2016 INTERNATIONAL FORUM KOREA

on Advances in Mechanical Engineering

Edited by Yong-Taek Im, Chae Whan Rim, and Young Joong Kim

IFAME

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on Advances in Mechanical Engineering

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nst National Research Council of Science & Technology

NAEK The National Academy of Engineering of Korea

KAST 한국과학기술한림원 The Korean Academy of Science and Technology

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PREFACE

The Fourth Industrial Revolution has begun, and the world is facing tremendous challenges. Efforts to increase the efficiency and productivity of each sector of the world economy have been made in various fields.

A new government was established in 2013 in Korea, and the Ministry of Science, ICT, and Future Planning (MSIP) was introduced to set up and promote a "creative economy," which was interpreted as creative economic activities to create new jobs by launching new start-ups and to find a new cash-cow to lead the Korean economy to a bright future, breaking through the US$30,000 barrier in terms of GDP per capita, which has been the limit in Korea since 2006.

KIMM has spurred the creative economy by launching International Forum Korea on Advances in Mechanical Engineering (IFAME) in 2014 in order to promote research, business and development (R&BD) in mechanical engineering. Previous IFAMEs have provided excellent opportunities to exchange experiences and discuss new directions of R&BD in mechanical engineering, attracting more than 200 participants from around the world.

The theme of the third IFAME was "Mechanical Engineering and Global Sustainability." With advanced nations around the globe rediscovering manufacturing as a source of economic growth and national security, KIMM has recognized its duty as a national research institute and opened up discussions to stimulate technological innovation and to create a fertile environment for convergence for manufacturing. I am delighted to have engaged in these meaningful discussions this year, as 2016 marks the 40th anniversary of the establishment of KIMM.

The one-day Forum featured outstanding presentations and open discussions by renowned speakers from industry, academia, and research institutions from Germany, the US, Switzerland, and Taiwan on the new initiatives, plans, and best practices concerning spearheading technological advances, in particular, for commercialization of nanotechnology, industry and entrepreneurship, and technology transfer of public research.

Dr. Chang-Jin Kim, Professor of Micro and Nano Manufacturing Laboratory in the Mechanical and Aerospace Engineering Department at the University of California at Los Angeles talked about "Superhydrophobic Surfaces for Reducing Frictional Drag: Dream or Reality?" In his talk, he explained when a solid object moves in a liquid, drag impedes its motion, calling for energy consumption. Since maritime transportation alone accounts for a significant portion of the global oil consumption and greenhouse gas generation, a reduction of the water drag by even a small fraction would have a considerable benefit worldwide. As the skin friction drag is the largest portion of the total drag experienced by water vehicles, numerous mechanisms to reduce the skin friction have been developed for decades. However, none has been widely accepted because of poor energy efficiency. About a decade ago, superhydrophobic (SHPo) surfaces started to receive significant attention because the air layer between water and the surface can lubricate the water flows, decreasing the skin friction. Unlike other existing gas-lubricating methods, SHPo surfaces would hold a gas layer (called plastron) within the microscopic structures on the surface, making it possible to reduce skin friction without consuming energy to provide the gas. He summarized what we know today in the community and explained what we need to accomplish in the future before the SHPo drag reduction finally becomes a reality for practical applications.

Dr. Helmut Schift, head of Polymer Nanotechnology Group at Paul Scherrer Institute in Switzerland talked about "Back to Mechanics – How Nanoimprint Lithography Changed the Way How We are Thinking about Nanomanufacturing?" In his talk, he started with Gordon Moore had predicted the 'inner law' of growth for (integrated circuit) microchip manufacturing, the well-known 'Moore's law', which is a transfer of economic rules into the world of lithography in 1965. In 1995, with the presentation of the high resolution capabilities of nanoimprint lithography (NIL) by Steven Chou, patterning by molding became a candidate for overcoming the limitations of photon based patterning by mechanical means. Since the take-up of NIL into the International Technology Roadmap for Semiconductors (ITRS) roadmap in 2003, 'More Moore' describes how this roadmap could be pursued by integration of NIL into the process chain, as a next generation lithography with high resolution. While 50 years of 'Moore's law' demonstrate how economic rules govern technological progress, 20 years of NIL development show the challenges of making a new technology – based on a paradigm of mechanical patterning – ready for production in semiconductor manufacturing. However, NIL can be used in a range of other applications, and is currently used in production of patterned sapphire substrates and photonic devices. In this respect NIL is nearer to the invention of the scanning force microscope (SFM) in 1985, which was a milestone in surface microscopy with a broad impact on research. In his talk, he has given an overview about the development of NIL within the last 20 years, how NIL has profited from the development of processes such as micromachining, polymer processing and surface treatment and the further needs to exploit the full potential of NIL by using the 3D nature of molding, a broad range of networks, collaborations across borders and dedicated companies providing tools and materials.

Dr. Hellmut Schmücker, retired head of Technical Division at Max Planck Institute for Physics in Germany talked about "KIMM – Birth, Growth, and Impact" with his memories and experiences as an advisor to KIMM from 1977 to 1981. He introduced that KIMM was born in 1976 as a joint effort of the Republic of Korea and Federal Republic of Germany. Korea was at the edge of industrialization and requested quality enhancement measures to strengthen the competitiveness of their products on the world market. The joint effort called for the establishment and operation of a machinery- and metal testing institute to offer services to relocated and newly established industries in the Changwon and Masan area. The political as well as the economic situation at the time of groundbreaking is highlighted, the interaction of the government and private sector in Science and Technology politics is considered and their success is evaluated in some strategic fields. Threats to further developments and growth are considered.

Dr. Jeong-Soo Lee, Vice President at Materials & Devices Advanced Research Institute of LG Electronics in Korea introduced "Innovative MEMS, Opto and Nano Technologies in LG Electronics." In this talk, today's fast changing business environment and diversified consumer segments require companies in the consumer electronics industry to respond quickly and decisively to market conditions and business growth opportunities. To cope with this change, LG Electronics is currently shifting its business domain from traditional consumer electronics (TV, mobile) to high growth B2B domains such as automotive and energy/environment. The fundamental R&D areas required in these new businesses are materials and devices which include MEMS, optoelectronics, photonics and nanomaterials. In this presentation, the development of key technologies such as MEMS devices will be covered.

Dr. Peter Hoffmann, Managing Director of Erlanger Lasertechnik GmbH in Germany talked about "Laser Welding in High Volume Production." In his talk, one of the automotive manufacturers´ strategies for cost reduction is the design of different models based on identical platforms. An actual example is the MQB platform of the Volkswagen Group with a shared modular construction of transverse, front-engined, front-wheel drive engines. Therefore, certain components have to be produced millions of times. Examples of sub-assemblies with a high need are shift forks, gear shift controllers or column jackets. With a view to material saving and optimum functionality they have a sheet metal design and many weld seams distributed all-over and need narrow tolerances between functional surfaces. Joining the individual parts by laser has several advantages: high speed welding, minimum heat input, no contact to a tool and only one-sided access necessary. The concept of the laser welding machine, especially the working range and the kinematics determines the accessibility from all sides. A totally new laser welding machine has been developed by ERLAS with the aim to minimize cycle times. Feeding of parts, clamping, removing of the processed assembly and quality check must not reduce the cycle time and have to be done in parallel to laser welding. These targets have been realized in an innovative production line which is totally different to the state of the art in general.

In addition, Dr. Don A. Lucca, Professor of School of Mechanical and Aerospace Engineering at Oklahoma State University talked about "Nanostructured Materials for Improved Mechanical Response" in April 2016, when he had paid a visit to KIMM before the IFAME 2016 was held. Even though he could not attend the forum, he presented a valuable lecture at KIMM, explaining how we can use nanostructuring of materials to improve the mechanical response and introducing two different materials: multilayered composites and metallic glasses. He focused on nanostructuring these materials with enhanced mechanical behavior for advanced applications.

Dr. Pamir Alpay, Professor and Department Head of Materials Science & Engineering at University of Connecticut talked about "Accelerating Materials Deployment and Manufacturing via Multi-Scale Modeling and Genomics." In his talk, there is a need for the development of comprehensive, multi-scale theoretical tools in the search for better materials. This is essentially at the core of the recent "materials genomics/informatics" initiatives that seek to accelerate materials discovery through the use of computations across length and time scales, supported by experimental work. Such methods will result in customizing, or entirely replacing, existing engineering metallic alloys, polymers, and ceramics which were developed based on trial-and-error approaches in the past century. Three examples of accelerated materials development success stories were provided: self-healing metallic electrical contacts, a new generation of polymeric capacitor materials with better dielectric properties, and high cooling capacity electrocaloric ceramics. He also discussed implications of these concepts in design and manufacturing of advanced parts for aerospace and automobile industries.

Dr. Man-Been Moon, Vice President of Hyundai Steel Company in Korea introduced "Hyundai Steel's Challenge - Toward Automotive Steel Specialized Steelworks." In his talk, since the financial crisis in 2008, global economy has undergone a challenging time recovering from the low growth, and such a low-growing economic circumstances and global over-supply in industries has expanded business risks of many industries. Now is when companies need to endure the risks from new business, and therefore it is necessary for them to have entrepreneurship of seeking their profit through creative innovation, known as Schumpeter's entrepreneurship. In 2004 Hyundai Steel has proposed an idea of integrated steelworks and has started operation of its first blast furnace in 2010 and of its third blast furnace in 2013. Based on this completion Hyundai Steel contributed to Hyundai Motor Group's Vision "From Iron Melt to Automotive." Hyundai Steel has accomplished the goal of "Automotive Steel Specialized Steelworks" as well as stabilization of Steelworks within a short period of time through strong leadership, precise business strategy and innovative technology to embody its long-term vision. For this accomplishment not only the board members did their best but there have been endeavors of all employees not to give in against risks. In the future Hyundai Steel will not draw its limit merely on material production. Hyundai Steel, as a provider of "Total Solution" to its customers with a high reputation, will improve its global competitiveness over the world and will eventually make dream come true of prospective accomplishment, the 100 year Steelworks.

Dr. Jack Chun-Chieh Wang, Director of Metal Processing R&D Department at Metal Industries Research & Development Centre in Taiwan introduced "The R&D Prospects of Additive Manufacturing (AM) Technology at MIRDC." In this talk, he introduced who is MIRDC, why they devoted themselves to the additive manufacturing field, what they want to do, and how to approach it in the future. MIRDC is established in 1963, after 50 years, they have become the third largest research center in Taiwan with more than eight hundred personnel. MIRDC is the only one research center whose headquarter is located in Southern Taiwan. They devoted themselves to the research of metal processing technologies, and they wish to assist the upgrade of competitiveness for Taiwan metal industries in the way they can. The most recent trend is to manufacture medical parts using various additive manufacture technologies. For example, powder bed fusion, binder jetting, and etc. These technologies show a great potential to overturn the existing manufacture technologies. Therefore, they decide to take one step ahead to conduct research in this field prior to domestic industries, so that they could provide timely help to them in the future.

Dr. Choongsik Bae, Professor, and Department Head of Mechanical Engineering, at Korea Advanced Institute of Science and Technology talked about "Vision of Energy Sustainability." In his talk, global energy demand has continued to rise due to population increase and economic development. National governments and international bodies try to seek the ways to reduce the energy demand growth. Energy Technology Perspectives (ETP) 2050 of International Energy Agency (IEA) has provided the current status of energy system, technology developments and external events that have evolved ETP scenario since 2006. Three scenarios (BLUE MAP, ACT MAP, BASELINE) were considered in ETP 2006 and 2008. The three scenarios were renamed to 2DS, 4DS and 6DS in ETP from 2012 to 2016. The status and prospects for key energy technologies of four sectors will be reviewed and assessed with regard to energy sustainability and environmental friendliness; power, transport, building and industry. Global energy trends show advances in decoupling demand from economic growth, but also reveal bottlenecks and uncertainties. Therefore, the fantasy and reality of energy technology scenario will be presented in detail for the sustainable future. The relevance of mechanical engineering in energy technology is identified, aiming to secure sustainable energy management. The efforts of mechanical engineering faculty in KAIST will be also introduced, such as new technology and efficiency improvement in combustion facility, fuel-cell technology, advanced packaging and thin films for solar cell, battery and fuel-cell, energy-harvesting, nano-environmental monitoring, super insulator, etc.

Dr. Young-Sup Joo, SME Minister at Small and Medium Business Administration of Korea talked about “Korean SME Policy Innovation for Creative Economy.” In his talk, the Korean government has been driving “Creative Economy” as a core economic development initiative to effectively create high-quality jobs. Since SMEs are creating the majority of new jobs in Korea, the SME policy innovation is getting more and more important to accomplish it. He briefed new Korean SME policies for exports, startups, and R&D to create more high-quality jobs by means of exports, startups, and new growth engines.

Lastly I reviewed how Korea Institute of Machinery and Materials (KIMM) is revamped for creative economy. Creative economy is a keyword for the current government to maintain the sustainable growth of Korean economy since 2013. The GDP per capita did not increase for last decade and the birth rate was the lowest in the world recently. As a new leader of the Korea Institute of Machinery and Materials, I interpreted the creative economy into combined activities of creating Knowledge, Innovation, Motivation, and Marketability and tried to forge it into the operating system at KIMM. In this talk, the governance change, research challenge, and technology transfer to the industry during my tenure will be highlighted. In result, the research productivity defined as the royalty income divided by the direct research input was improved from 6.8% to 7.6% and the medium and long-range research project system was newly introduced. The new way of working and decision process introduced can be further augmented in promoting the sustainability of research activities at KIMM to enhance the quality of our lives in the future. I really hope challenges and change experienced so far will play a pivotal role in revitalizing and further strengthening the manufacturing sectors of Korean industry in the world market.

I sincerely hope that these proceedings will contribute to advance manufacturing technologies and to the achievement of sustainable economic growth to improve the quality of our lives for the future.

Thank you.

Yong-Taek Im
President
Korea Institute of Machinery and Materials

ACKNOWLEDGMENTS

When we launched the first IFAME in 2014, no one expected that we could handle a world-class forum with renowned speakers from all over the world. However, we hosted the first one quite successfully, and the second one was also a great success.

This year marks the IFAME. Now, we have three years’ continued experience to steer and organize the international forum. Dr. Yong-Taek Im, president of KIMM, deserves special acknowledgment for his contribution to the forums thus far. Mr. Jae yoon Kim and Mr. Sungkyu Cho, in charge of organizing the Forum, were the head and team leader of Department of External Relations, respectively. They steered the task force with great passion, so that I was able just to put the final touches on the Forum.

Inviting speakers was again a difficult task due to the busy schedules of all the attendees. I would like to thank all the speakers for taking their precious time and delivering fruitful contents on Mechanical Engineering and Global Sustainability.

Many thanks go to all the speakers and participants from all around the world, as their contributions made the Forum extraordinary. Most of all, the steering and organizing committee spared no effort for a successful and meaningful Forum, and this was very much appreciated.

Dr. Hellmut Schmücker’s presence at the Forum, who was an advisor to KIMM from 1977 to 1981, was certainly a welcomed sight to all KIMM members. He dramatically contacted Dr. Yong-Taek Im, before the 40th anniversary of KIMM and the Forum. The steering committee invited Dr. Schmücker, as he guided KIMM’s birth from its starting point in the 1970s. His memories and experiences as an advisor to KIMM highlighted this year’s Forum and were greatly appreciated.

