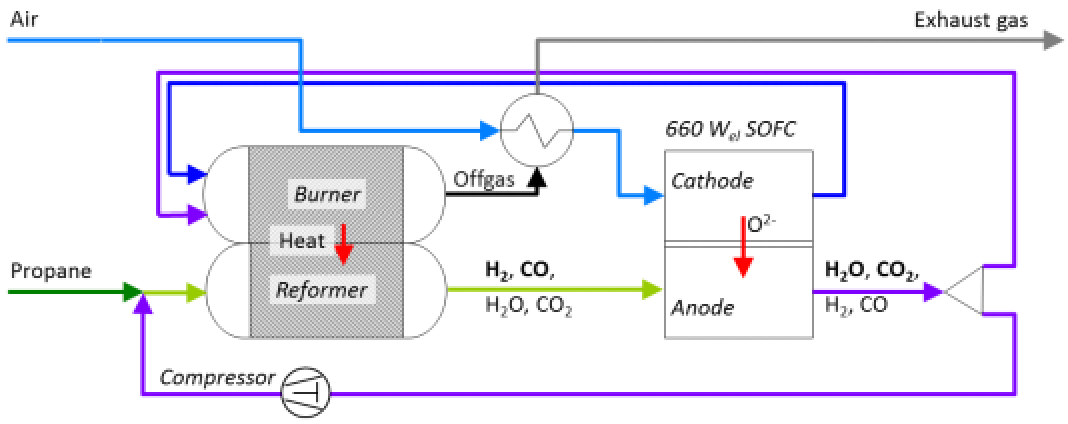
Cathode: $1/2\ O_2 + e- \rightarrow O^{2-}$

Overall: $H_2 + 1/2\ O_2 \rightarrow H_2O$

Figure 9: Schematic of SOFC operation in principle.

2.2.2 System Layout

SOFC system requires operating at high temperature, as a result, insulation, burner, heat exchanger are all required in a system to main the stack temperature at optimum condition. The schematic shown in figure X gives an example of conventional SOFC system layout.



2.2.3 Stack Structure

In a SOFC stack, it is composed of several key components: solid electrolyte, cathode, anode, sealant, and interconnects. A single cell of SOFC is a combination of anode, electrolyte and cathode. When more cells are stacked together, there are interconnects and sealant to bind cells together and provide path for external electron to flow through. The fuel is oxidized at the anode, and the oxygen is reduced at the cathode, anion such as O^{2-} flows from cathode to anode complete the fuel cell basic reaction. In figure 10 below, it shows a schematic design of a conventional planner SOFC stack design.

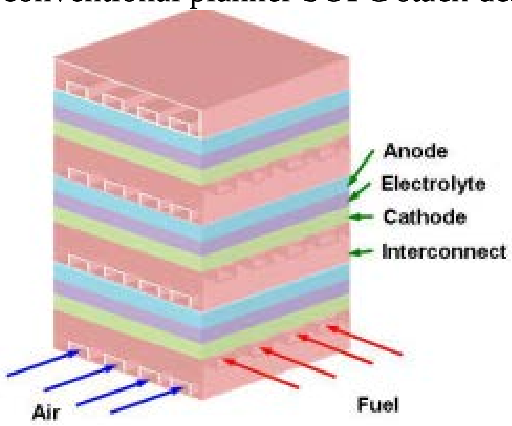


Figure 10: Conventional planner SOFC stack structure

The electrodes of SOFC are anode and cathode, and they must contain important properties in order to achieve high performance. The catalytic activities for oxygen dissociation and incorporation reactions in cathode and for electrochemical oxidation of H_2 or CO and other fuel in anode must be high. The electronic conductivity should be higher than 10 S/cm. The chemical stability and compatibility as well as the mechanical compatibility with other materials are also important. For example, the compatibility of electrolyte and interconnect must be high to avoid thermal expansion mismatch which can cause cell break down.

The most common anode material is a porus Ni-YSZ cermet, in which nickel provides the electronic conductivity and YSZ provides the oxygen-ion conduction. Strontium titanate ($SrTiO_3$) has also been proposed as an alternative anode materials. It is chemically stable and shows electronic conduction upon reduction due to the presence of Ti^{3+}.The electrical conductivity could be enhanced by donor doping with tri or pentavalent oxides such as La^{3+}, Y^{3+}, or Nb^{5+}.

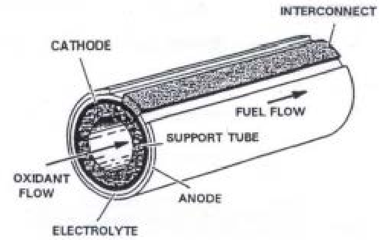
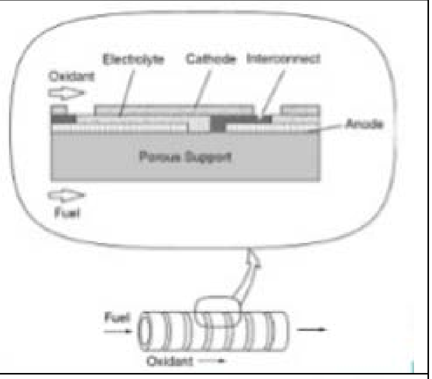
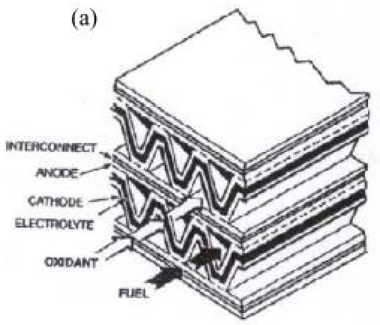
The most common type of cathode material is perovskite-based LaMnO3, and strontium is normally used to dope with LaMnO3, which becomes ($La_{1-x}Sr_x$) MnO3 (LSM). The electron conductivity is enhanced after doping. The thermal expansion coefficient of LSM match well with that of YSZ, but the ion conductivity is relatively low. As a result, there have been several studies on the increasing of LSM conductivity as well as its electrolyte close thermal expansion.