I would like to specially thank Mr. Jae Moon Park, Deputy Minister for the Office of R&D Policy of Ministry of Science, ICT and Future Planning; Dr. Sang Chun Lee, Chairman of National Research Council of Science and Technology; Mr. Eun Kwon Lee, Mr. Sang Min Lee, and Dr. Yong Hyeon Shin, Members of the National Assembly of Korea for delivering their speeches and video presentations during the Forum.

I also thank Dr. Seung Duk Park; Dr. Hun Cheol Kim; Dr. Hae Ung Hwang; Dr. Kyung Hyun Hwang; Dr. Tae In Choi, the former presidents of KIMM; Mr. Sun Kyung Kim, auditor of KIMM for contributing their valuable time and effort. Special thanks to Dr. Hyungju Park, President of National Institute for Mathematical Sciences; Dr. Hai-Doo Kim, President of Korea Institute of Materials Science; Dr. Dong Il Kwon, President of Korea Research Institute of Bioscience & Biotechnology; Dr. Ki Hun Hong, President of Korea Institute of Ocean Science and Technology; Dr. Hye Jeong Lee, President of Korea Institute of Oriental Medicine; Dr. Du Cheol Kim, President of Institute for Basic Science; Dr. Kyu Han Kim, President of Korea Institute of Geoscience and Mineral Resources; Dr. Jae Young Lee, President of National Nanofab Center; Dr. Sang Hyun Seo, President of Korea Research Institute of Ships & Ocean Engineering; Mr. Ju Han Kim, Deputy Minister of Science and Technology Strategy Office at Ministry of Science, ICT and Future Planning for contributing their valuable time and effort.

The generous support of Dr. Chun Hong Park, Dr. Hee-Chang Park, Dr. Joon Yub Song, Dr. Eui Soo Yoon, Dr. Jae-Jong Lee, Dr. Yongjin Kim, Dr. Hyun-Sil Kim, Dr. Sang Jin Park, and Mr. Kye Hyeon Lim is very much appreciated. The Forum was organized under the auspices of MSIP, the Ministry of Trade, Industry, and Energy (MOTIE), National Research Council of Science and Technology (NST), Daejeon Metropolitan City, the University of Science and Technology (UST), the Korea Academy of Science and Technology (KAST), the National Academy of Engineering of Korea (NAEK), and the Daejeon International Marketing Enterprise.

The publication of the Proceedings of the Forum would not have been finished without the editorial support from Dr. Young Joong Kim, current Director of R&D Commercialization & Cooperation and Mr. Mik Fanguy, visiting professor of Scientific Writing at KAIST, who transcribed the manuscript.

Special thanks go to Ms. Soo Young Hur for taking numerous photos and Ms. Ji Young Im and Ms. Min Jung Kim for designing fantastic banner and cover of the Forum. And I would like to thank Mr. Jae Yoon Kim, Mr. Sung Kyu Cho, Dr. Ji Hyeon Lee, Mr. Gwang Bum Seo, Ms. Jinni Kang, Mr. Wooram Kim, Ms. Ji Hyeon Seo, Mr. Il Kwon Yang, Mr. Dong Eon Kim, Mr. Seung Mo Lee, Mr. Chang Won Lee, and Mr. Han Chang Woo for organizing the forum and preparing venue facilities.

The outstanding administrative support from the organizing staff is too vast to mention in detail here but cannot be overemphasized.

I am confident that the next IFAME, which will take place in 2017, will be more exciting and stimulating. I am looking forward to seeing you all together next year.

Thank you very much.

Chae Whan Rim
Former Director of R&D Commercialization & Cooperation
Korea Institute of Machinery and Materials

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Summaries of Abstracts in Korean (발표내용의 국문 초록)

마찰 저항을 줄이기 위한 초소수 표면 기술

김창진, UCLA **항공 기계공학과 교수, 미국**

고체가 액체 안에서 움직일 때, 마찰력으로 움직임이 지연되며 에너지 소비를 야기한다. 해상수송만 해도 국제적 오일 소비와 온실가스 발생에 많은 영향을 미치고 있으므로, 매우 적은 양의 표면 마찰이라도 줄일 수 있다면 세계적으로 주목할만한 결과를 얻을 수 있다. 표면 마찰력이 수상 운송 수단에 발생하는 저항력 중 가장 큰 비중을 차지하기 때문에, 수십 년 동안 표면 마찰을 줄이는 여러 메커니즘이 개발되어왔으나 매우 낮은 에너지 효율로 인해 실제 사용에는 한계가 있었다. 10여 년 전부터 물과 표면 사이의 공기 층이 마찰을 줄이면서 물 흐름을 원활하게 할 수 있는 초소수 표면 기술이 주목받기 시작했다. 가스 윤활법과는 다르게 초소수 표면 기술은 표면의 미세한 구조물 사이에 플라스트론(plastron)으로 불리는 가스 층을 유지시켜, 가스를 공급하는 데 쓰이는 에너지 소비 없이 표면 마찰을 줄일 수 있게 해 준다. 최근 몇 년간 많은 초소수 표면에서 발견된 대량의 미끄럼 현상은 마찰력 감소에 유용하게 사용될 것으로 기대를 모았지만, 몇 가지 이유로 실제 상황에서 성공했다는 소식은 아직 보고되지 않고 있다. 대부분 중요한 응용 처에서 충분한 양의 미끄럼 현상을 유도할 수 있는 초소수 표면이 플라스트론을 유지할 수 없기 때문이다. 보통 논문들에서는 이러한 근본적인 문제가 무시되며, 꿈을 현실인 것처럼 말하곤 한다. 이번 발표에서는 초소수 표면의 마찰 저항 감소를 실제로 응용하기 위하여 필요한 내용을 이론적으로 다루었다.

나노임프린트 리소그래피는 나노생산에 대한 우리의 인식을 어떻게 변화시켰을까?

헬무트 쉬프트, 폴 쉐러 연구소 폴리머 나노기술그룹장, 스위스

1965 년, 고든 무어는 리소그래피 세계의 경제 법칙과도 연관이 있는 마이크로칩 집적도 증가를 예언하였으며, 이것은 '무어의 법칙'이라고 불린다. 1995 년, 스티븐 초우가 발표한 '나노임프린트 리소그래피 (NIL) 고해상 능력'에 관한 논문에서, 몰딩 기반 패터닝이 광자 기반 패터닝의 한계를 극복할만한 후보로 떠올랐다. 2003 년 NIL 이 반도체 기술 로드맵에 포함된 이후로, 차세대 고해상도 리소그래피 공정은 NIL 을 공정 사슬에 통합시켜 발전을 가속화시키고 있다. 50 년 동안 무어의 법칙이 경제법칙의 기술과정 결정을 증명하였다면, 20 년 동안의 NIL 발전은 반도체 제조공정에 적용 가능한 기계적 패터닝을 기반으로 하는 새로운 기술에 대한 도전을 보여준다. 또한, NIL 은 다른 여러 영역에서도 적용될 수 있으며 현재 사파이어 기판 및 포토닉 장치에 사용되고 있다. 이러한 측면에서 NIL 은 연구자들에게 광범위한 영향을 미친 표면 현미경의 이정표와 같은 주사탐침현미경에 가깝다. 이번 발표를 통해 지난 20 년 동안 NIL 이 어떻게 미세기계가공, 폴리머 공정, 표면처리 등의 공정 발전에 기여했는 지 논할 것이며, 3D 몰딩 분야 및 재료와 장비 기업과의 분야별 콜라보레이션을 이용하여 NIL 의 잠재력을 높이는 방안에 대해서 설명했다.

한국기계연구원 – 탄생, 성장, 영향력

헬무트 슈뮈커, 전 막스플랑크 연구부장, 독일, 한국기계연구원 설립자문(1977~1981)

한국기계연구원은 대한민국과 독일의 협력으로 1976 년 설립되었다. 한국은 산업화의 시작점에 있었고, 국제 시장에서 자국 제품의 경쟁력을 강화하기 위해 품질 향상이 요구되는 시점이었다. 당시 창원과

마산 지역에서 새로이 시작되는 산업체들에게 서비스를 제공하기 위해 기계와 금속을 시험하는 기관의 창립과 운영이 요구되었다. 저자는 초대 기술고문으로 설립 당시의 경제적, 정치적 상황을 생생하게 보여주고, 정부와 민간 부문의 상호 작용에 대해서도 자세히 설명하고 있다. 또한 지금까지의 관찰을 통해 앞으로 한국의 제조업이 나아가야 할 방향에 대해서도 조언을 아끼지 않고 있다.

LG 전자의 혁신적인 멤스-옵토-나노 기술

이정수, LG 전자 상무 / 생산기술원장, 한국

오늘날 빠르게 변화하는 사업 환경과 다양한 소비층의 욕구는 가전제품 생산 기업들에게 빠른 도전과 혁신을 요구하고 있으며, 기업의 대응 정도에 따라 새로운 사업 성장의 기회를 가질 수 있다고 저지는 지적한다. 이 같은 기업 환경 변화에 대응하기 위해, LG 전자는 기존의 가전제품 생산에서 자동차 및 에너지 환경 등 B2B 의 영역으로 옮겨가고 있다. 신사업에서 요구되는 혁신적인 R&D 영역은 MEMS, 광전자, 포토닉스, 나노재료 등을 포함한 재료와 장비의 개발이다. 이번 발표에서는 LG 전자에서 이루어지고 있는 주요 기술의 발전을 다루고 있다.

대량 생산에 적용되는 레이저 용접 기술

피터 호프만, 에어랑겐 레이저기술연구소 소장, 독일

자동차 회사의 비용 절감을 위한 전략 중 하나는 다른 모델을 같은 플랫폼 기반으로 설계, 생산하는 것이다. 실례로 폭스바겐은 전륜 구동 엔진의 공유 모듈 제작에 사용되는 MQB 플랫폼을 개발하였다. 시프트 포크, 기어 변속 컨트롤러 및 column jacket 등 수요가 많은 하위 부품들은 수백만 개가 생산되며, 재료 절약과 최적 서비스 기능의 관점에서 효율적 생산 디자인 가능성과 여러 개의 부품, 전면에 분포된 용접층, 다양한 기능을 가지는 표면 물성 등, 다양한 조건을 한꺼번에 만족시키는 것이 요구된다.

레이저로 개개의 부품을 연결하는 것은 고속 용접, 최저 열원, 무접촉, 국소 가열 등 여러 장점이 있다. ERLAS 는 사이클 타임 최소화를 목표로 새로운 레이저 용접 기계를 개발하고 있다. 부품 공급, 접합, 가공조립, 품질 검증 과정에서 사이클 타임을 줄이기는 힘들며 레이저 용접과 동시에 이루어지는 것이 효율적이다. 이러한 목표들을 이루기 위해 일반적 수준과는 다른 ERLAS 에서 개발된 혁신적인 생산 라인을 소개하고자 한다.

나노구조재료의 기계적 성능 향상

돈 루카, 오클라호마 주립대 기계항공공학과 교수, 미국

본 논문에서는 차세대 원전 기술에 적용될 수 있는 내방사선 특성을 갖는 나노 크기의 다층 구조 복합체와 연성이 증가된 나노구조 금속형 유리 재료의 두 가지 사례 소개를 통하여 물질의 나노 구조가 기계적 성능을 향상시키는 데 어떻게 활용될 수 있는 지를 함축적으로 보여준다. 나노 크기의 다층 구조 복합체는 기판 위에 나노물질을 번갈아 적층한 것으로 결정질/결정질 다층 구조와 결정질/비결정질 다층 구조의 두 가지 유형이 있다. 다층 구조 복합체는 개별 층의 두께가 감소함에 따라 강도가 증가하고, 점 결함에 대한 효율적인 에너지 흡수원 역할을 하는 계면으로 인해 내방사선 성능이 향상된다.

금속형 유리 재료의 연성을 증가시키기 위한 방법으로 이온빔 조사 공정을 사용하였다. 이온 빔 조사는 재료 내부에 자유 체적이 증가하는 효과와 결정화를 유도하는 효과가 있다. 재료 내의 자유 체적이 증가함에 따라 보다 균질한 변형이 가능하며, 나노 결정 형성은 전단 밴드의 활성화를 억제함으로써 연성을 증가시키는 효과를 보여 준다.

멀티스케일 모델링과 유전체학을 통한 재료 개발 및 생산의 효율화

파미르 알페이, 코네티컷 대학교 재료공학과 학과장, 교수, 미국

더 좋은 재료를 생산하기 위해 멀티 스케일에 대한 이론적 툴 개발에 대한 요구가 높아지고 있다. 이것은 실험적 연구의 지원과 길이와 시간 척도에 대한 전산 계산을 통해 새로운 재료 개발을 가속화하기 위한 최근의 "재료유전체학/계산정보학" 발전의 중심에 있다. 이러한 방법들은 지난 세기 동안 시행착오 방식을 기초로 개발되어 온 공업용 합금, 폴리머, 세라믹 등을 주문생산 하거나 전체를 대체하는 결과를 초래한다. 본 발표에서는 세 가지의 예시를 통해 가속화된 재료 개발에 대한 성공 스토리를 소개하고 있다. 자기 치료 금속 전기 접점, 차세대 중합체 축전 재료, 고 냉동능력 전열 세라믹, 항공 우주 및 자동차 산업에 사용되는 첨단 부품의 설계 및 생산에 대한 적용에 관해서도 설명하고 있다.

"자동차 강판 특화 제철소"를 향한 현대제철의 도전

문만빈, 현대제철 상무, 한국

2008 년 경제 위기 이후로 세계 경제는 저성장을 극복해야 하는 도전에 직면했으며, 이러한 저성장 경제 환경과 국제적 과잉 공급 상황은 여러 산업에 사업 위험성을 고조시켰다. 이제는 기업들이 새로운 사업의 위험성을 감내할 시간이며, 슘페터의 기업가정신으로 알려진 창조적 혁신을 통해 이익을 추구해야 할 때이다. 2004 년, 현대제철은 통합적 철강 생산 작업을 제안하였고, 2010 년 첫 운영을 시작으로, 2013 년에 세 번째 용광로에 불을 지폈다. 이를 바탕으로 현대제철은 "제철에서 자동차까지"라는 비전을 이루어가고 있다. 현대제철은 장기 비전을 달성하기 위한 강한 리더십, 단순한 경영 전략 및 혁신적인 기술 개발 등을 통해 짧은 기간 동안 제철작업의 안정화뿐만 아니라 "자동차 강판 특화 제철소"의 목표를 조기 달성했다. 이는 경영진뿐만 아니라 모든 직원들이 최선의 노력을 다한 결과이다. 본 논문을 통해 현대제철은 단순히 철강 생산에만 머무르지 않고, 고객들에게 인정 받는 '토탈솔루션'을 제공하는 회사로서 국제 경쟁력을 향상시켜 100 년 간 지속가능한 제철소가 되는 꿈을 이루어 나가기 위한 원대한 비전을 제시하고 있다.