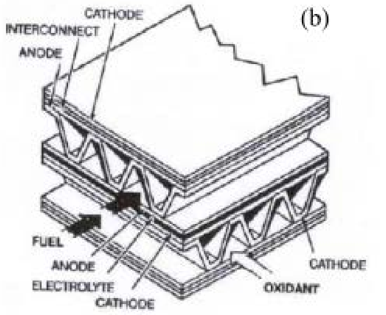
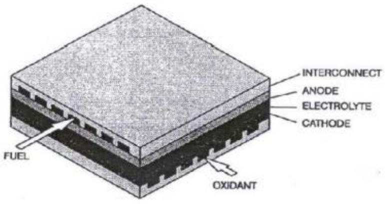
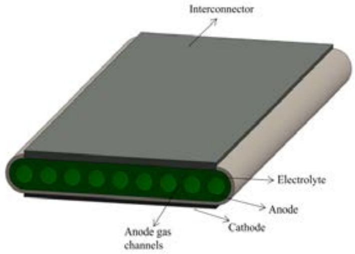
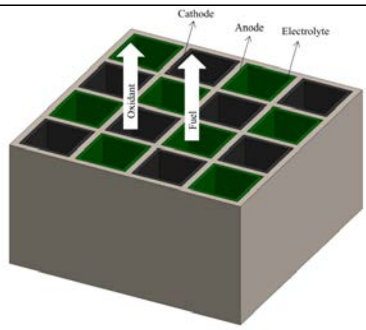
The interconnect material which is in contact with the two electrodes must be stable in both oxidizing and reducing atmospheres. Further, it must be an electronic conductor and have similar characteristics to that of electrolyte. Its chemical compatibility and coefficient of thermal expansion must be matched with the other cell components so there is no stress during operating condition. This interconnect could be either ceramic or metal/alloys materials. Ceramic interconnects are normally used between 800 and 1000^{o}C, while metallic interconnects are preferred at 750^{o}C and lower. The doped LaCrO3 is normally used as ceramic interconnects. The dopants are typically strontium or calcium to increase the conductivity. The ceramics interconnects are generally stable with YSZ electrolyte, but the limitations of their uses are the high cost and the decreasing of conductivity with decreasing temperature. Therefore, metallic interconnects are also developed which typically are Cr-based alloys and ferritic steels. They have a number of advantages over ceramic interconnects, such as its extremely high electrical conductivity, high thermal conductivity, and enhancement of the ability to accommodate thermal stresses. The chromium based alloys are attractive with dispersing of stable oxides but it is relatively costly to fabricate. The metal interconnects also have disadvantages, such as the electrical contacts between metallic interconnect and ceramic electrodes, matching of thermal expansion, oxide scale formation on the metallic surface, and cathode poisoning.

The sealant material needs to fulfill all the criteria for all components of a stack. They must be able in a wide range of oxygen partial pressure while minimizing thermal stresses during high temperature operation. The seal quality is also important, since even small leaks in these seals can affect the cell potential, resulting lower performance. Sealant development is additionally complicated because the optimal sealant depends on the materials of other components of SOFC. The rigid and compressive seals are being developed for SOFCs. A major advantage of compressive seals is that the seals are not rigidly fixed to the other SOFC components thus the exactly match of thermal expansion is not required but the load must be applied continuously during operation. The compressible seals are normally the metal gaskets, for example silver and mica-based materials. The infiltration of mica based materials can be applied to improve their properties which the infiltration can block the gaps between the mica flakes. On the other hand, rigid seals do not require the continuous load but the thermal expansion must closely match those of other SOFC components. Glasses and glass ceramics are typically used as rigid seals.

There are four common conventional SOFC stack designs, namely seal-less tubular design, segmented cell in series design, monolithic design, and flat plate design. In addition, researchers have developed new stack design such as flat-tube and honeycomb structure. In the table below, we summarize their characteristics and design schematic.

Table 5: Summary of SOFC stack structure and design

Stack Design	Characteristics	Schematic
Seal-less tubular design	● A tubular support tube that covers with cathode, electrolyte, anode, and interconnection. ● The oxidant is introduced through the center of the support, the fuel flows at the outside of the support tube. ● Elimination of seal problem, but there is gas diffusion limitation and cell internal resistance increase problem.	
Segmented cell in series design	● Similar to seal-less tubular design, but fuel is introduced through the center of the support tube, while the oxidant flows at the outside of the support tube. ● Individual segment cells are connected to each other in series.	
Monolithic design	● The design utilizes the cell components into a compact corrugated structure. The gas flow are either co-flow or cross-flow configurations. ● The advantages of this design are compact cells, self-supporting corrugated structures, and thin cell components. ● The difficulty of this design is the fabrication of materials. Any difference in the thermal expansion coefficient can result in cell cracking.	

		
Flat plate design	● The design is a flat multilayer ceramic plate composing of anode, electrolyte, and cathode. The flat multilayer ceramic plate is covered with interconnect plates, which have small gas flow channels for fuel and oxidant.	
Flat-tube design	● Flat tubular SOFC is designed to improve the lower power density of the conventional tubular design by reducing the internal ohmic loss. ● Flat tubular design is a combination of the tubular and the planar cell structures, it may provide high power density together with high thermal resistance.	
Honeycomb design	● The honeycomb design provides high mechanical strength, durability and high volumetric power density. The structure is made of honeycomb channels used as fuel and oxidant routes in an alternating sequence. ● The structure can be either electrolyte or electrode supported, the interconnection and electrical lead are the main issues with this design. ● As a result, researchers have focused on enhancing the honeycomb	

	SOFC performance by fabricating electrode supported structure or employing alternative electrolyte materials providing high relatively high ionic conductivity.	

2.2.4 Key developing technologies and components

The developing trend in SOFC is to make novel electrolyte and wet impregnated infiltrated nano-structured cells. The electrolyte supported cells provide several advantages compared to the anode supported cells, such as less susceptible to failure due to anode reduction and re-oxidation cycles known as redox and offering dense sealing regions. However, the performance of electrolyte supported SOFC is relatively low due to employing thick electrolyte layer as the primary mechanical support and thus relatively a high operation temperature is required in order to obtain acceptable cell performances. As a result, the current trend in the electrolyte supported SOFCs is to fabricate electrolytes containing thin and thick regions. The thick regions (150-200um) act as a mechanical support while the thin region (30-50um) provides higher electrochemical performance due to reduced oxide ion transfer path. NextTech Materials, Ltd. has been developing a new design called FlexCell, it is based on a two-layer membrane having a thin electrolyte layer mechanically supported by another electrolyte layer in the form of a honeycomb mesh, as shown in Figure 11. Approximately 70% of the electrolyte within the active area is thin enabling high performance.

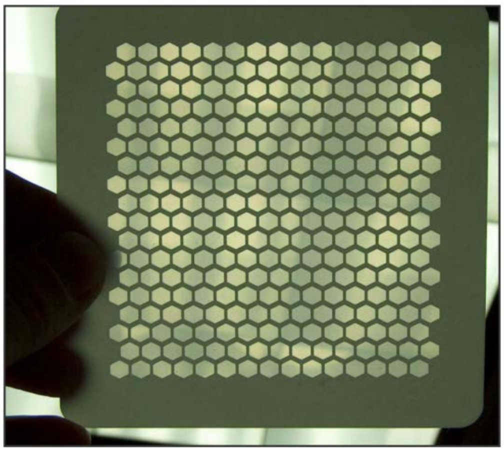


Figure 11: Novel SOFC stacks with honeycomb structure.

The anode or the cathode electrode of SOFC contains generally co-sintered catalyst and electrolyte materials in order to improve the cell performance by increasing the length of active triple phase boundaries (TPBs). This electrode structure is generally achieved by simply mixing the suitable catalyst powders with the electrolyte powers at a certain ratio. The real SOFC electrodes are porous heterogeneous materials, therefore, the electrochemical reactions can be expected to be also non-homogeneous due to the dead zones and isolated TPBs formed during the fabrication process leading to decrease in the number of TPBs. It is essential that each phase within the TPBs must be a part of a percolating network in order to contribute to the electrode performance. The number of dead zones may very cell to cell depending on the fabrication technique involved and even the environmental conditions during the fabrication. This change in the number of dead zones within the electrodes may explain the performance fluctuations between two cells which are thought to be identical cells and this is the main problem that most of the SOFC researchers have encountered especially during the scale-up studies.