MIRDC의 적층 가공기술 R&D 전망

잭 춘취 왕, 대만 MIRDC 재료공정연구부장, 대만

MIRDC 는 1963 년 설립 이래로 53 년이 지난 현재, 직원 800 명 이상이 종사하고 있는 대만에서 3 번째로 큰 금속 연구 기관이 되었다. 더욱이, MIRDC 는 대만 남부 가오슝에 본사를 둔 유일한 연구기관이다. MIRDC 는 지금까지 금속 공정 기술 연구에 많은 노력을 기울였으며, 대만 금속 산업 경쟁력 향상에 크게 이바지해왔다. 의료 부품 생산 분야의 최근 동향은 적층 가공 기술 (additive manufacturing)을 이용하는 것이다. 이는 3D printing 으로도 불리고 있으며, PBF (powder bed fusion), 바인더 젯 등도 이에 해당되며, 이 기술들은 현재 사용되고 있는 생산 공정들을 모두 대체할 가능성이 매우 큰 미래기술로 주목 받고 있다. 이러한 이유로 MIRDC 는 새로운 장소에 연구소를 신설하여 이 분야를 연구하기로 결정하였으며, 향후 관련 산업계에 큰 도움을 줄 수 있을 것으로 생각하고 있다.

에너지 지속가능성의 비전

배충식, KAIST 항공기계공학과 학과장, 교수, 한국

인구 증가와 경제 발전으로, 세계 에너지 수요는 지속적으로 증가해왔다. 국내 정부와 국제기구들은 에너지 수요 증가를 줄일 방법을 찾는 노력을 기울이고 있다. 국제 에너지 기구 (IEA)가 발간한 Energy Technology Perspectives (ETP) 2050 은 에너지 시스템, 기술 개발 및 외부 요인들에 대한 현황을 제공한다. 블루맵, 액트맵, 베이스라인 등 세 가지의 시나리오가 ETP 2006 및 2008 에서 고려되었다. 2012 년부터 2016 년까지 ETP 에서 언급된 세 가지 시나리오는 2DS, 4DS, 6DS 로 재명명되었다. 에너지 지속가능성과 친환경의 측면에서 전력, 수송, 건물, 산업 등 네 부문에 대한 주요 에너지 기술의 현황과 전망을 본 논문에서 소개하고 있다. 국제 에너지 동향은 경제 성장으로부터 탈동조화된 수요를 보여주는 동시에 병목현상과 불확실성을 보이기도 한다. 또한 본 논문에서는 지속가능한 미래를 위하여 에너지 기술 시나리오의 환상과 현실에 대한 자세한 내용을 발표하고 있다. 아울러 연소분야 신기술, 연료 전지 기술, 태양전지용 패키징 및 박막기술, 에너지 하베스팅, 나노-환경 모니터링, 슈퍼 인슐레이션 등 KAIST 기계공학과의 연구개발 현황을 소개하였다.

창조 경제를 위한 한국 중소기업 정책 혁신

주영섭, 중소기업청장, 한국

한국의 박근혜 정부는 질 좋은 일자리를 효과적으로 창출하기 위해 “창조 경제”를 주요 경제 발전 전략으로 내세웠다. 한국에서 새로운 일자리의 대부분은 중소기업이 창출하므로, 중소기업 정책 혁신의 중요성은 점점 더 높아지고 있다. 본 발표에서는 주 영섭 청장이 직접 수출, 창업, 신성장 동력 창출을 통해 질 좋은 일자리를 만들 수 있는 새로운 한국 중소기업 정책을 소개하고 있다.

한국기계연구원과 창조 경제

임용택, 한국기계연구원장

2013년 이래로, 창조 경제는 한국 경제의 지속적인 성장을 유지하기 위한 현 정부의 키워드가 되었다. 지난 10년 간 1인당 GDP의 증가세는 정체되고 있고, 출산율은 OECD 국가 중 전 세계 최저치를 기록했다. 한국기계연구원의 새 기관장으로서 창조 경제를 Knowledge (지식 창출), Innovation (혁신), Motivation (동기 부여), Marketability (시장창출)로 재해석하고, 이를 연구원 운영 체계에 접목시키고자 노력한 과정을 본 논문은 보여주고 있다. 변화된 연구 운영 체제, 도전적 연구, 시장으로의 기술 이전 및 연구소 창업을 몇 가지 사례를 통해 대표적으로 소개하고 있다. 기술료 수익을 직접연구비 투자액으로 나눈 값으로 정의한 연구 생산성은 결과적으로 6.8%에서 7.6%로 개선되었으며, 중장기 연구과제 시스템 또한 새롭게 도입되었다. 새로운 업무 방식 및 의사 결정 과정은 국민의 행복지수 향상을 위한 연구원 연구활동의 지속 가능성을 증대시켜 나갈 것이다. 지금까지 경험한 연구원의 도전과 변화가 한국 제조업의 재활성화를 통한 새로운 도약의 주춧돌이 되기를 저자는 본 논문에서 기대하고 있다.

PRESENTER BIOGRAPHIES

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Professor CJ Kim received his B.S. from Seoul National University, M.S. from Iowa State University, and Ph.D. from the University of California at Berkeley, all in mechanical engineering, and joined the faculty at UCLA in 1993. Directing the Micro and Nano Manufacturing Laboratory, his research is in MEMS and Nanotechnology, including design and fabrication of micro/nano structures, actuators and systems, with a focus on the use of surface tension. The recipient of the Research Excellence Award (Iowa State Univ.), TRW Outstanding Young Teacher Award (UCLA), NSF CAREER Award, ALA Achievement Award, Samueli Outstanding Teacher Award (UCLA), and Ho-Am Prize in Engineering, Prof. Kim has served on numerous professional and governmental committees and panels in MEMS and nanotechnology, including General Chair of the 2014 IEEE International Conference on MEMS. An ASME Fellow, he is currently serving as Senior Editor of the IEEE Journal of MEMS; on the Editorial Advisory Board for IEEJ Transactions on Electrical and Electronic Engineering; and on the International Steering Committee of IEEE MEMS. He has also been active in the commercial sector, as a scientific advisor, consultant, and founder of start-up companies.

Helmut Schift
Head of Polymer Nanotechnology Group
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Switzerland

Helmut Schift studied electrical engineering at the University of Karlsruhe, Germany, and at the ENSPS in Strasbourg in France, then he performed his Ph.D. studies at the Institute of Microtechnology Mainz, Germany. His dissertation was on "LIGA technology for micro-optical elements". He received his diploma in 1991, and Ph.D. (Dr.-Ing.), both at the University of Karlsruhe in 1994. He specialized in micro-optics, high aspect ratio lithography and replication (LiGA technology). After his graduation in 1994, he joined the Paul Scherrer Institute. He is head of the Polymer Nanotechnology Group.

Over the last 20 years, H. Schift has gained a vast experience in polymer processing using molding techniques. As one of the pioneers in nanoimprint lithography (NIL), a next generation manufacturing technique for a range of future applications with down to sub-20 nm resolution, he has developed enabling techniques for the patterning of functional surfaces with topological and chemical surface contrast, and used these processes in different research and application fields. In particular, he has contributed to the development of the basic understanding of the rheology of thermoplastic thin films used as resists in thermal NIL. The polymer nanotechnology group contributed via development of technology, tools, and processes, i.e. the full toolbox for replication processes needed for academic research and industrial applications. This toolbox is further enlarged within networks and via collaborations with industry and research partners on national and international level. H. Schift has supervised many scientific projects and participated in juries of several PhD theses. In the European FP7 NaPANIL project (2008-2012), H. Schift was sub-project leader with over 1000 person months. He is a co-author of 100 scientific papers, including reviews and book chapters, and editor of the NaPa Library of Processes (http://www.psi.ch/lmn/helmut-schift).

Hellmut Schmücker
Head (retired), Technical Division,
Max Planck Institute for Physics
Germany
Advisor to KIMM In 1977 to 1981

Hellmut Schmücker was raised in the south of Bavaria close to the mountain range. There he attended primary school and high school before he decided to study mechanical engineering at the Technical University of München (TUM). After receiving his Dipl.-Ing. in Mechanical Engineering in 1966 he joined the Institute for Thermodynamics to study liquid metal heat transfer and thermodynamics under Prof. U. Grigull. He received his PhD in Heat Transfer in 1974. He joined Georgia Institute of Technology in Atlanta, Georgia, US, to investigate fabric flammability. At Kyoto University he studied boiling heat transfer and nuclear reactor safety. He was promoted to senior scientist until he joined GTZ to become senior advisor to the newly established KIMM in Korea. After he returned from his Korean mission he joined Krupp Industrietechnik GmbH to head the design department for thermal desalination plants to be built for Lybia, the Emirates and the Iran. In 1984 he returned to München and became head of the technical division of the Max Planck Institut für Physik, Werner Heisenberg Institut, one of the Max Planck Institutes with the longest history, going back to its founder A. Einstein. He was in charge of the H1 Detector for HERA at DESY, the ALEPH detector at LEP for CERN, and the ATLAS detector for LHC also at CERN, Geneva. In 1999 he joined the ATLAS Collaboration at CERN, Geneva, to coordinate international hardware contributions and quality assessments. Upon his retirement in 2004 he started to study musical science in Salzburg and devoted most of his time to study musical acoustics of classical guitars.

Jeong-Soo Lee
Vice President
Materials & Devices Advanced Research Institute
LG Electronics
Korea

Jeong-Soo Lee received B.S. in Metallurgical Engineering at Korea University, and M.S. in Materials Science & Engineering and Ph.D. in Materials Science & Engineering of Korea Advanced Institute of Science and Technology (KAIST) in 1991.

After one year of Post-doctoral experience (Transmission Electron Microscopy) at Arizona State University, he joined Materials & Devices Lab in LG Electronics, where he served as the leader of the Materials Characterization Group, developing analytical method for semiconductor surface and structure from 1993 to 2003. Afterwards, he served as the leader of Opto-Electronic group at the same Lab., developing epi-growth high power blue/ green LED Chip from 2003 to 2004. He was promoted to vice president at 2005 and moved to LED R&D Lab. as director and developed Vertical Type LED Chip and world's first wafer level package using MEMS technology from 2005 to 2007. He served as the director of LED Lighting Task where he developed, organized and launched LED Lighting and LED Back Light Unit for Large Size LCD-TV until 2009. He served as the director of Materials & Components Lab. which included 11 R&D Teams (Opto-Electronic, Optical system design, Nano-Materials & Devices, Solar Cell, Medical Diagnostics, etc.) He developed world's first 100 inch ultra-short through laser front projection TV (named Laser TV, received CES 2013 Innovation awards) and full HD mini sized LED projection TV (named Mini beam TV). He achieved world best solar cell efficiency for silicon thin film solar cells (2012) and gallium arsenide solar cells (2015) from National Renewable Energy Laboratory (NREL). He also co-organized LG-NIMS (National Institute for Materials Science) Center of Excellence for Materials Science, cooperating to develop functional nano materials such as new composite phosphors. Currently, he is the director of Materials & Devices Advanced Research Institute in LG Electronics.

Peter Hoffmann
Managing Director
Erlanger Lasertechnik GmbH (**ER**LAS)
Germany

Peter Hoffmann received a degree in Engineering in Production Technology from the University of Erlangen-Nuremberg, Germany, in 1988, and his Ph.D. in 1991. From 1988 to 1993 he was a scientific co-worker at the department of Manufacturing Technology. In 1991 he became head of the research group of laser material processing. He launched two companies: in 1993 a non-profit making company as a spin-off of the university, the Bavarian Laser Centre (BLZ) and in 1998 the industrial enterprise ERLAS Erlanger Lasertechnik GmbH. Currently he is owner and managing director of ERLAS.

Since 2002 he has been teaching as an associate lecturer at the department of mechanical engineering of the University of Erlangen-Nuremberg.

The activities of Peter Hoffmann have been granted with several awards so far. Among others he received the Otto-Kienzle-Medal for excellent work in the field of laser technology by the Scientific Community of Production Technology in 1994 and he was officially appointed as sworn expert for laser technology and laser material processing. In 2001 the Chamber of Industry and Commerce awarded him for one of the most innovative and successful enterprise foundations during the last five years. In 2007 the Bavarian Minister of Science, Research and Arts appointed Peter Hoffmann to an Honorary Professor.

Don A. Lucca
Regents Professor
Department of Mechanical and Aerospace Engineering
Oklahoma State University
U.S.A.

Don A. Lucca is currently Regents Professor and Carl and Gladys Herrington Chair in Advanced Materials in the School of Mechanical and Aerospace Engineering at Oklahoma State University.

He also holds the position of Guest Scientist in the Center for Integrated Nanotechnologies Group in the Materials Physics and Applications Division at Los Alamos National Laboratory. He received a BS degree from Cornell, MSE from Princeton, and PhD from RPI all in Mechanical Engineering. Professor Lucca is a Fellow of CIRP, SME and ASME. Currently, he is the vice president of CIRP and has served on the Board of Directors of the American Society for Precision Engineering and the North American Manufacturing Research Institution.

He is a recipient of the Alexander von Humboldt Research Award for Senior Scientists, and has held positions of Visiting Professor at the Stiftung Institut für Werkstofftechnik at Universität Bremen and at the Politecnico di Torino. He was awarded a Mercator Professorship by the Deutsche Forschungsgemeinschaft in Germany, the Russell Severance Springer Professorship in Mechanical Engineering at the University of California, Berkeley, and the SME Frederick W. Taylor Research Medal, and holds an honorary doctorate from Universität Bremen.

Pamir Alpay
Professor and Department Head
Department of Materials Science & Engineering
University of Connecticut
U.S.A.

S. Pamir Alpay received his PhD in Materials Science and Engineering in 1999 from the University of Maryland. He was a post-doctoral research associate at the Materials Research Center at the University of Maryland until 2001. Alpay then joined the Department of Materials Science and Engineering (MSE) of the University of Connecticut (UConn) in 2001 as an Assistant Professor. Prof. Alpay is currently serving as the Department Head of MSE at UConn. His research focuses on materials in electromagnetic applications and multi-scale materials modeling. Alpay received the NSF-CAREER Award in 2001 and the UConn School of Engineering Outstanding Junior Faculty Award in 2004. He is a Fellow of the American Physical Society, an elected member of the Connecticut Academy of Science and Engineering (CASE), and an Editor for the Journal of Materials Science. Alpay is the author of >160 publications in peer-reviewed journals, 20 peer-reviewed conference proceedings, four invited book chapters, and an invited book on compositionally graded ferroelectric materials. He delivered >90 invited talks/seminars in international meetings and at academic institutions, national laboratories, and industry.

Man-Been Moon
Vice President, head of Process Technology Division
Hyundai Steel Company
Korea

Man-Been Moon received B.S. in Metallurgical Engineering from Sungkyunkwan University in 1985 and M.S. in Metallurgical Engineering from Yonsei University in 1987.

Immediately after the Master's program he started his industrial career from Dongbu Steel R&D Center and spent about 8 years working in the center. In 1995 he left Dongbu Steel and joined Hyundai Hysco as a research member in the R&D Center. While working at Sunchon works of Hysco he continued his study as a doctoral student and received Ph.D. in Metallurgy and Material Engineering from Sunchon National University in 2003. His Ph.D. dissertation was nominated for awards from Galvatech2004, Chicago.

In 2005 he received the President's Commendation as "National Honorees of Iron & Steel." In 2006 he was elected as "International Secretary" of ISO TC107 (Inorganic Metallic Coatings)/SC08 (Conversion Coating) and was registered as one of "Marquis Who's Who" members in 2008. As well as his academic reputation, he has moved forward on his career path at Hysco. In 2009 he was promoted to a Manager-director charging the R&D Center and to a Director in 2011. He was again promoted to a Vice President in 2013, and in the same year he also finished the CEO MBA program (75th AMP) from Seoul National University.
As Hyundai Hysco was merged and acquired by Hyundai Steel in 2014, his position was changed to a head of Process Technology Department in Hyundai Steel R&D Center. In 2015 he served as a head of Automotive Steel Material Division. Currently, he is a head of Process Technology Division in the Hyundai Steel R&D Center.

Jack Chun-Chieh Wang
Director
Metal Processing R&D Department
Metal Industries Research & Development Centre
Taiwan

Chun-Chieh Wang received B.S. in Department of Materials Science and Engineering from National Tsing Hua University and M.S. in Institute of Materials Science and Engineering from National Taiwan University in 1987. After one year military service, he began to work in Metal Forming Technology Division of Metal Industries Research & Development Centre as an engineer in 1989. From 1995-1998, he served as Chief of Metal Forming Technology Division, Chief in Project Development Section from 1998-2002, Project Leader in Metal Processing R&D Department from 2002-2006, and Deputy Director in Metal Processing R&D Department from 2006-2014. After that, from 2014 until now, he served as Director in Metal Processing R&D Department. During these 27 years, he received various awards and honors such like Chairman Paper Award from Microscopy Society of Republic of China in 1987, Excellence Paper Award from Taiwan Forging Association in 1993, Excellence Paper Award from Taiwan Forging Association in 1995, Best Paper Award from The Taiwan Society of Metal Heat Treatment in 2002, Gold Medal Award from 2012 Taipei Int'l Invention Show & Technomart Invention Contest, and Best Pushing Hands Award from Achievement recognition contest of Technology Development Programs (TDPs), Taiwan's Ministry of Economic Affairs (MOEA) in 2012. Meanwhile, he has lots of professional experience such as Vice Secretary General in Taiwan Forging Association from 1990-1997, Secretary General in Taiwan Magnesium Association from 2009-2012, Executive Committee Secretary in Asian Light Metals Association from 2005-2014, Director in Taiwan Forging Association from 2011-present, and Awards Committee member in Taiwan Light Metals Association from 2014-present.

Choongsik Bae
Professor, Chair
School of Mechanical & Aerospace Engineering
Korea Advanced Institute of Science and Technology
Korea

Choongsik Bae received B.S. and M.S. in Aerospace Engineering from Seoul National University, and Ph.D. in Mechanical Engineering from the Imperial College, London in 1993. After two years of research associate experience at Imperial College, he began teaching and research at Mechanical Engineering Department of the Chungnam National University in 1995. He joined the faculty of the Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology (KAIST) in 1998. From 2014, he serves as Chair, School of Mechanical and Aerospace Engineering and Head of Mechanical Engineering. He is also the director of Combustion Engineering Research Center (CERC) in KAIST, vitalizing the efforts in research as well as education. He was the Chair of IEA IA ECERC (International Energy Agency Implementing Agreement Energy Conservation and Emission Reductions in Combustion) leading international collaborative tasks in combustion technology among 12 OECD countries through 2011 to 2012. He was the visiting professor of University College of London in 2005. He is the invited professor of Tokyo Institute of Technology from 2012. He is also active in the interaction with the industry that he has worked as a Technical Advisor of Hyundai Motors on the occasion of his sabbatical leave in 2011 to 2012.

He received Arch T. Colwell Merit Award in 1997 and Harry Horning Memorial Award in 2006 from Society of Automotive Engineers (SAE) for his outstanding contribution to the literatures in powerplant system. He was elected as a fellow of SAE in 2012. He received Academic Award from Korean Society of Automotive Engineers in 2004 and Distinguished Research Award from KAIST in 2011. He was honored as one of the Korea Presidential Researchers in 2000. He received A Man of Merit Award from Ministry of Knowledge Economy (MKE) in 2012.

Young-Sup Joo
SME Minister
Small and Medium Business Administration
Korea

Dr. Joo has been working for the Korean government as SME Minister and Head of SMBA (Small & Medium Business Administration) since January 2016. Until then he had been a member of the National Economic Advisory Council, a consultative body for the Korea President since August 2015, and also had been engaged with Seoul National University as Professor (visiting) and Chairman of Industry Collaboration Committee at College of Engineering since June 2013. He had been serving for the Korean government as Managing Director (MD) in charge of the Korean core industry sector at Office of Strategic R&D Planning (OSP), Ministry of Trade, Industry, and Energy (MOTIE, formerly MKE) since June 2010. Prior to that, he had spent 30 years with the industry, mostly in the automotive and electronics industry, and took many leadership positions including President & CEO at Hyundai Autonet, Bontec, GE Thermometrics Korea and Asia Pacific, and executive at Daewoo Electronics. He received a Ph.D. degree in industrial engineering from Pennsylvania State University, an M.S. degree in production engineering from Korea Advanced Institute of Science and Technology, and a B.S. degree in mechanical engineering from Seoul National University. He is a senior member of the National Academy of Engineering of Korea. He also used to be engaged in several government programs and activities, including a member of the Special Committee on National Future Growth Engines in National Science & Technology Council, a member of the Convergence Research Committee in National Research Council of Science & Technology, and Chairman of the Smart Convenience Committee in National Industrial Convergence Forum.

Yong-Taek Im
President
Korea Institute of Machinery and Materials
Korea

Yong-Taek Im received B.S. in Mechanics and Design and M.S. in Mechanical Engineering from Seoul National University, and Ph.D. in Mechanical Engineering at the University of California, Berkeley in 1985. After one year of Post-doctoral experience at Berkeley, he began teaching and research at the Industrial and Systems Engineering Department of the Ohio State University until 1989. After that, he joined the faculty of the Department of Mechanical Engineering, Korea Advanced Institute of Science and Technology (KAIST), where he served as Associate Dean of University Planning and Coordination in 1991 and established the Office of International Relations in 1993. From 2007 to 2011, he served as Dean of the Office of External Affairs and Associate Vice President of the Office of Special Projects and Institutional Relations. Since 2008, he launched and coorganized the International Presidential Forum on Global Research Universities four times. He served as Chairman of the Asian Science and Technology Pioneering of Research and Education League in 2011, Director of the Mechanical Engineering Division of the Korea Institute of Science and Technology Evaluation and Planning, and Editor-in-Chief of the Journal of Mechanical Science and Technology of the Korean Society of Mechanical Engineers (KSME). He received Humboldt Research Fellowship from Germany and Australia-Korea International Education Policy Exchange Program Fellowship from Australia. He was elected to be a Fellow of American Society of Mechanical Engineers and the Korean Academy of Science and Technology, and member of National Academy of the Engineering of Korea. Prof. Im received various awards such as F. Staub Award, Johnson Gold Medal, GCMM Outstanding Research and Scholarship Award, SDPS Award, Presidential Commendation Award from the Korean Government, the first Academic Excellence Award from the Korean Society of Technology for Plasticity, and Designated Affiliate Professorship of POSCO. He has published 210 domestic and international refereed papers and registered 23 patents. Currently, he is President of Korea Institute of Machinery and Materials.

OPENING REMARKS

Yong-Taek Im
Chair of IFAME and President, Korea Institute of Machinery and Materials

Good morning, ladies and gentlemen.

My name is Yong Taek Im. I am greatly honored this morning to welcome all of you for this 40th anniversary of the Korea Institute of Machinery and Materials (KIMM) and also the 3rd International Forum Korea on Advances in Mechanical Engineering (IFAME).

Two years ago, I took the office as president and I asked my colleagues to have this forum for discussing the future of mechanical engineering and to find ways to be a global leader, as Dr. HoonChul Kim, one of the former presidents of KIMM has talked about. When I have suggested organizing such a forum to my colleagues at KIMM, they speculated on whether they can have a successful international forum here in Daejeon. But luckily, with all your participation and support from abroad and Korea, we could have this wonderful meeting again this morning.

I really appreciate your contribution to develop a better future and welfare for humankind. Special thank goes to Dr. Hellmut Schmücker from Germany, the first advisor to establish KIMM in 1979. Participations from other countries, companies, and embassies of Germany, Switzerland and Pakistan are greatly appreciated as well.

I thank Dr. Jae Moon Park, Deputy Minister of Ministry of Science, ICT and Future Planning, and Prof. Dr. Sang Chun Lee, Chairman of National Research Council of Science and Technology and the former president of KIMM for delivering their congratulatory remarks today.

In addition, I appreciate congratulatory remarks delivered by members of the National Assembly of Korea, Mr. Sang Min Lee, Mr. Eun Kwon Lee, and Dr. Yong Hyeon Shin, although Dr. Shin could not participate in the Forum today due to her earlier commitment. The former member of the National Assembly, Dr. Sang Ki Seo, who was also former president of KIMM, joined the welcoming dinner with speakers last night. He sent his greetings to everyone and congratulated us on the forum.

Again, I really appreciate your participation and voluntary coming to the forum.

This is the announcement of the official beginning of the International Forum Korea on Advances in Mechanical Engineering (IFAME).

Thank you.

CONGRATULATORY REMARKS

Jae Moon Park
Deputy Minister for the Office of R&D Policy, Ministry of Science, ICT and Future Planning

I am honored to be here to celebrate the 40th anniversary of the Korea Institute of Machinery and Materials (KIMM). KIMM has been contributing to the Korean mechanical industry and sharing the historical context of the development of the national economy. I am very pleased to be here to congratulate the 40th anniversary of KIMM.

Also, I would like to express my sincere congratulations on the opening of the 3rd International Forum Korea on Advances in Mechanical Engineering. I believe this International forum would provide precious opportunity to create synergies through the creative thoughts from the specialists in research and industries.

The Ministry of Science, ICT and Future Planning recognizes technology commercialization through the 'Industry–University–Research Institute Collaboration' as a major project. I expect this forum would be the opportunity to learn how the technologies developed by research institutes all around the world have taken their root into industries through the collaboration.

The Ministry of Science, ICT and Future Planning will do its best to build the environment for researchers to contribute to the national economy growth through 'Industry–University–Public Research Institute Collaboration'.

I once again offer my congratulations for the successful organization of the 2016 International Forum Korea on Advances in Mechanical Engineering.

Thank you.

CONGRATULATORY REMARKS

Sang Chun Lee
Chairman, National Research Council of Science and Technology

I am very pleased to congratulate the 40th anniversary of Korea Institute of Machinery and Materials (KIMM). Also, my congratulations go to KIMM for the successful opening of the 2016 International Forum Korea on Advances in Mechanical Engineering.

The history of KIMM has been sharing the context with the development of Korean industries including the development of mechanical engineering. Since I used to serve at KIMM as the president, the 40th anniversary is highly meaningful to me, as well.

Today, the importance of 'collective intelligence' is becoming more important in the society. Since a lot of eminent specialists are here to discuss the future of mechanical engineering, I believe that precious thoughts and talks would be shared through the discussions at this forum.

Also, I hope national research institutes, including KIMM, would practice the 'Open Science,' the sharing of each other's understanding through this precious opportunity.

There are various problems that science has to solve, such as climate change, energy, environment and so on. I, as the chairman of the National Research Council of Science and Technology, will devote myself to improve the quality of life, as well.

I congratulate the opening of the 2016 International Forum Korea on Advances in Mechanical Engineering again.

Thank you.

CONGRATULATORY REMARKS

Eun Kwon Lee
Member of the National Assembly of Korea

I would like to offer my sincere congratulations on the 40th anniversary of the Korea Institute of Machinery and Materials (KIMM). KIMM has been leading the growth of Daedeok research complex, the heart of the scientific stronghold, Daejeon Metropolitan City for 40 years. Everyone in this place is the witness of the history and deserves the congratulations.

We are facing the 4th Industrial Revolution and we need to change the traditional paradigm, seeking new growth engines for years. In this new global trend, 2016 International Forum Korea on Advances in Mechanical Engineering is expected to be a great chance to analyze the opportunities and threats to the humankind. We will discuss how mechanical technologies will be able to change the world in positive ways.

Once again, I would like to express my heartfelt congratulations on the 40th anniversary of KIMM and the successful organization of the 2016 International Forum Korea on Advances in Mechanical Engineering. Also, I hope opportunities to lead the new industrial era go to everyone here.

I will do my part at the National Assembly to accomplish the creative economy and to build an environment for researchers to concentrate on their researches.

Thank you.

CONGRATULATORY REMARKS

Sang Min Lee
Member of National Assembly of Korea

I am very pleased to congratulate the 40th anniversary of the Korea Institute of Machinery and Materials (KIMM).

Since the establishment as Korea Test Institute of Machinery and Metals, KIMM has been contributing to the development of Korean industry and mechanical technology by expanding its research area to materials, aerospace and ships.

I hope this occasion becomes an opportunity that KIMM designs its future initiatives.

Also, I would like to congratulate the opening of the 2016 International Forum Korea on Advances in Mechanical Engineering today.

The manufacturing industry is known to be in a global crisis. But developed countries have their initiatives to cope with this crisis, such as 'Industry 4.0' of Germany and 'Reshoring' of the United States. I also recognize how manufacturing industry is important to enhance the foundation of national economy.

I anticipate that the future of manufacturing industry and initiatives to develop the mechanical technology will be discussed through the International Forum Korea on Advances in Mechanical Engineering.

As a National Assemblyman, I also will spare no effort to establish the way that the intelligence from the science and technology world contributes to the national development.

Once again, I would like to congratulate the 40th anniversary of KIMM and the successful organization of the 2016 International Forum Korea on Advances in Mechanical Engineering.

Thank you.

CONGRATULATORY REMARKS

Yong Hyeon Shin
Member of the National Assembly of Korea

I would like to express my sincere congratulations on the 40th anniversary of Korea Institute of Machinery and Materials (KIMM) and the opening of 2016 International Forum Korea on Advances in Mechanical Engineering.

Nowadays, it is required that Korea has to convert its R&D paradigm from the catchup style to the leading up style R&D. I expect the 2016 IFAME would be a great opportunity to seek for a solution to overcome the crisis of the manufacturing industry and discuss how to grow with the sustainability.

I hope today's forum promote the creative discussions from the world-class specialists in mechanical field and the industrial world.

I will do my best at the National Assembly to improve the quality of life and national competitiveness through the development of science and technology.

Once again, I congratulate the successful organization of the 2016 International Forum Korea on Advances in Mechanical Engineering.

Thank you.

Session 1

Micro-Opto-Nano-Bio Technology

Superhydrophobic Surfaces for Reducing Frictional Drag: Dream or Reality?
Dr. Chang-Jin (CJ) Kim

Back to Mechanics – How Nanoimprint Lithography Changed the Way How We are Thinking about Nanomanufacturing?
Dr. Helmut Schift

KIMM – Birth, Growth, and Impact
Dr. Hellmut Schmücker

Innovative MEMS, Opto, and Nano Technologies in LG Electronics
Dr. Jeong-Soo Lee

Laser Welding in High Volume Production
Dr. Peter Hoffmann

Nanostructured Materials for Improved Mechanical Response
Dr. Don A. Lucca

Superhydrophobic Surfaces for Reducing Frictional Drag: Dream or Reality?

Dr. Chang-Jin (CJ) Kim
Professor Mechanical and Aerospace Engineering
University of California, Los Angeles

It's my great pleasure and honor to be here having a chance to talk about my recent research focus. My name is CJ Kim, and I am a professor at UCLA.
Today, I will talk about what is called superhydrophobic surfaces for drag reduction, frictional drag reduction. And this topic has been very hot for the last ten years maybe, but there is a lot of doubt about whether this will ever be a reality or not. And I will talk about why and where the problem is and how you solve the problem.