2.2.5 Major Players and Suppliers

The major players of SOFC in the market nowadays are Bloom Energy in the USA, Sunfire GmbH and AVL List GmbH from Germany, Elcogen and Convion Oy from Finland, Ceramic Fuel Cells Ltd. from Australia, and MiCo Ltd. from Korea. In the area of material supply, CERA-FC Co. Ltd. from Korea, CerPo Tech AS from Norway, DOWA from Japan and Germany supply relevant materials and components.

2.3 Direct Methanol Fuel Cell

2.3.1Fundamental of DMFC

A direct methanol fuel cell (DMFC) uses methanol or methanol solutions as fuel and works at near room temperature. As shown in figure 12, methanol and water are oxidized in the anode catalyst layer and release electrons and protons during operation. Very similar to PEMFC, the electrons are transported through an external circuit to the cathode while the protons penetrate the electrolyte membrane to the cathode. In the cathode side, oxygen from the ambient air reacts with the electrons and protons and produce water to complete the chemical reaction. The overall reaction is explained in the following equations:

Anode: $CH_3OH + H2O \rightarrow CO_2 + 6H^+ + 6e^-$

Cathode: $6H^+ + 6e^- + 1/2\ O_2 \rightarrow 3H_2O$

Overall: $CH_3OH + 1/2\ O2 \rightarrow CO_2 + 2H_2O$

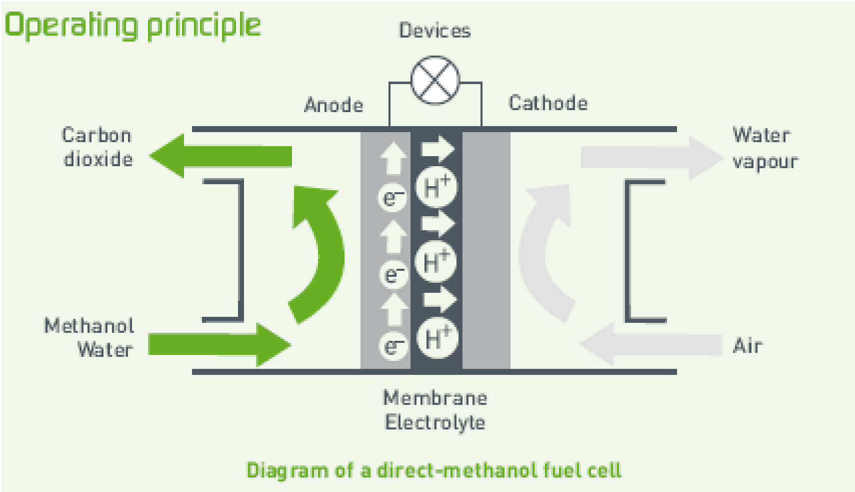


Figure 12: A schematic of a DMFC operation principle.

DMFCs are better suited for power-hungry portable devices than PEMFCs fed with hydrogen and oxygen or lithium ion batteries. In addition, DMFCs have high energy density due to methanol has a theoretical energy density of 6.1kWh/kg, equivalent to 610Wh per 100g of methanol, which can allow a conventional notebook PC to operate more than 20 hours. DMFCs can be categorized as active, semi-passive, or passive based on the fuel and oxidant supply modes. DMFCs have advantages over rechargeable batteries, but the current power supply systems in portable electrical devices are still mainly dominated by rechargeable lithium and nickel based batteries. The commercialization of DMFCs has been postponed due to their high cost, low life time, and technical barriers. Further developments are required to solve methanol crossover issue in order to increase the methanol concentration without much dilution by water, which decreases the energy density. Figure 13 explains the fuel crossover path in a DMFC stack.

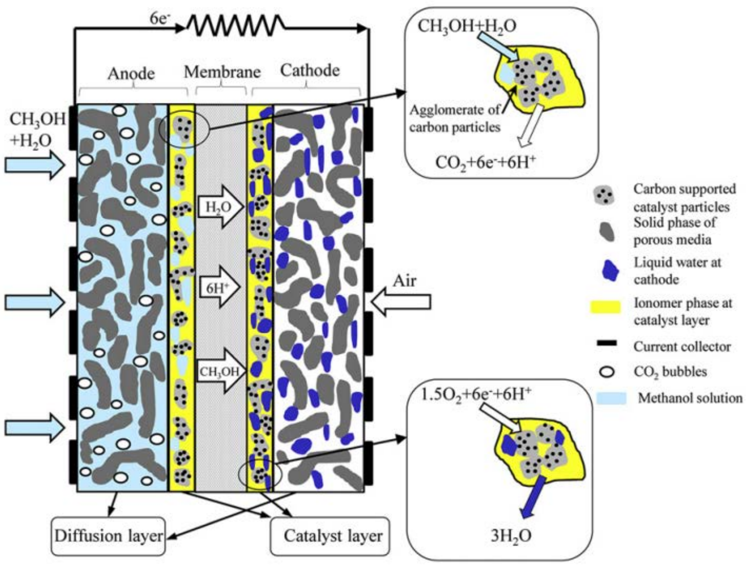


Figure 13: A schematic of DMFC operation, showing fuel cross over path.

2.3.2 Stack Structure

The stack structure of DMFC is very similar to PEMFC, except it is fed by methanol solution as fuel. Differently, a DMFC stack has a liquid feed on the anode side, and it requires a escaping path to allow CO_2 to come out. In a DMFC stack, methanol crossover and water management of DMFC are important tasks to handle, which are the factors limit the power output of the fuel cell stack. Until now, DMFC stack is still in small scale compare with the technology of PEMFC

DMFC stacks are categorized in passive, semi-passive, and active; and their stack designs are different. Passive DMFCs use no auxiliary components for the supply of methanol, water, and oxygen. The supplies are passively transported from the methanol tank reservoir and ambient air to the membrane electrode assembly (MEA) by capillary forces, gravity, and concentration gradients. Passive DMFCs are more compact, simple, and reliable, but its output power range is often less than 10 watts.
Active DMFCs are fed with methanol solutions and oxidant using pumps, fans, sensors, heaters, and humidity components. In an active system, the fuel and oxidant supply rates can be accurately controlled, producing the highest performance when necessary. To achieve high power output, an active DMFC system design is required. Semi-passive DMFCs have either a passive anode or cathode, and an active anode or cathode, respectively. Whether to select passive or active design, it is related to the types of applications, and it is also based the requirement of overall system efficiency. Figure 14 shows a schematic of an active DMFC cross section, demonstrating the structure concept of a stack.