Introduction

First, let me introduce Fig. 1, for those who don't know me, this is what I do research for. I do MEMS. So my research area is to make things very small in the microscale, structures having something to do with the nanoimprint of the last talk. But this is where I am. However, the applications I am currently focusing on have application areas which are in meters and 10 meters and sometimes 100-meter size. So there is a huge difference between where I play for my expertise and where I want my expertise to be applied. That connection started maybe from here. So these MEMS parts are in the microscale or some millimeter scale; there is a unique property nature in which the surface tension of liquid plays a big role, unlike our own world. So that is the scale I am interested in in terms of nature or science. And that one has some big application in reducing the friction for water or liquid flow (Figure 1).

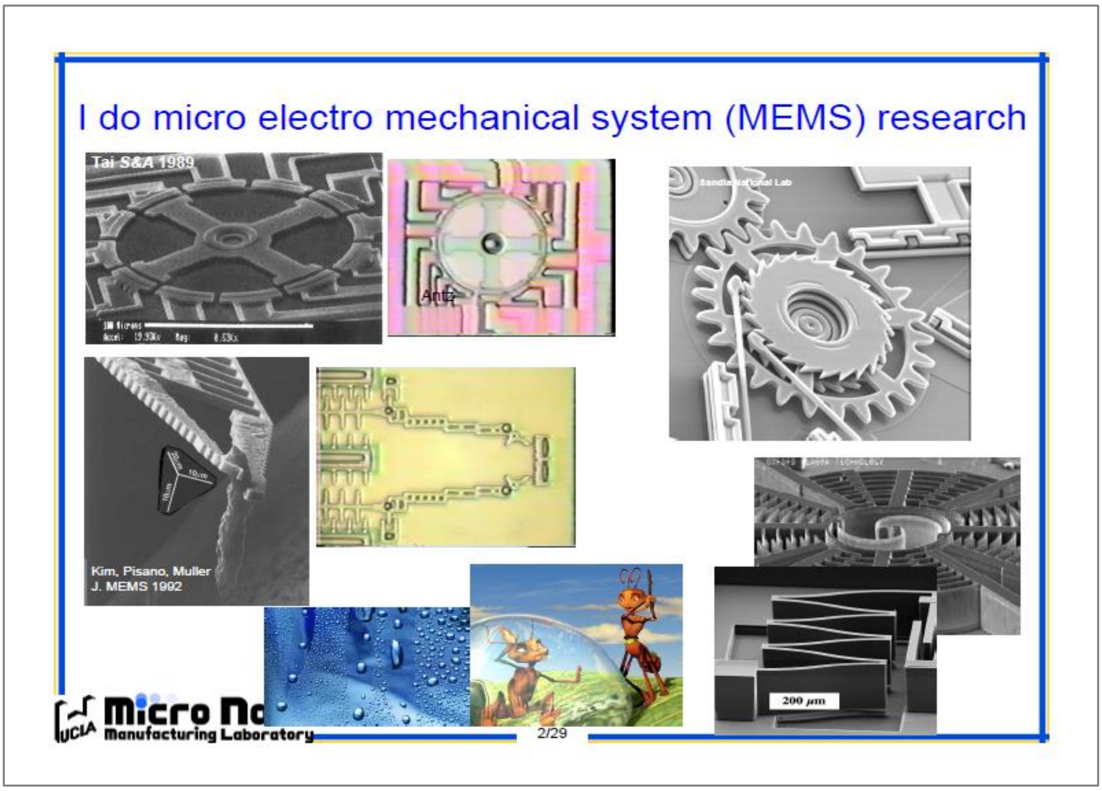


Figure 1. Micro Electro Mechanical System (MEMS) Research

Friction between Moving Objects

So, first, let's talk about friction itself in a big picture. So friction, we know, between solid and solid, you have a dry friction against motion. So usually what we do is we put some kind of liquid to lubricate to reduce friction. This is probably the fundamental for today's or modern mechanics, especially in engineering. This is well-known. What about, however, if a solid is moving on a liquid? Can we use gas to lubricate? That is the fundamental point of our approach, and the answer is yes. But the problem is how do we put gas in there? That's more important (Figure 2).

Drag between Solid and Liquid

Unlike the friction between solid and solid, which is really friction, when there is a solid moving against a liquid, we usually call it drag because it's more than friction. So when a boat moves in open water, or liquid flows into a pipe, we usually call it drag. Our interest is, of course, though already ready, but right now, our main first interest of application is for a boat. When a boat moves in water, there are typically three sources of drag. One is the actual friction, the one we are talking about, friction on the surface. Second is what is called "form drag." Because a large object is going through a liquid surface, there is a pressure; stagnant pressure has to overcome. That is called form drag. Also, you are creating waves and something, so some energy should be spent to create that energy. That's wave resistance. While we are talking, I am going to talk about today that drag reduction cannot do anything about these two kinds of drags. But I'm trying to reduce the friction, skin frictional drag. That's where we are, what I am trying to reduce (Figure 3).

Consider Marine Transportation

So my interest is in reducing the skin friction among all the drag. So first is, well, which has the biggest contribution for the overall drag? The answer is "it depends," but mostly it's actually the skin frictional drag that is involved. For the motivation of why skin frictional drag is important, it's good to look at the overall picture of energy consumption. So, according to some sources, the skin frictional drag among the three drag components, most of the typical cargo ships, 60 to 70 percent of the drag is coming from skin frictional drag. If it's an oil tanker, a large oil tanker going relatively slow, then it's even more. If it's under the water, there is no wave creation, so even more. So typically large boats going slower will have more skin friction contribution, meaning our boats will have more impact. So again, if it's an oil tanker example, actually the majority of drag is coming from skin friction drag. So yes, if you can reduce the drag of skin friction, it actually can reduce overall drag quite a bit.

How much energy is consumed especially for marine transportation alone? Overall global oil supply, a huge amount of oil consumption. More than 8 percent of it is just for marine transportation. So if we can reduce the energy consumption for marine transportation, it alone not only can have a huge economic impact but even a huge environmental impact. This is one of the big cargo ships (Figure 4).

Not only that, in terms of environmental issues, again for entire global CO_2 emissions, marine transportation alone contributes to pretty a big and significant part of overall in global CO_2 emissions. So as you can see, it's pretty big. Not only that, especially when you look at not just CO_2 but carcinogenic health hazard gas, those are especially bad for cargo ships because they use typically very low grade petroleum, which ejects a lot of health hazard gas. As one example, for a large boat, typically a 200-meter size cargo ship, the cancer- and asthma-causing pollutants, which are typical sulfuric gases, one boat is equivalent to 50 million cars. That's how bad they are. So as you can see, reducing some of the gas consumption has a huge impact. So I hope we understand the impact of potentially successful drag reduction not only to the economy but for the human environmental health (Figure 5).

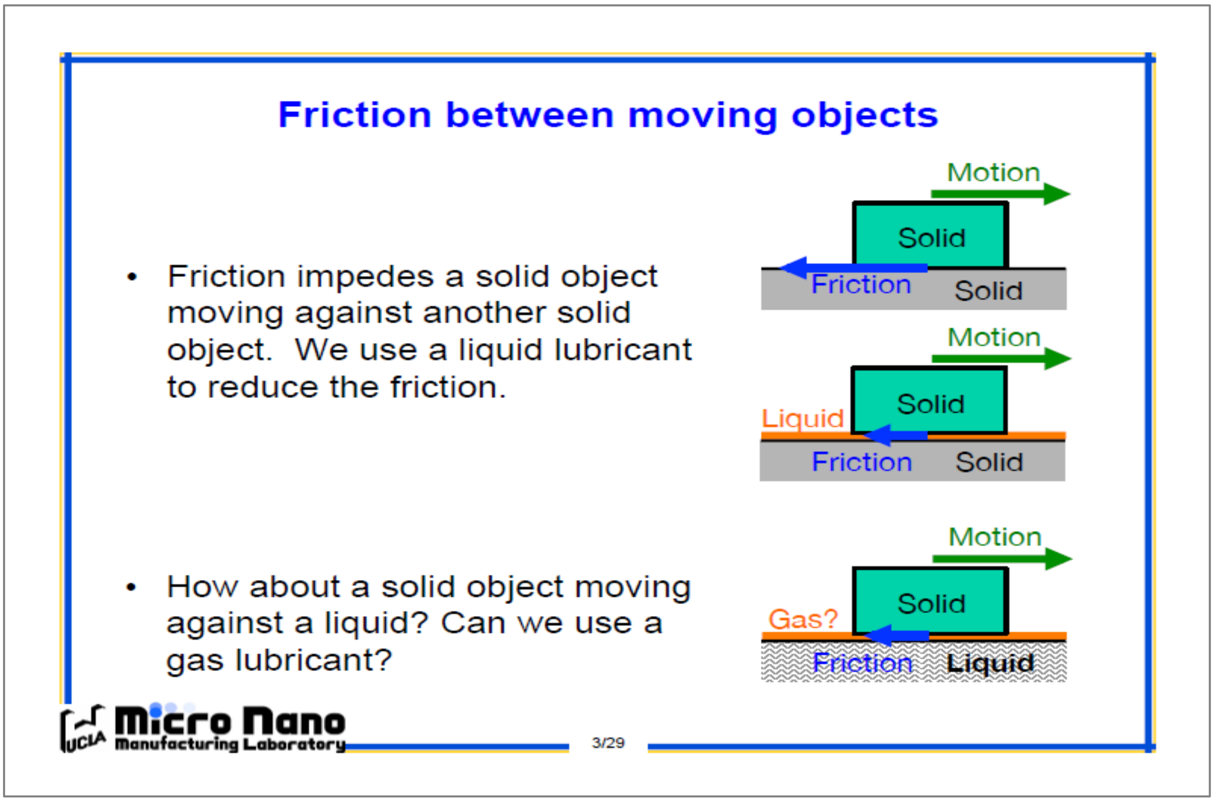


Figure 2. Friction between Moving Objects

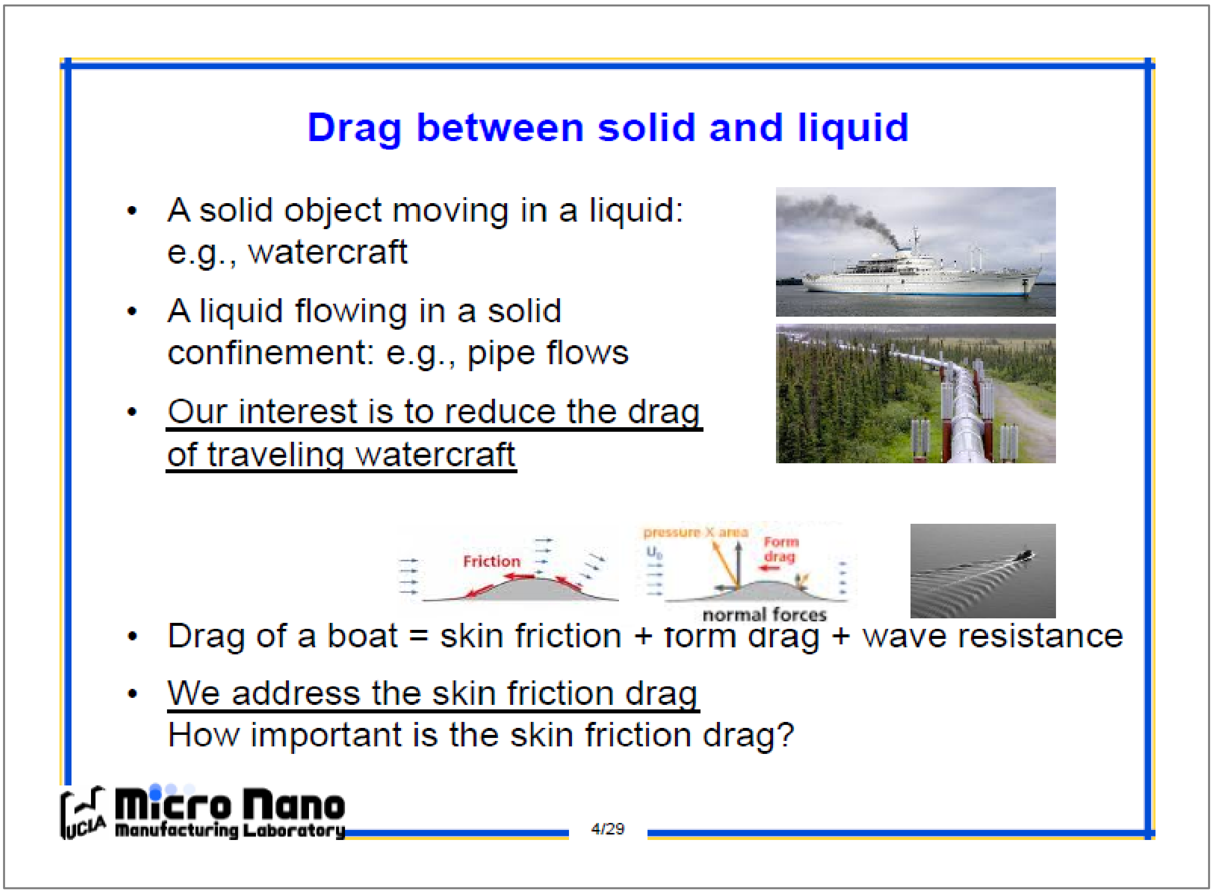


Figure 3. Drag between Solid and Liquid

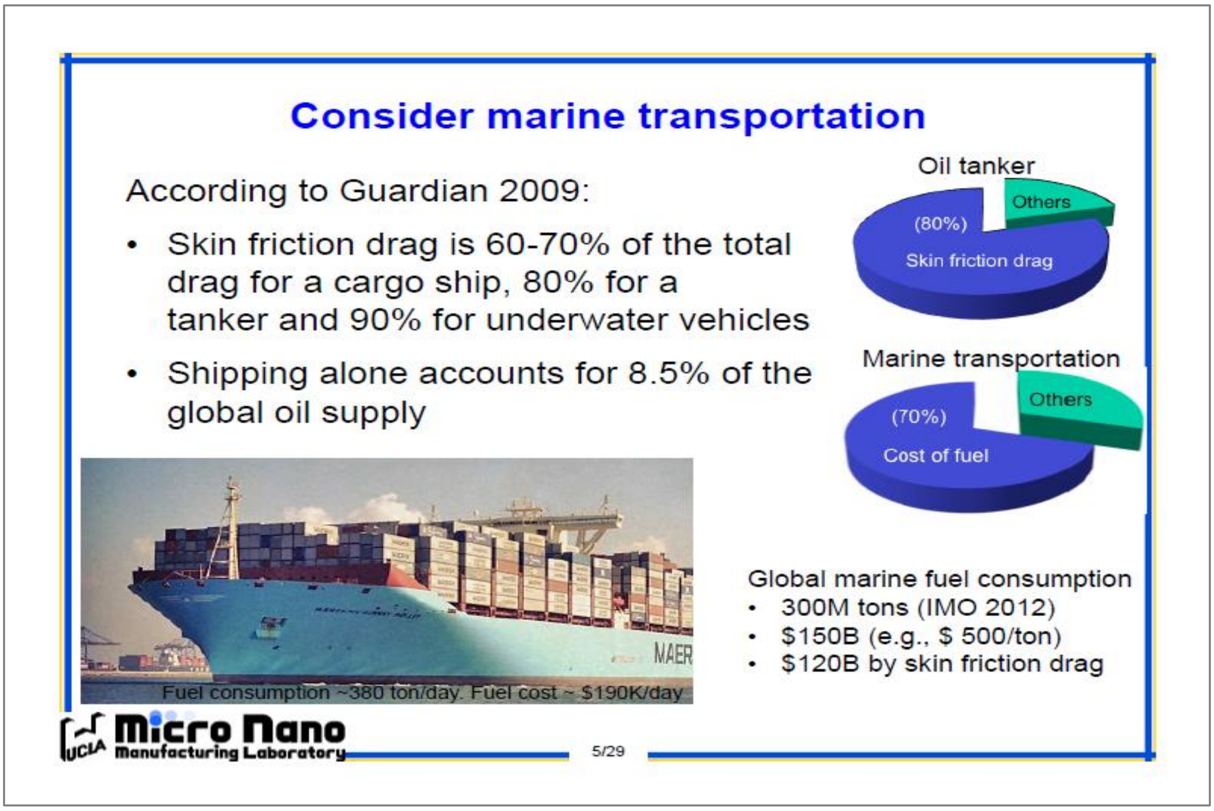


Figure 4. Consider Marine Transportation (1)

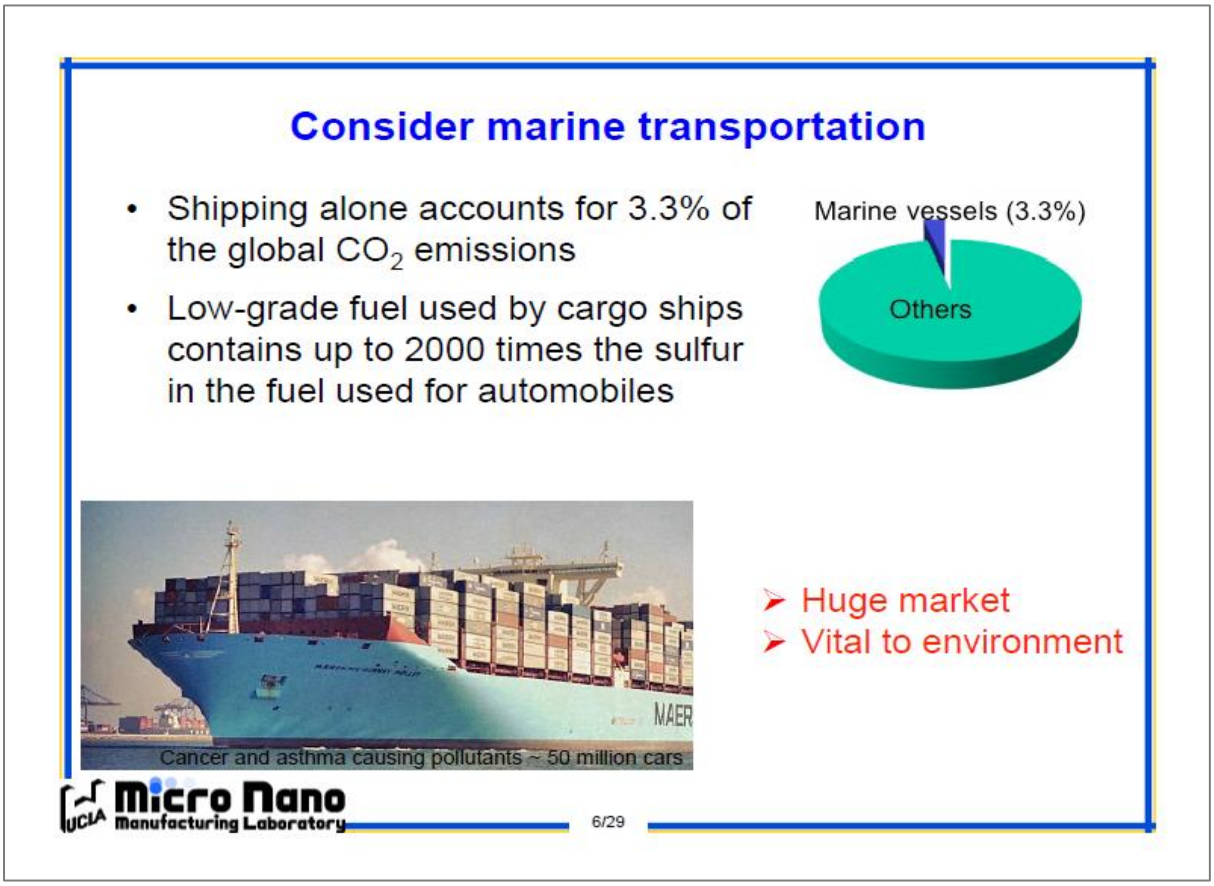


Figure 5. Consider Marine Transportation (2)

Lubricate the Skin Friction with Air

Ok, so, now, let's get into the technical issue. So as I said earlier, yes, conceptually, it's possible, of course, to reduce the drag to provide the lubrication using air between the water and the object. So for example, these are existing for many years. This is an example of a torpedo, what is called supercavitation. If you enclose the entire object in the water with the gas, obviously gas will propel very fast because the gas around the object will give you a very low viscosity environment. So, unlike water, you can go actually many times the speed of a typical in-water torpedo. Also, even if it has a boat, if you provide a lot of air gases or any gas bubbles, that also can reduce friction, skin friction. So, yes, that has been around for many years. It's pretty obvious. It is not that difficult to understand why it reduces the drag.

The problem is you end up consuming more energy to create this gas than you save because these gases won't stay there. This is the supercavitation case; as soon as the object passes by, these all break into bubbles and disappear, either condensed in this case or they leave as bubbles. So at the end of the day, you don't really gain any energy. You actually lose energy. It's just scientifically interesting. And in the torpedo's case, you don't care about the energy consumption. So that has been around for decades. So about a decade and a half ago, in early 2000, when superhydrophobic surfaces became popular in science, people started thinking, including myself, "Well, can we use these gases which are trapped on the surface between the liquid and the surface? Can we use this gas to lubricate and provide the slippery effect?"

So obviously the answer is conceptually yes. It will reduce some drag, but is it large enough? If it's only 0.1 percent of drag reduction, it's interesting scientifically, but it doesn't have much impact on engineering. So can we do it? Second is, well, the assumption was, in the superhydrophobic case, compared with these cases, the gas will remain there. You don't have to provide the gas all the time. For a few minutes, it will stay, but how long would it stay? Can it stay for days or can it stay for months? That's another question. And lastly, well, is it really going to be cheap enough?

Today, I will talk about these two scientific issues of whether a superhydrophobic surface can provide drag reduction that is large enough to be significant with engineering significance. Second is, "Is it possible to keep this gas for a long time?" At least days, hopefully at least for a few weeks, hopefully for months. Practically, the current issue is, maybe something I won't talk about today because usually, when scientifically something is proven, engineers come up with the way to manufacture something cheap enough (Figure 6).

Superhydrophobic (SHPo) Surfaces

So first, for those who are not so familiar with superhydrophobic surfaces, this is what superhydrophobic surfaces look like. The ongoing definition is, on a superhydrophobic surface, water will form a contact angle greater than 150°, which is not natural. For smooth surfaces, Teflon is one of the most water-repelling surfaces. It will give you a contact angle of about 120°. So a contact angle bigger than 120° is not natural. You can only get this through superhydrophobic surfaces. And a superhydrophobic surface typically is a hydrophobic material roughened. So these are very rough, microscopically rough surfaces that are hydrophobic material. And in that case, yes, you can get a very large surface contact angle, and water will form droplets and roll away.

Okay, sounds like this surface hates water, so it should repel water and probably should reduce the friction. That is understandable, but a very common misunderstanding. So this is what I am trying to say here. The widely spread misunderstanding is the air trapped on the superhydrophobic surface gives you this impression of highly water-repelling surfaces that will make water repel. And its droplets roll off, so the surface should also reduce the drag of water flow. That's an understandable, again, expectation, but it's not true. If you remember your fluid-mechanics 101, what you learn is, whatever the material, whatever the surface, whether it's a glass surface or a Teflon surface, there is no slip condition. The fluid, any kind of liquids flowing on a solid surface, should have velocity of zero on the surface; it doesn't matter whether it is hydrophobic or not. So, if you follow that principle, actually, this is wrong. But again, that's a very widespread misunderstanding, even in the scientific community.

Also, the water droplets rolling on a surface like this video here, it's not the same. It's different from water, a block of the water, slipping by on a surface which is submerging. That's actually very, very different. That's another big misconception you commonly find in the literature. Again, anyway, based on this, what I can tell you is today what we know for sure is, if you get these two, then you will get drag reduction (Figure 7).

To Obtain Drag Reduction of Engineering Utility

So, to obtain drag reduction of the engine utility, a boat, in open water, a superhydrophobic surface should be able to reduce the frictional drag of water flow by a useful amount, which has meaning in engineering not just scientifically, scientific meaning, but technically meaningful. That means, at least, maybe 10 percent of drag reduction. Then, we can really talk about something of engineering importance.

For large flow systems, I will go to, pretty soon, what I mean by large flow systems. These reductions have been actually shown for micro-systems and MEMS systems, but have not been shown for large systems.

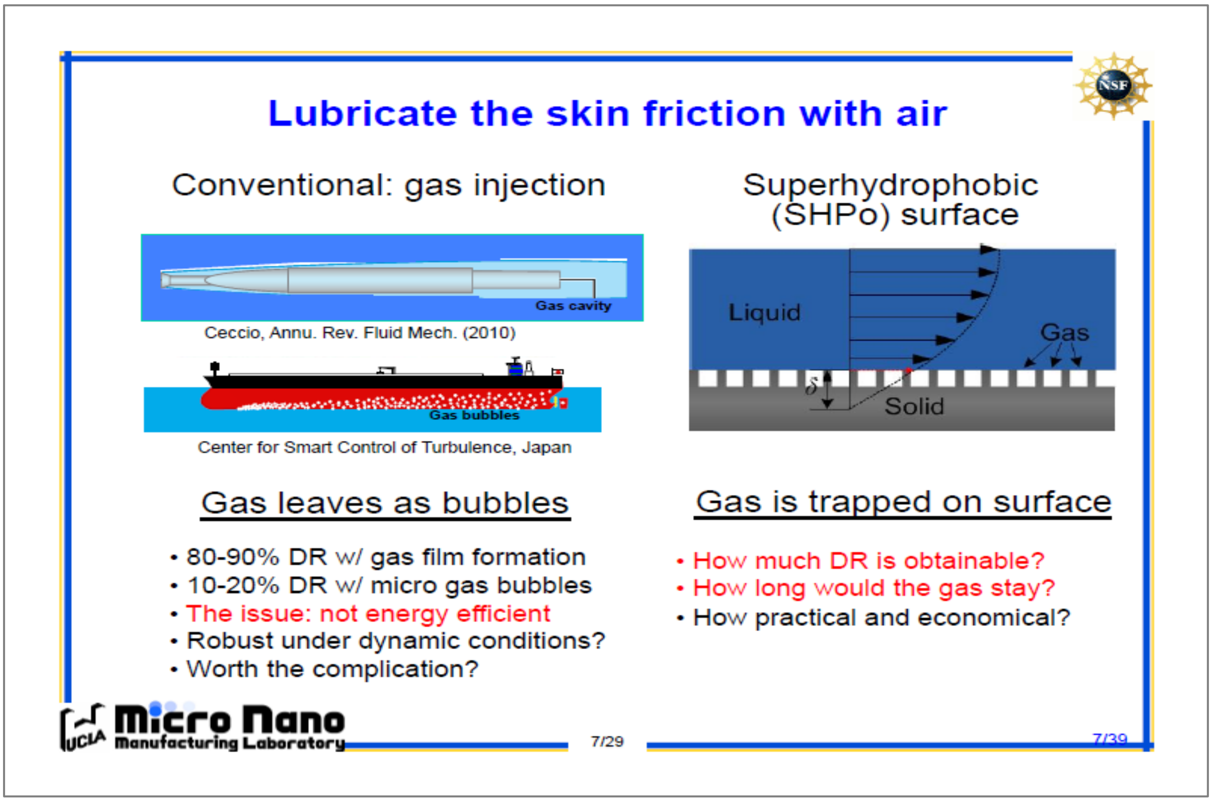


Figure 6. Lubricate the Skin Friction with Air

And there is a reason for that. So, the number one requirement is that if somebody can make a surface which has slip large enough for a large surface, that's great. And since we already assume that there is air on the surface under the water, if the air layer persists during the surface under the water for a long time, if both of them are true, then, yes, we can get drag reduction in practical conditions (Figure 8).