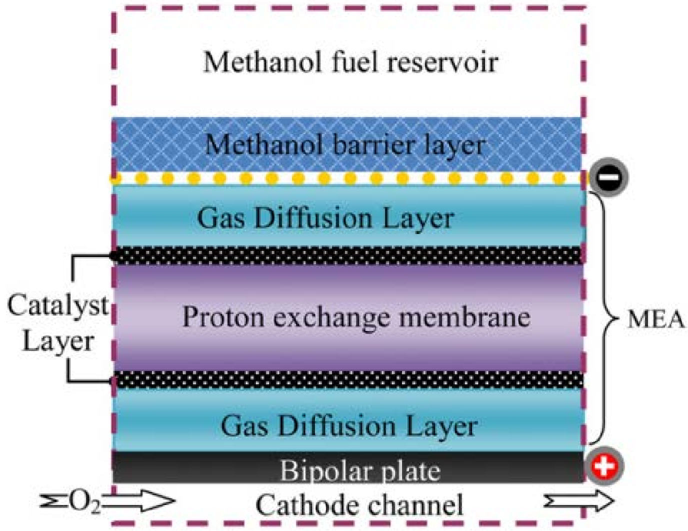
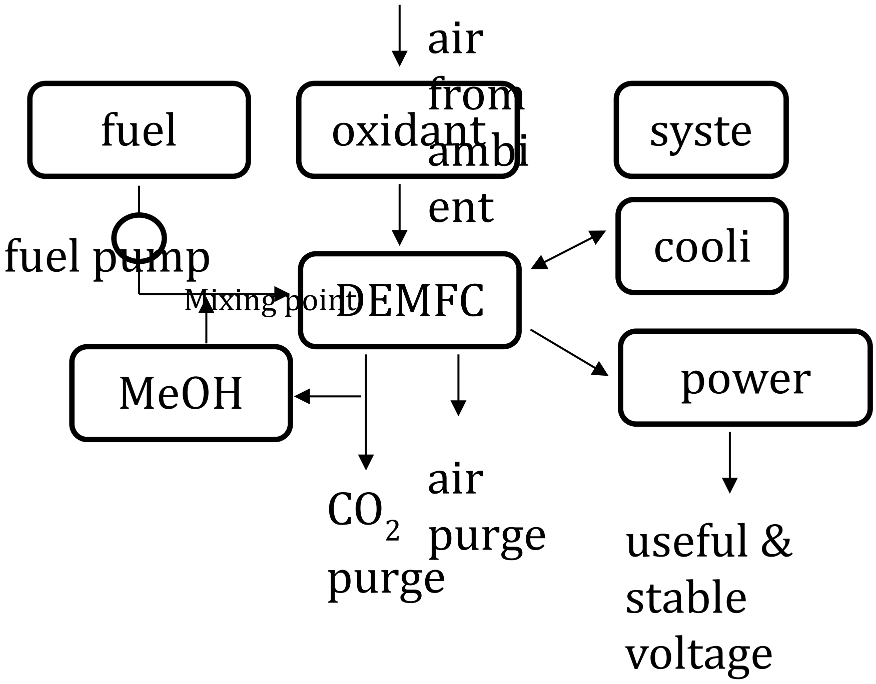


Figure 14: A schematic of a semi-passive DMFC fed with high concentration methanol

2.3.3 System Layout

In this section, we will summarize the system layout of an active DMFC. EFOY is a well know commercially available DMFC system. It is taking diluted methanol solution to generate electricity in an active and well controlled DMFC system. EFOY has its advantages over traditional lead-acid battery on storage life time, energy density, and operation temperature. DMFCs can be a great solution to extend battery run time in a remote area. Figure 15 shows a system layout of a DMFC system.



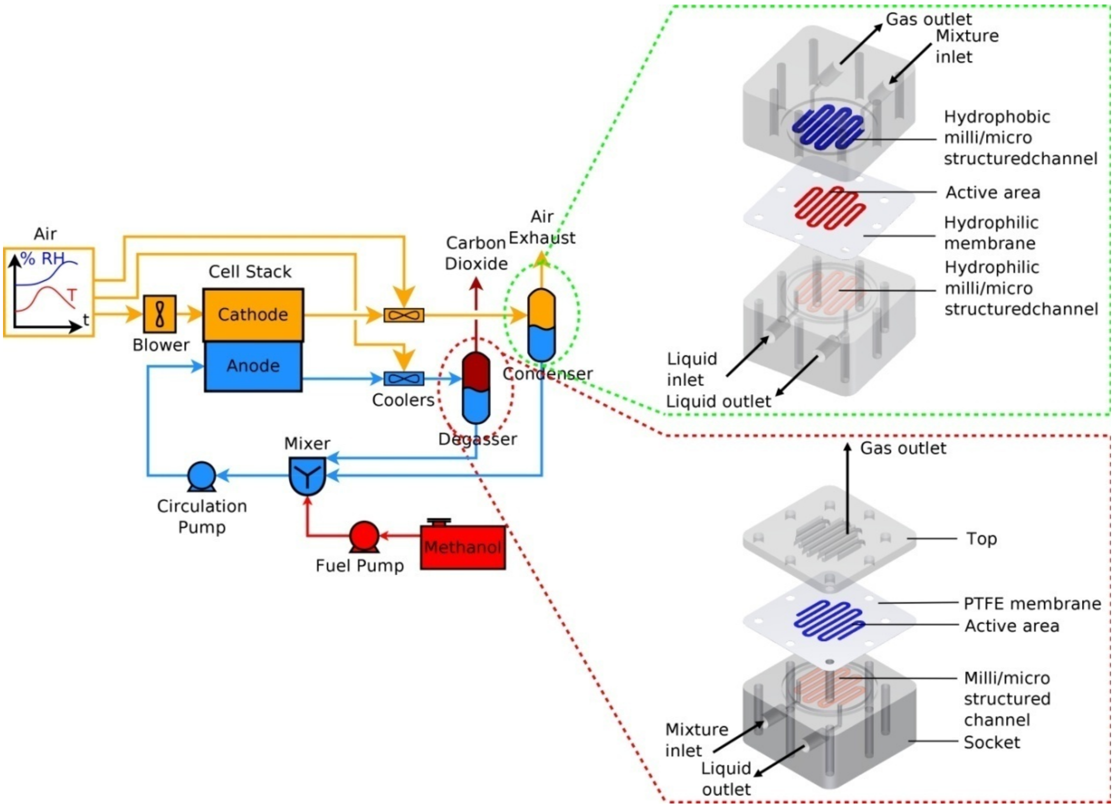


Figure 15: A system design of a portable DMFC system with gas and liquid separators.

2.3.4 Key developing technologies and components

The blooming market for portable electronic devices forecasts that there will be huge demand for portable power systems with high power and energy density. By hybridizing with lithium batteries, DMFCs are suitable for the applications, but there are still some technical barriers to overcome. The development trends on further improvements of DMFC are ongoing, in this section, we summarize the target areas for further development.

Table 6: DMFC future technology development directions

Further Development Area	Description
Methanol concentration sensors	In a high concentration DMFC system, it is necessary to control the concentration of methanol solution b recovering water from the cathode side. The continuous change of electric load requires rapid change of the fuel concentration. So a sensitive methanol concentration sensor with a fast response time is the most critical component of the system in order adjust the concentration of fuel supply. The sensor should also be energy efficient and compact.
Reducing CO_2 crossover	CO_2 crossover to cathode will decrease the water back flow rate and decrease the cell performance. CO_2 will impede the O_2 transportation at the cathode side and cause mass transfer limitation for the cathode reaction. It is important to reduce CO2 crossover and allow it to escape at anode.
Low contact resistance MEA	Contact resistance of MEA composes 65-90% of the total stack resistance, the high contact resistance at the interfaces of the fuel cell affect the heat and mass transfer. It is important to improve contact resistance of MEA s of DMFC technology.
Compact stack design	DMFC is mainly for portable and remote power applications, it is important to minimize stack size and make the system as compact as possible.
Increase durability and lower cost	The durability and cost of DMFCs are the two important technical factors impact the commercialization of DMFCs, a target of 5000 hours lifetime is required by DOE, further improvement on cost has been extensively researched. Since DMFC system does not require expensive fuel storage and additional fuel reformer, the main cost is on stack and MEA. It is important to lower the stack cost so the overall system will have big advantages.

2.3.5 Major players and suppliers, and trends

DMFC supplies are not as many as PEMFC, due to its technology readiness is not as mature as PEMFC. Two active companies who supply commercially available products are SFC Energy and Oorja. Other companies which are involved with DMFC development are LG, Samsung, MeOH Power from MTI, Neah Power, and Jülich from Germany. The current largest DMFC system is less than 1 kW with combinations of small stacks operating in series and parallel. Although the power output of DMFC is not as large as PEMFC, the trend for lower power consumption of power electronic products could soon meet the power output of DMFC, which means if the cost of DMFC is lowered by volume production, DMFC is a promising technology to solve the issue of power-hungry consumer electronic products.

2.4 High Temperature PEM Fuel Cell

High temperature proton exchange membrane fuel cells (HT-PEMFCs) share similar stack structure with the well-know low temperature PEMFCs, however, HT-PEMFCs are highly tolerant to CO concentration in the fuel streams. CO, carbon monoxide, is a known fuel cell poison and is a result of utilizing reformates gas or liquid fuels. HT-PEMFC operates at higher temperatures (typically 160 - 180 ^{o}C) than the conventional LT-PEMFC, as a result, HT-PEMFC has a high degree CO tolerance and can be operated with low-purity hydrogen. The fuel cell can tolerate up to 3% (30,000ppm) CO and up to 20ppm of sulphur without permanent stack degradation. Since this stack operates at higher temperature, additional benefits include non-humidification, higher grade heat recycle, which means less balance of plant (BoP) power is required and higher system efficiency in theory.

2.4.1 Fundamental of HT-PEMFC

In contrast to LT-PEMFC, HT-PEMFC incorporates a different membrane, which is a polybenzimidazole doped polymeric membrane with phosphoric acid (PBI/H3PO4). In comparison with Nafion, this high temperature membrane (PBI based) has high proton conductivity at higher operation temperature (Figure below).As a result, HT-PEMFC shares some advantages over LT-PEMFC. In the following section, we explain the reasons for these advantages.

High CO tolerance advantage

A trace level of carbon monoxide, which is a byproduct of fuel reformation, can cause a large decrease in the performance of the LT-PEMFC due to catalyst poison. In HT-PEMFC, this problem can be avoided by operating above 150^{o}C, and this offers a significant advantage as many stages of fuel processing and gas cleaning can be removed therefore lower down fuel cost and simplify the reforming system design.

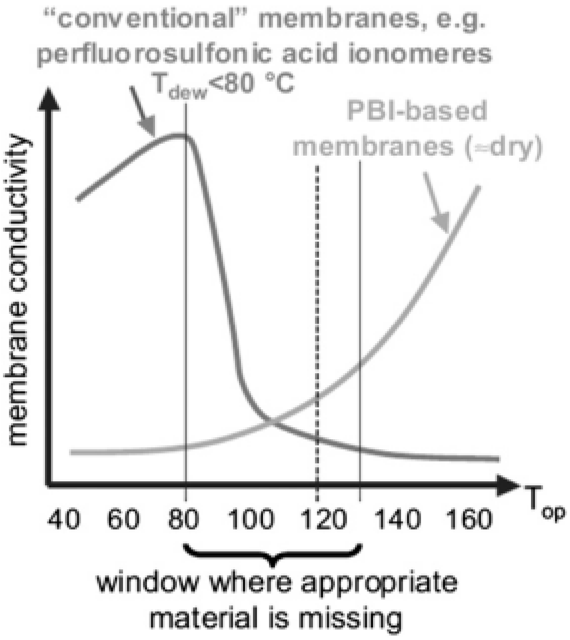


Figure 16: Membrane conductivity at low and high temperature conditions

The adsorption of CO on Pt is associated with high negative entropy, which indicates the adsorption is strongly favored at low temperatures, and disfavored at higher temperatures. At 130oC, for example, Pt-based catalyst can tolerate up to 1000 ppm CO. Yang et. al. reported that increased tolerance to CO is related to the thermodynamics of adsorption of CO and H2 on Pt. Research found that CO tolerance can be 30000ppm when operating at 200oC, this means the high temperature fuel cell can use hydrogen directly from simple reformer.

A plot shown below illustrating the equilibrium coverage of CO on Pt at CO concentrations ranging from 1 to 100 ppm with a H2 pressure of 0.5 bar. It is clear that operation at higher temperatures increases the ability of the fuel cell anode to perform in the presence of small amount of CO by decreasing the coverage of CO on the catalyst surface.

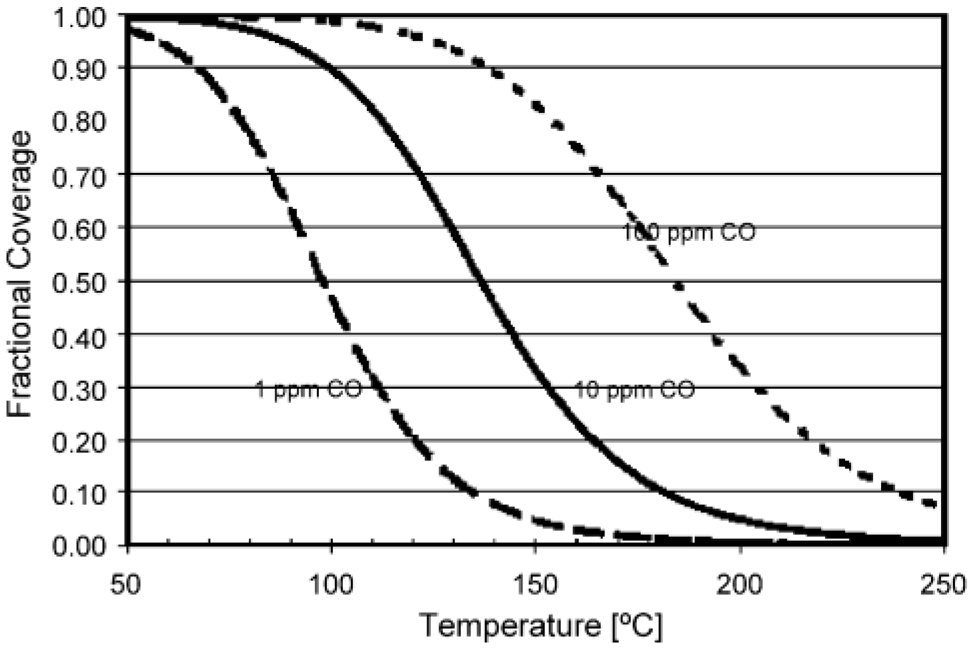


Figure 17: Illustration of CO coverage fraction on platinum as a function of CO concentration and temperature. The partial pressure of H2 is at 0.5 bar.