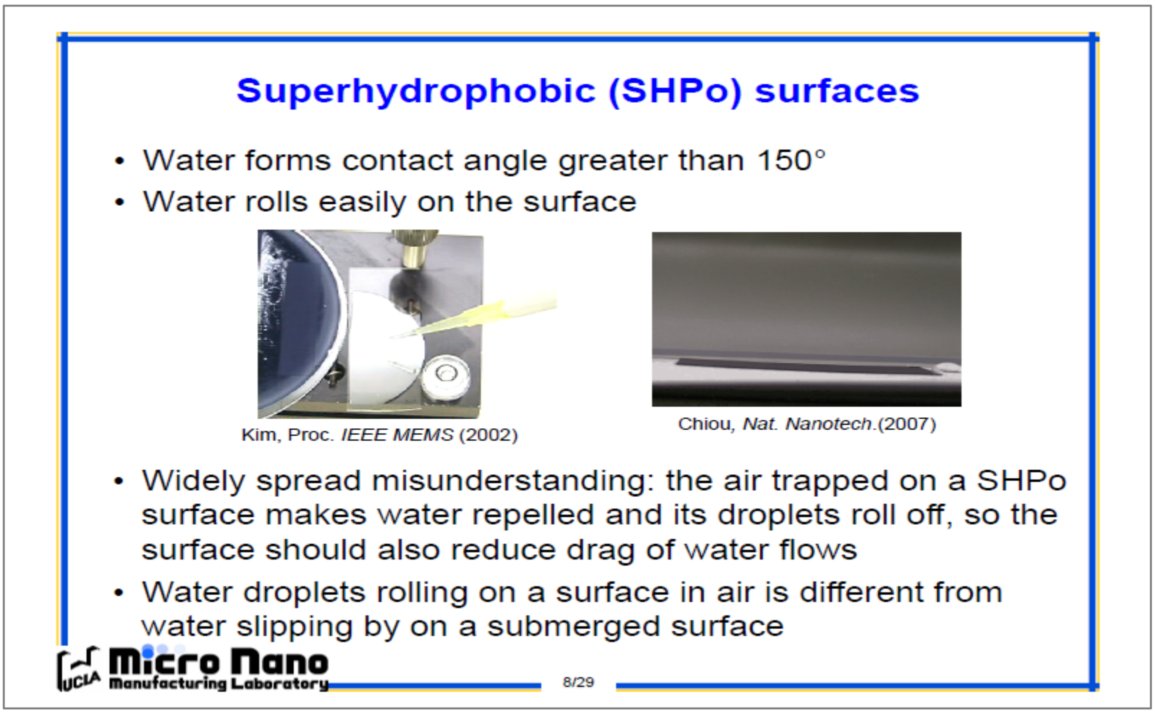


Figure 7. Superhydrophobic (SHPo) Surfaces

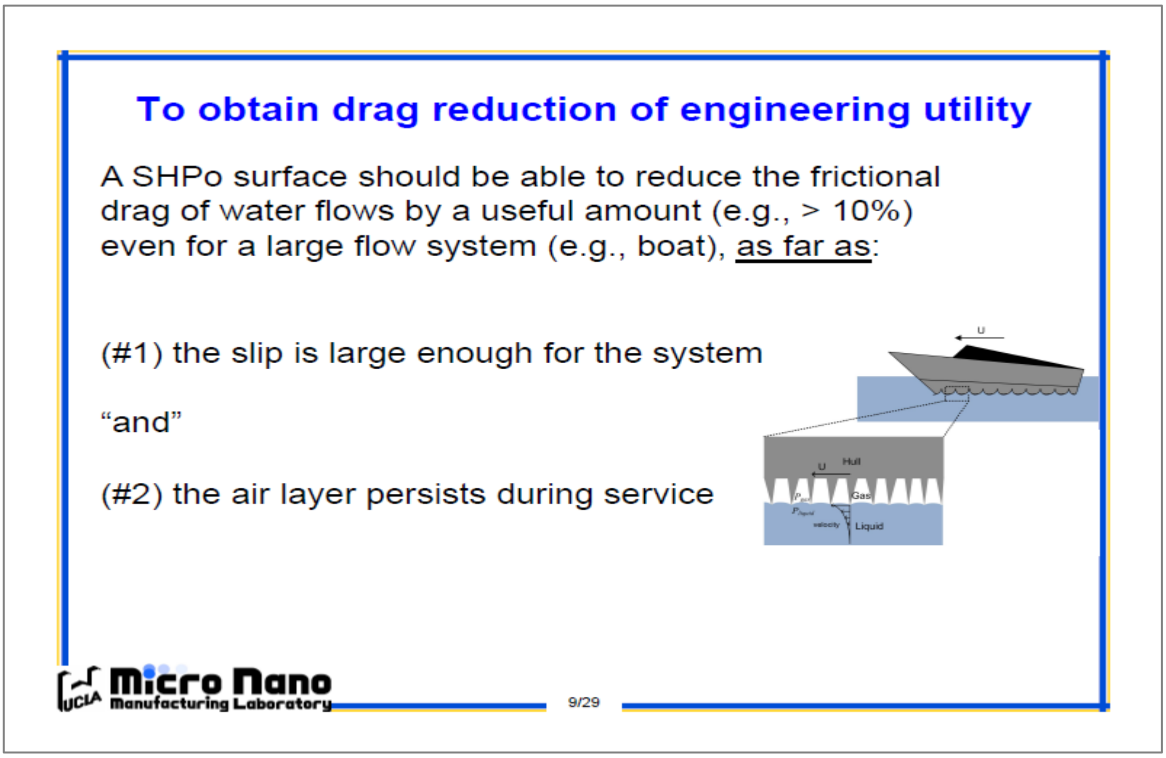


Figure 8. To Obtain Drag Reduction of Engineering Utility

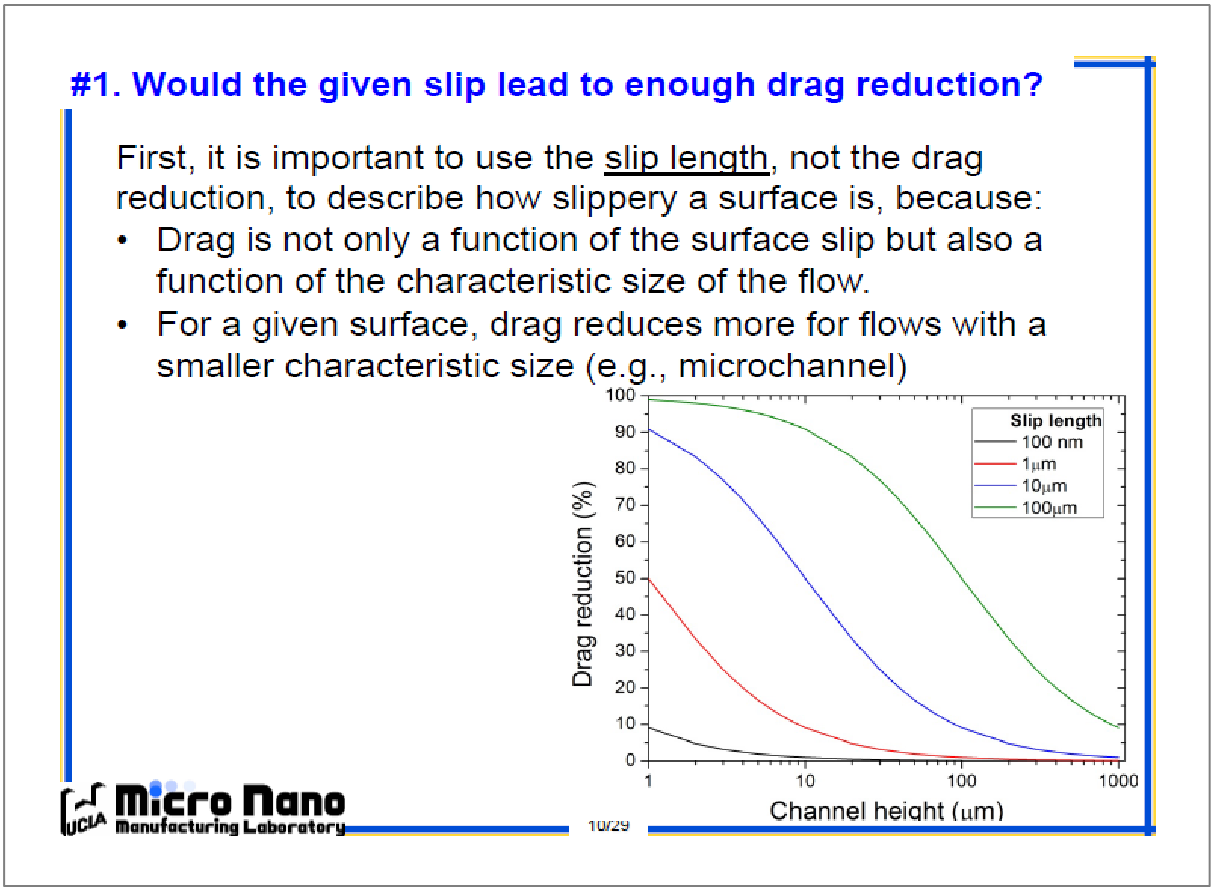


Figure 9. Would the Given Slip Lead to Enough Drag Reduction?

#1. Would the Given Slip Lead to Enough Drag Reduction?

I've divided my talk into these two: to answer whether this is possible, and both are possible. So first is "Can we get drag reduction large enough to be meaningful?" So first, before I go to drag reduction, I have to talk about what is slip length. So that's the scientific definition of how a slippery solid surface is against flow; in this case, it's water that's flowing on it. So that is basically the characteristics of some surface. So slip length, not the drag reduction, is used to describe how slippery the surface is, because drag is not only the function of how slippery your surface is, but also what kind of flow system you are. So if you look at this graph, if you flow a liquid inside the channel pipe, and channel diameter maybe, in this case, a micrometer, so one millimeter here and smaller and smaller and smaller, and it's what is called slip length. If slip length is large, of course, it means it's more slippery. If slip length happens to be one millimeter—that's this green line—then you can reduce the drag of the pipe flow by about 10 percent if the channel diameter is one millimeter. However, if the channel diameter is 0.1 millimeters, well, using the same surface, you will get about 40 percent of drag reduction. So as you can see, even if we use the same superhydrophobic surface, depending on what kind of flow system you create, we can get large drag reduction or small drag reduction. So that's why drag reduction is a very misleading property.

So second thing, as you see, I just said, one millimeter. But I'd like to apply this technology to a boat which is ten meter, meaning, even if you have really good slip length surface, your drag reduction becomes very, very small as your system becomes larger and larger. So it sounds like, there is no hope to apply this technology to a boat which is 10-meter scale or 100-meter scale. Sometimes, nature helps us. To jump a little bit, there is another nature that comes into the picture. So that, yes, even if your boat is 100 meters, the key event happens within a millimeter, right on the surface. That makes it possible to create drag reduction for a 100-meter boat even if what has happened is only one millimeter above the surface of the hull. Ok, so I hope I was able to show you that slip length is the key, not drag reduction, in terms of scientific studies (Figure 9).

Need a Slip Large Enough for Regular (Macro-scale) Flows

Ok, so now, we know that you need superhydrophobic surfaces which have large slip length, not drag reduction. Yet, to jump to the conclusion first, to have a macroscale flow effect for a boat, even for a 100-meter size boat, the bound layer right on the whole surface, within a millimeter thickness, is where everything happens. To have the effect of drag reduction or friction drag reduction, in that one-millimeter thickness, we need slip length above one-tenth of it to have any engineering importance. So what we are searching for is slip length as close as possible to 100 micrometers.

Ok so, first, to design this kind of superhydrophobic to have impact, at the beginning, there were no theories or scientific backgrounds on what kind of surface will give you this kind of slip length. That had to be developed. So superhydrophobic drag reduction had been talked about in 1999, 2000, and 2001. Even today, there was no success, and there is a reason for it. Because there was no science to start from. So early experimental study, without having this knowledge, did not provide any conclusive information. There have been hundreds of publications which are scientifically interesting and important but not very useful for engineering purposes. So I will give you a background, the story of how we now know the science part of it (Figure 10).

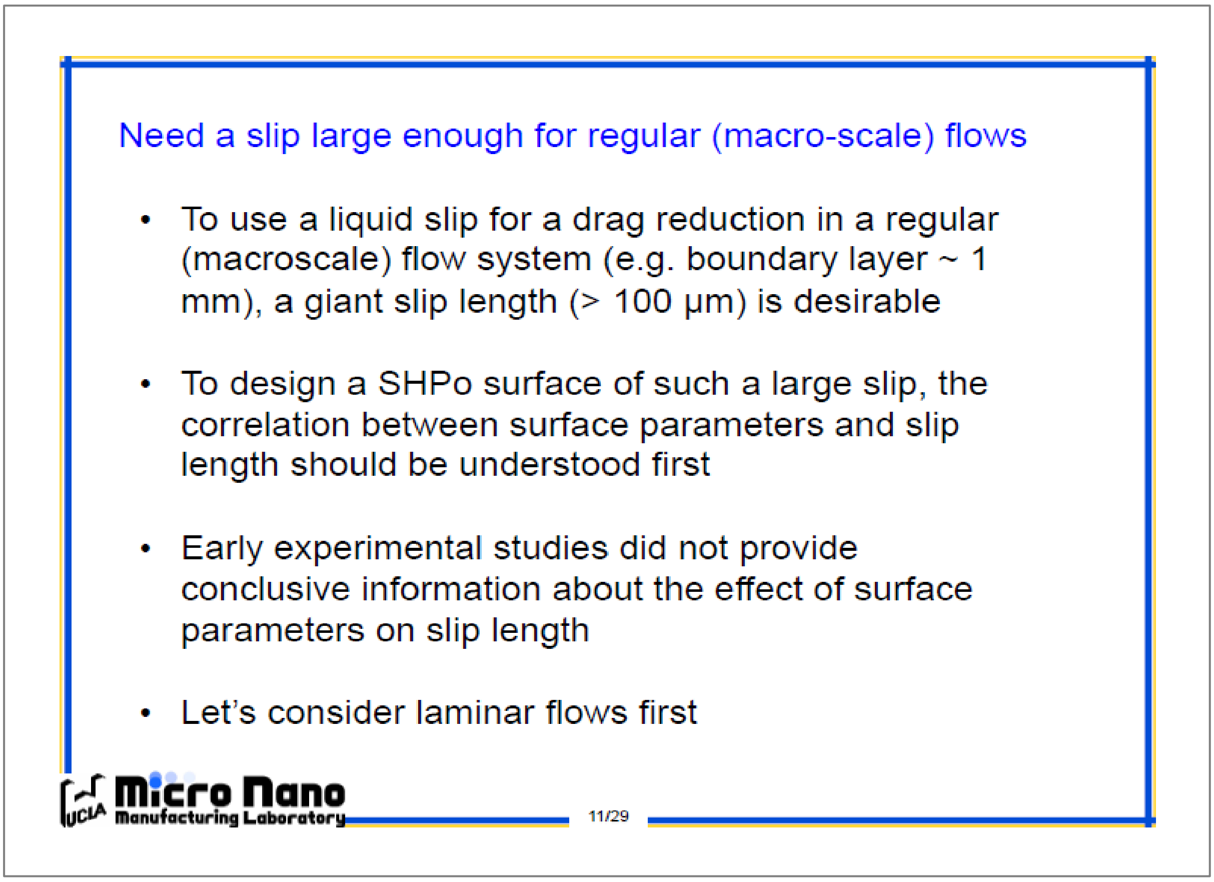


Figure 10. Need a Slip Large Enough for Regular (Macroscale) Flows

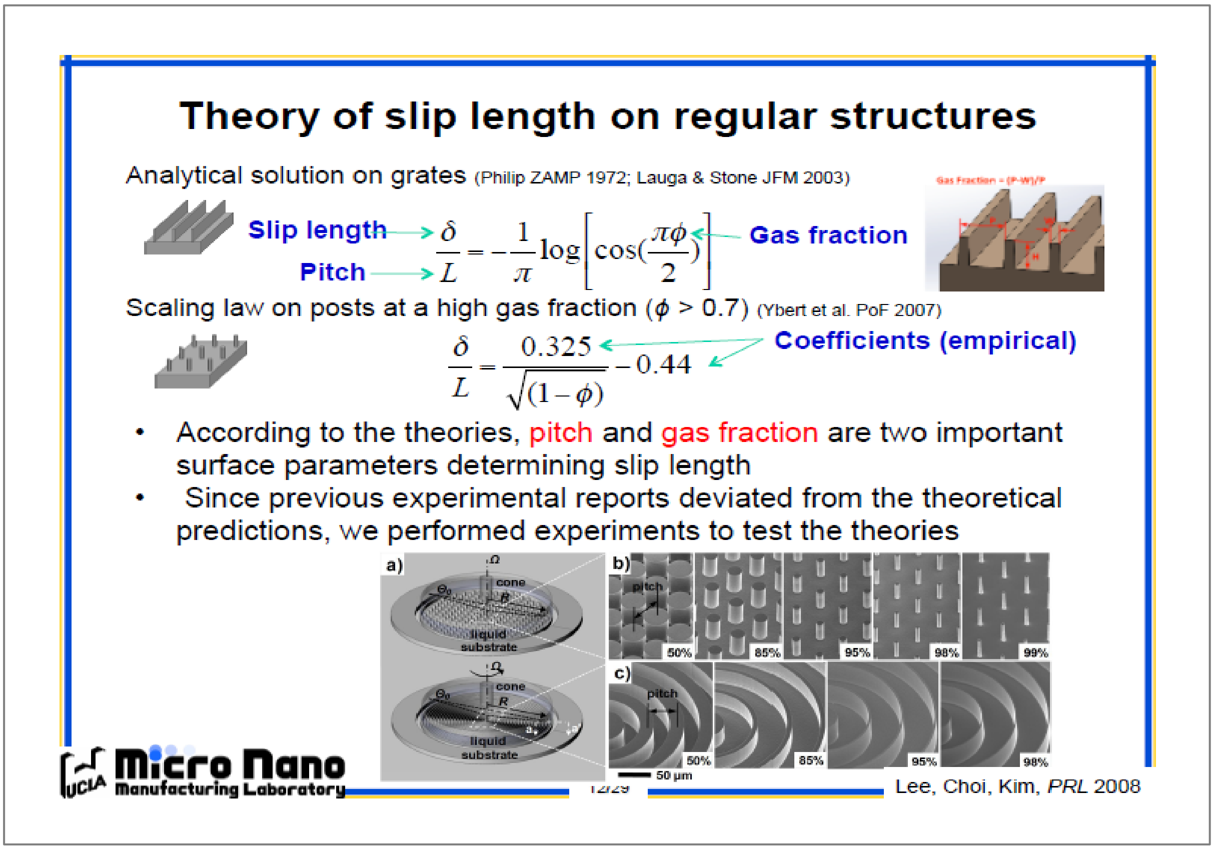


Figure 11. Theory of Slip Length on Regular Structures

The Slip Length Data of Laminar Flows in the Literature

So let's first consider laminar flows. Don't worry about the details. In a laminar flow, where things are predictable mathematically, there have been some theories, and our lab was using the MEMS technology; we were able to create surfaces which are precise enough to create a certain microscopic geometry to conform what kind of theory was correct. So it took another maybe five or six years, but eventually we figured it out. And now that theory is proven at least for the laminar flow (Figure 11).