Heat and water management

Fuel cell generates electricity and heat, in a typical fuel cell, 40 to 50% of the energy is produced as heat. As a result, heat must be removed quickly in order to avoid membrane dehydration and material degradation. At higher operating temperature, the heat transfer rate is increased due to larger temperature gradient between the fuel cell and ambient condition. Therefore, cooling becomes relatively easier, and more useful heat can be recycled for cogeneration and on-board reforming.

Water management becomes simpler when dealing with HT-PEMFC system operation. In the high temperature condition, there is only a single phase of water present, water is in gaseous form, therefore the transport of water in the membrane, electrodes, and diffusion layer is easier and flow field plate design can be greatly simplified. In addition, at higher temperature, the reactant and product gases are expected to have increased rate of diffusion, and the absence of liquid water allows more active surface area thus more reaction can occur.

Improved cathode kinetics

In a typical LT-PEMFC, the exchange current density for the electrochemical oxygen reduction (ORR, in a scale of 10^{-8} to 10^{-9} A/cm^2) is much smaller than that of the hydrogen oxidation reaction (HOR, in a scale of 10^{-3} to 10^{-4} A/cm^2). Since HOR at the Pt nano particle/PEM interface is reversible, the over-potential for HOR is negligibly small compared with that of ORR when the anode is adequately hydrated. in a conventional LT-PEMFC. As a result, the overall electrochemical kinetics of a LT-PEMFC is determined by the relatively slow oxygen reduction reaction (ORR).

By switching to higher temperatures, the ORR reaction rate is significantly improved therefore can improve the overall performance of the PEMFC.

The performance of a PEMFC in the kinetically controlled regime can be represented by the following Tafel equation:

$$E = E_{rev} + b\ log\ io - b\ log\ i$$

$$b = -2.3\ \frac{RT}{\propto n F}$$

where E is electrode potential,

E_{rev} is reverse potential

b is Tafel slope

i is current density

i_o is exchange current density

a is transfer coefficient

n is the number of electrons transferred in the rate determining step

Through experiment, it was found that the Tafel slope corresponding to the ORR increases with temperature in the low current density region, while it is independent of temperature in the high current density region. Kinetic parameters associated with the ORR at Pt/PEM interfaces have been investigated using electrochemical impedance spectroscopy (EIS) and linear sweep voltammetry (LSV) in a solid-state electrochemical cell using microelectrodes. It is found that current exchange density, i_o, increase with temperature.

However, in the case of HT-PEMFC when operating above 100^{o}C, anode dehydration may become a significant challenge. For example, lower temperature PEMFCs employ aqueous-base polyelectrolyte membranes, for which proton conductivity depends strongly upon the relative humidity. At higher operating temperature, membrane dehydration and the subsequent decrease in proton conductivity is a significant issue. Moreover, components experience structural and chemical degradation at elevated temperatures. These problems are challenges for the scientists and engineers who involve with the research and development of HT-PEMFC technology to overcome. We will describe further on key developing technologies and components in the next section.

2.4.2 System Layout

The general power generation principle of a typical high temperature proton exchange membrane fuel cell (HT-PEMFC) is the same with that of the low temperature proton exchange membrane fuel cell (LT-PEMFC). However it also features greater power efficiency and a wider range of thermal energy usage. The HT-PEMFC is operated between 100 to 200℃ while the LT-PEMFC is operated between 60 to 80℃

In contrast to the LT-PEMFC, which requires expensive and complicated configuration and components due to its complex water management and low durability against CO (less than 10ppm in the fuel), the HT-PEMFC has advantages which include a simpler design and lower cost due to the reduced number of components as well as the generation of less condensed water and high durability against CO. With the high temperature feature, the thermal energy usage rate is increased, thereby allowing both cooling/heating services to be provided at the same time as the heat generation. The reforming system of HT-PEMFC is simplified by the removal of CO cleaner and air stream humidifier, a sample system layout is shown in below figurers.

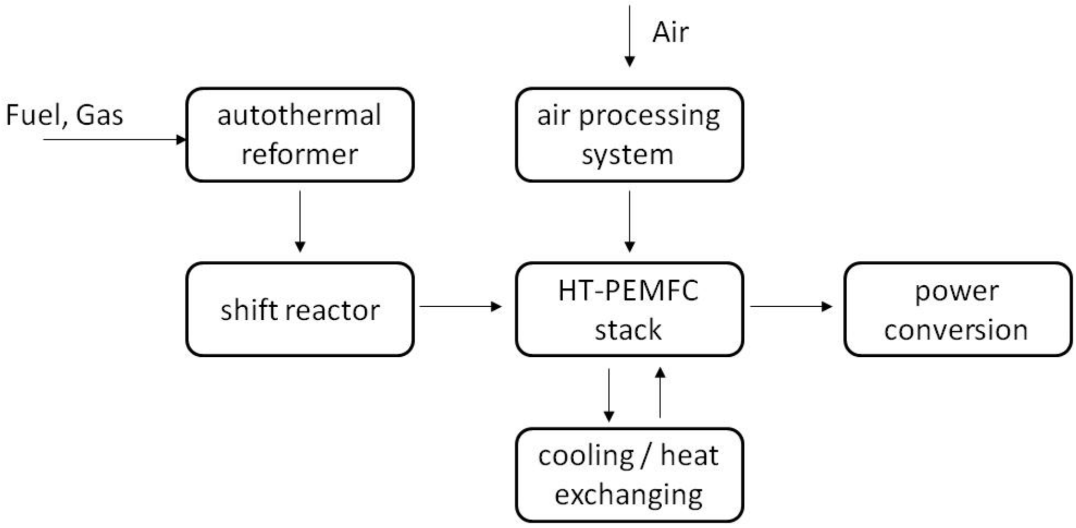


Figure 18: A schematic of HT-PEMFC system layout

2.4.3 Stack Structure

The stack structure of HT-PEMFC is similar with conventional LT-PEMFC, which is composed of bipolar plates, gas diffusion layer, and membrane electrode assembly. The following figure shows an example of typical HT-PEMFC stack structure.

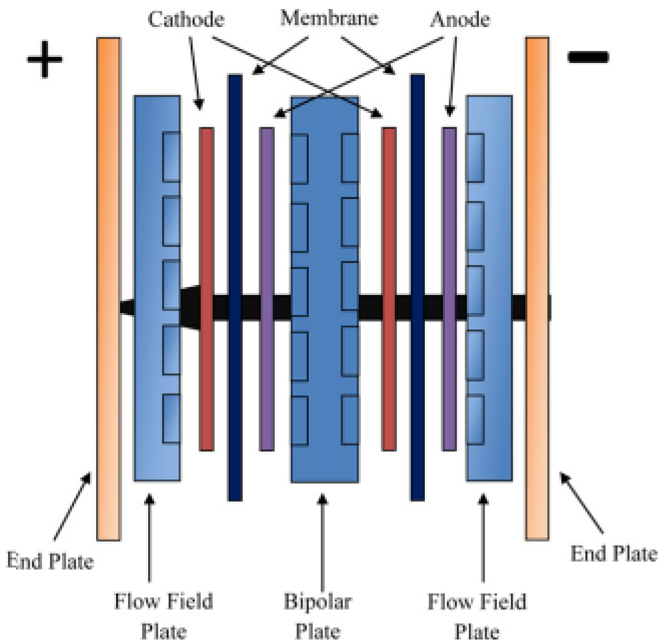


Figure 19: HT-PEMFC stack structure example

2.4.4 Key developing technologies and components

Although HT-PEMFCs has several attractive advantages, they actually also encounter great challenges when being operated at higher temperatures, mainly face material durability and heating problem. Table below shows a summary of potential challenges. Many technologies development activities are in progress to make this technology more mature. In the past, 90% of the research and development activities are focused on membrane. We will discuss the progress of research in this section.

Table 7: A summary of HT-PEMFC technology challenge and future development

Challenges	Description
Membrane acid leaching	Acid-based HT-PEMFC membranes, typically well known phosphoric acid doped PBI materials are thought to be a way of addressing dehydration issue at elevated operating temperature. However, acid leaching from these materials leads to serious degradation of the fuel cell components.
Start-up time delays	PEMFC is well known for its quick start-up time, yet the high temperature operation requires slowly heat-up to the optimum condition, could take up to half an hour.

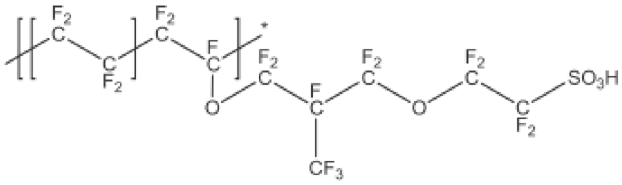
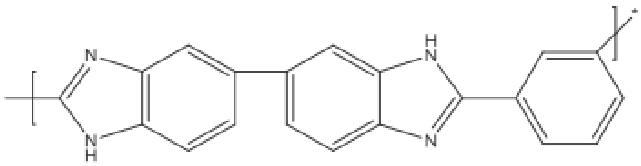
Membrane development

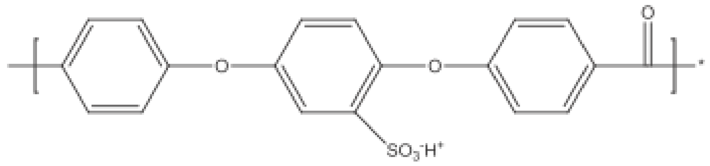
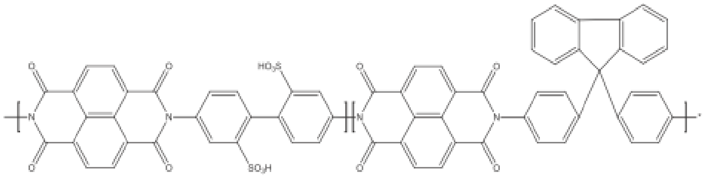
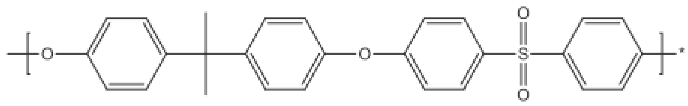
Many researchers are aiming to develop new membranes for temperature up to 200 ^{o}C, this is because as the operating temperature increased, it leads to higher CO tolerance. If CO tolerance can be increased, the overall reforming design can be simplified and cost can be reduced. Fuel selection can also be flexible with liquid alcohol or natural gas.

For all types of proton carriers there are similar conditions. First, the membrane materials must absorb an optimum amount of proton carrying medium to reach best conductivity. The medium for HT-PEMFC, typically, is phosphoric acid (H_3PO_4). The loss of conducting medium results in the reduction of conductivity, degradation of membrane, damage or flood the electrodes and blockage of the flow field plate channel. Conductivity takes place via diffusion or proton hopping. The mechanism that takes place depends on which proton conducting medium is present. Water containing membrane includes Nafion, other fluorinated membranes and a large class of sulfonated aromatic hydrocarbons. The non-water membranes include acid-base systems such as polybenzimidazole (PBI) doped with phosphric acid and materials rendered conductive by ionic liquids. To increase the update of the proton carrier, the concentration of the polar group (acid or base) on the polymer backbone must be maximized.

In table 8, it presents some of the most common polymer based membrane for HT-PEMFC application.

Table 8: Summary of common HT-PEMFC polymer membranes

Membrane	Description
Nafion/PFSA 	Perfluorinated sulfonic acid (PFSA) membrane is an alternative to Nafion, it has been optimized for HT-PEMFC application. Various short side chain (SSC) PFSAs have been developed over the years and research team of Dr Stassi recently obtained good single cell performance with an Aquivion membrane at 130oC and 100%RH obtaining a power output of 870 mW/cm2 compared to 620mW/cm2 for Nafion N112 under the same condition.
PBI 	Polybenzimidazole (PBI) can be prepared by polymerisation of an appropriate diamine and carboxylic acid in polyphosphoric acid at 180-200^{o}C. Recently, research group Dr Lin reported increased mechanical strength and single cell performance for an epoxy crosslinked PBI achieving a maximum power density of 172 mW/cm2 at 160oC and 0%RH. A new type of sulfonated PBI prepared by random copolymerisation was recently reported with relatively high conductivity of 0.037 S/cm at 170^{o}C and 0%RH with single cell performance around 300mW/cm^2.
SPEEK	Sulfonated hydrocarbon polymers form another class of membranes wich are suitable for higher temperature PEMFC. The

	starting material for SPEEK is often commercial PEEK which is then sulfonated with concentrated sulphuric acid.
SPI 	Sulponated polyimine (SPI) can be prepared by reacting a sulfonated diamine monomer, triethylamine, naphthalenetetracarboxylic dianhydride, a hydrophobic diamine monomer, benzoic acid and m-creosol at temperature from 150 to 195^{o}C
SPSU 	In the same fashion as SPEEK, sulfonated polysulfone (SPSU) can be prepared by the sulfonation of commercial PSU with chlorosulfonic acid or by the polymerisation of sulfonated and unsulfonated monomers.

Besides the above mentioned polymer membrane, composite membranes are attracting a great deal of attention as means for increasing the temperature tolerance of conventional PEM materials. They are manufactured by doping a polymer with a filler material. The main objective of adding filler is to improve water update and retention so the conductivity at high temperature and low humidification is enhanced. Most types of polymer electrolyzes have successfully been doped with inorganic fillers such as hygroscopic oxides, clays, zeolites, mineral acids, heteropoly acids and ziconium phosphates.

Inorganic or solid acid membrane is another promising class of membrane for higher temperature fuel cells. This class of materials undergoes a superprotonic phase transition. As when passing through a specific temperature point, their proton conductivity increases by several orders of magnitude. Dr Dupuis has done extensive review of the materials. The most promising material appears to be CsHSO4 with a superprotonic temperature of 140^{o}C. The recent study shows its conductivity of 0.04 S/cm at 200^{o}C (**). However, cell and stack performances still require further investigation. The challenges of these materials are water solubility, mechanical instability, and compatibility with other cell components, which all needed to be addressed.

Table 9 shows a summary of potential high temperature membranes materials and the entries that are highlighted have met DoE targets of 2015.

Table 9: A summary of potential high temperature membranes materials and the entries that are highlighted have met DoE targets of 2015.

Membrane material	Conductivity/Temp/%RH
Nafion®/(5 wt%) SPPSQ*	0.157 S cm^{-1} at 120 °C and 100 %RH
PBI/H_3PO_4/(40%) SiWA	0.177 S cm^{-1} at 150 °C and 0 %RH
Recast Nafion® **	0.002 S cm^{-1} at 130 °C and 100 %RH
Nafion® *	0.035 S cm^{-1} at 120 °C and 30 %RH
Nafion® 117/(20 wt%) ZrSPP	0.1 S cm^{-1} at 100 °C and 90 %RH
Recast Nafion®/(20 wt%) ZrSPP*	0.05 S cm^{-1} at 110 °C and 98 %RH
Recast Nafion® */SGO	0.047 S cm^{-1} at 130 °C and 30 %RH
SPEEK-WC	0.00022 S cm^{-1} at 96 °C and 85 %RH
SPEEK-WC/SiW (9.6 wt%)	0.0013 S cm^{-1} at 96 °C and 85 %RH
SPEEK/poly(imi-alt-CTFE)	0.001–0.015 S cm^{-1} at 120 °C and 25–95 %RH
SPEEK/ZrP–NS)	0.079 S cm^{-1} at 150 °C and 100 %RH
SPI with fluorene groups	1.67 S cm^{-1} at 120 °C and 100 %RH
SPI with fluorene groups	0.003 S cm^{-1} at 160 °C and 12 %RH
SPI with sulfophenoxypropoxy pendants	1 S cm^{-1} at 120 °C at 100 %RH
SPU with fluorene	0.5 S cm^{-1} at 110 °C and 50 %RH
CF_6–PBI	0.12 S cm^{-1} at 175 °C and 10 %RH
SO_2–PBI	0.12 S cm^{-1} at 180 °C and 5%RH
PBI/SPAES	0.045 S cm^{-1} at 200 °C no external humidification
PSU with pyridine and hydroquinone groups	0.02 S cm^{-1} at 120 °C 0 %RH
72TEOS–18PDMS–10PO $(OCH_3)_3$/40%[EMI][TFSI]	0.00487 S cm^{-1} 150 °C 0 %RH
TMOS–TMPS–TEP/(40%) $BMIMBF_4$	0.006 S cm^{-1} 150 °C 0 %RH
30TMOS–30TEOS–30MTEOS –10PO$(OCH_3)_3$/(40%) $EMIMBF_4$	0.01 S cm^{-1} 155 °C 0 %RH
60TMOS–30VTMOS –10PO$(OCH_3)_3$/(40%) $EMIMBF_4$	0.0089 S cm^{-1} 155 °C 0 %RH

2.4.5 Major players and suppliers

The field of HT-PEMFC is still relatively new compare with LT-PEMFC. There are few players involved in this segment. Serenergy A/S is a well known company from Denmark which has been devoted to the development of high temperature PEM in stack design and system integration. In addition, Elcore and Truma provide small scale system for micro-CHP and auxiliary power unit, respectively. In the area of membrane supply, Advent is a company who has invested in R&D and pilot manufacturing in the Greese and USA, who continues to supply HT-PEMFC membrane after BASF exited the market. Besides Advent, Danish Power Systems also manufacture high temperature MEAs.

Table 10: A summary of major HT-PEMFC players and suppliers

Suppliers	Products
Advent	Membrane, TPS® HT membrane Membrane, PBI base (P1100W) licensed from BASF
Danish Power Systems	Membrane, **Dapozol®** MEA
Bac2	ElectroPhen® Bipolar plate for HT-PEMFC
ENrG	HEXIM™,integrated ceramic heat exchanger for HT-PEMFC
Borit	Bipolar metallic plate using hydroformation for HT-PEMFC
SerEnergy	System Integrator, stationary & transportation
EnerFuel	System Integrator, stationary
Elcore GmbH	System Integrator, stationary mCHP

The potential market for HT-PEMFC technology is micro-CHP, power production and APU, portable power, battery extender, and hydrogen separation.

2.4.6 Technology Trend

The success of the HT-PEMFC direction is very much dependent on the development of the membrane material, followed by the optimization of the MEA. This two will determine a whole range of other factors, such as the MEA fabrication technique, the FFP material choice, the stack design, and the system design. The only membrane material to come close to meeting all the DOE targets at high temperature is acid doped PBI. Yet, it works at a temperature that is not suitable for mobile applications. The requirement of membrane humidification limits the development of this type fuel cell. Further improvement on membrane conductivity at low humidification still requires.

Besides membrane development, the development for new catalyst for HT-PEMFC is also a trend. It is important to utilize platinum catalyst well. One of the major issues with using platinum as a catalyst is its propensity to degrade. Researchers have found that by using ionomer such as Nafion as a surfactant, they were able to stabilize the platinum particles. As a result, this allows for 90%

utilization of the platinum as Nafion can help to achieve good interfacial contact between water and proton. Further research would be required to see whether it is possible to utilize the same techniques using the high temperature PBI based membrane ionomers to see the result. It may also be possible to use alternative catalyst such as iron and cobalt because of the increased kinetics due to operating at higher temperature.

HT-PEMFC has great potential to lower down the overall system cost and solve the requirement of high purity hydrogen issue. When new and better membranes are developed, and novel and more stable catalyst are synthesized for cost reduction and durability, HT-PEMFC is a very promising technology for the application of micro-CHP, portable power, APU, and electrical vehicle range extender.

Reference

1. A review of polymer electrolyte membrane fuel cells: Technology, applications, and needs on fundamental research.
2. Reviews on solid oxide fuel cell technology
3. Phase Selective Membrane Based Separators for Portable Direct Methanol Fuel Cell Systems
4. G. Xiao, Q.F. Li, A.H. Hans, N.J. Bjerrum, J. Electrochem. Soc. 142 (1995) 2890-2893.
5. C. Yang, P. Costamagna, S. Srinivasan, J. Benziger, A.B. Bocarsly, J. Power Sources 103 (2001) 1-9
6. Q.F. Li, R.H. He, J.O. Jensen, N.J. Bjerru, J. Electrochem. Soc. 150 (2003) A1599-A1605
7. Parthasarathy, S. Srinivasan, A.J. Appleby, C.R. Martin, J. Electrochem. Soc. 139 (1992) 2530-2537
8. Review and advances on direct methanol fuel cells (DMFCs)
9. A review on stack design for high performance solid oxide fuel cells
10. The fuel cell industry review 2014
11. Description of PEM fuel cells system
12. A review of polymer electrolyte membrane fuel cells: Technology, applications, and needs on fundamental research.
13. High temperature (HT) polymer electrolyte membrane fuel cells (PEMFCs) - A review
14. High temperature PEM fuel cells