We had fun to put all the publication theories in the literature back into the picture and found things very interesting. So these lines are now proven as scientific predictions. So these are for grating structures, these are for post structures, and these are for randomly rough structures. And this is slip length non-dimensionalized. And this is gas fraction. Gas fraction is basically how thin a solid structure is. So large gas fraction means when water is on top, water touches more air than solid. So large gas fraction means water touches more air than solid surface. So as you can imagine, as the gas fraction becomes higher and higher, you get more slip length. It's a raw graph.

So as you can imagine, when experiment goes well, it will approach theoretical predictions. Usually experiments do not go well. You are supposed to have less than theoretical possibilities, right? So these are at least correct. It's not totally getting the theoretical expectation, but the experiment is at least right. So looking back, these data are experimentally proven, obviously, to be wrong because, theoretically, they are not even possible. And I had to use the raw graph because, especially early data was providing experimental data which was, one, two, three… all those magnitudes higher than even possible in theory. So, that's how you can see.

My conclusion from here is these unreasonable data in the early years, without knowing the scientific facts, actually made follow-up experiments on study very, very difficult because expectation is way above what's even theoretically possible. The worst is actually for random surfaces. As you can see, this is theory, theoretically possible. As you can see, most of the published data are all those magnitudes higher than even theoretically possible. Why did it even happen (Figure 12)?

Ok. So, first of all, the slips on superhydrophobic surfaces and drag reduction in laminar flows are at least understood today. So now, there is not much argument whether something is true or not. So using that theory that we know, we decided to go to these grating structures and trench structures, not random structures. Not only that, we know exactly how to get that kind of slip length that has meaning for a real boat. So these are requirements.

But so far, I said everything is in laminar because it's not predictable. Scientifically, you can study. But how about turbulent flow? Well, even for turbulence, even for those who study turbulence for their lives, over the last one hundred years, they still don't know what's really going on. So it's very, very difficult. But unfortunately, that's where most boats are traveling in open water. You have open water with turbulent flow. So since there is no theory even possible, we have to do some experiments (Figure 13).

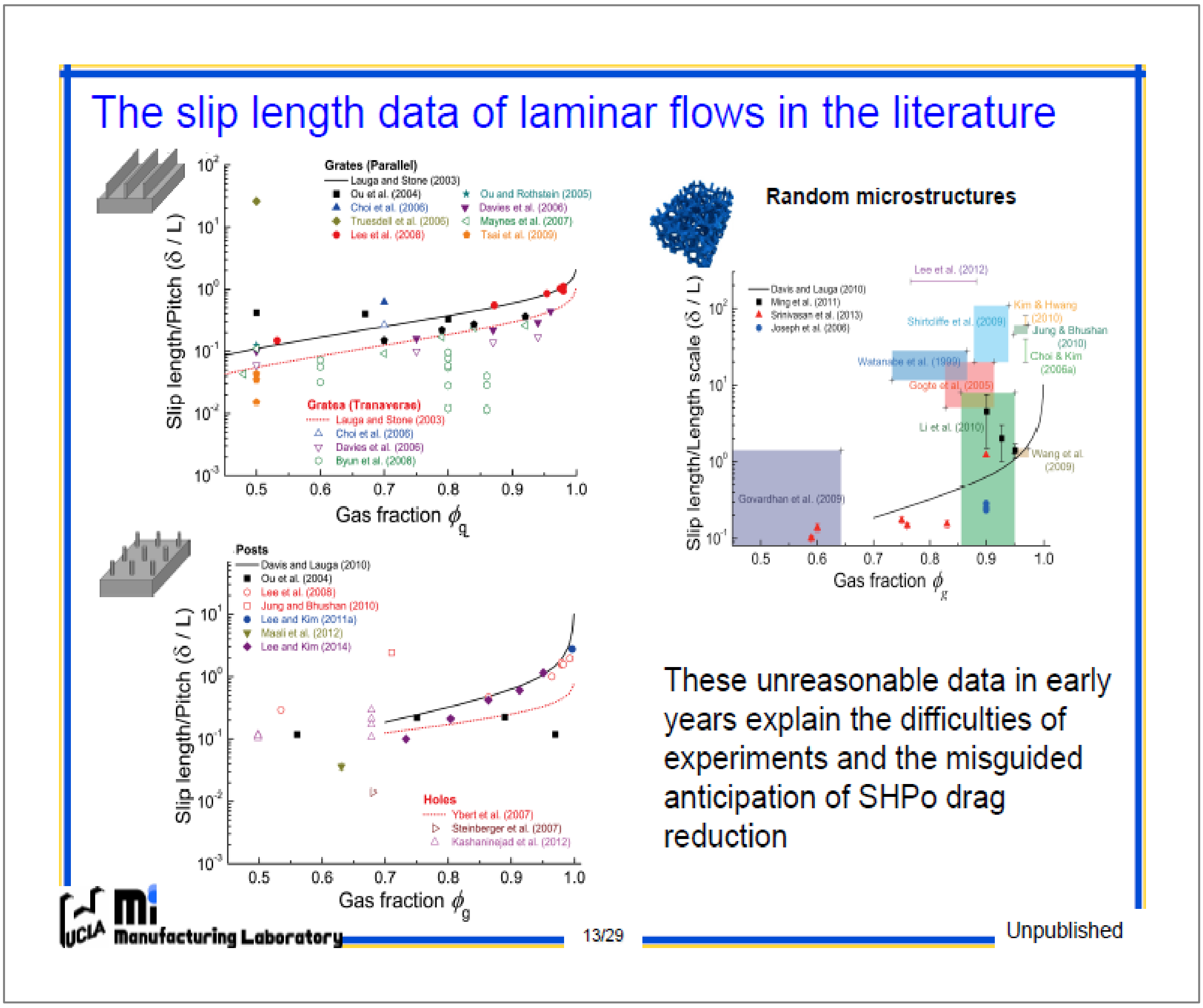


Figure 12. The Slip Length Data of Laminar Flows in the Literature

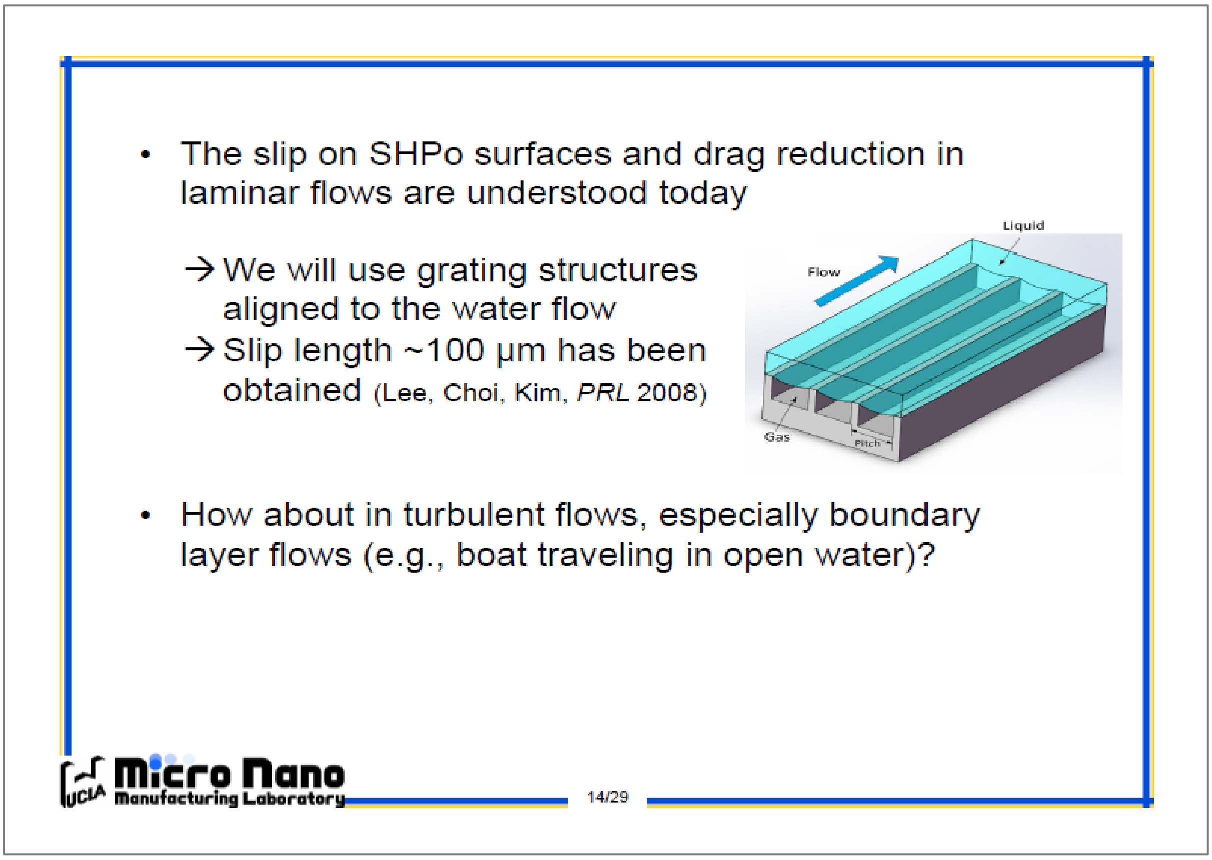


Figure 13. How about in Turbulent Flows?

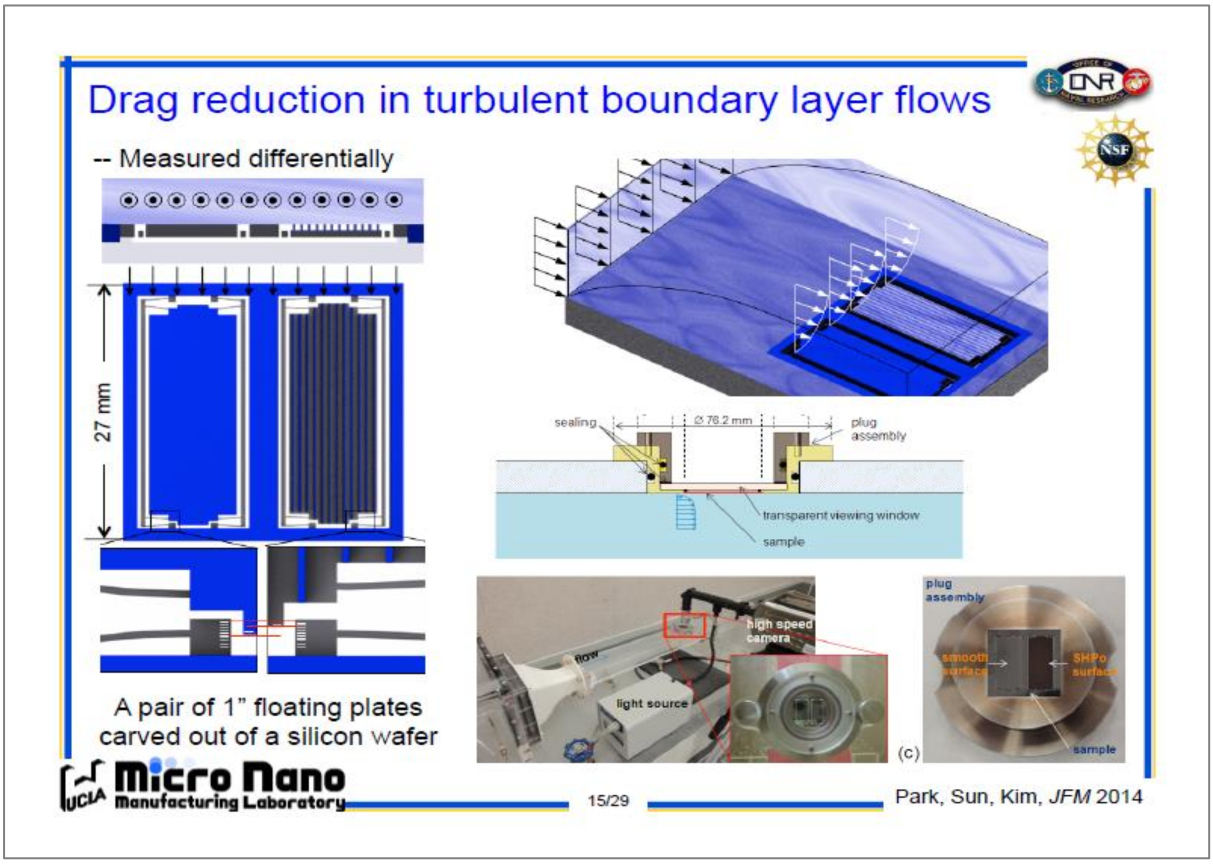


Figure 14. Drag Reduction in Turbulent Boundary Layer Flows

Drag Reduction in Turbulent Boundary Layer Flows

So now, using the MEMS, the technology to make our samples, it's a very small sample, but the key is we create two plates which are suspended by beam springs using MEMS. So they are pretty much exactly the same spring constant on the surface. But one surface has these structures, and the other surface is smooth. Both of them are Teflon-coated. So the only difference between the two plates are one is structured and the other is smooth. And we did test this one in our water channel shown here. And we measured how much is the drag. So, by optically measuring, the difference between these plates' placement, we can measure what is drag reduction. So if you look at this video, a smooth surface shifts more than a superhydrophobic surface (Figure 14).

And this is the first direct verification that you can get drag reduction in turbulent flow, turbulent open water flow, and the result even amazed us in that, in certain conditions, of course, with large gas fractions, we were able to remove as much as 75 percent of the drag, gone. Only 25 percent left. That sounds great. So now we are increasing the Reynolds number more and more to obtain more realistic results (Figure 15).

Dream or Reality?

Well, sounds like a dream is coming true? It's not that fast because…actually, because of timing, I want to jump a little bit. However, these are all in water channel experiments. So in water channel experiments, we had huge drag reduction, and other people also had drag reduction even using these rough surfaces. Even those many successful drag reductions in flow water channels have never translated to success in open water. And people wonder why (Figure 16).

So that the problem has been constant lab success but failure in field demos. And we think, and I believe, the main reason is, especially for rough surfaces in a water channel (the way a water channel works is actually the water channel is always saturated or supersaturated with air), there is always air coming from the liquid or the water into the gas. But in reality, in open water, that water, in open water, is undersaturated with air. So in open air, in field conditions, this water will take the gas away from the surface. That's, I believe, why people had so much success in the lab water channel but never had success in open water (Figure 17).

Not only that, going back to the theory, even today, most of, all the drag reduction report in water channels, that reduction is much, much higher than theoretically possible. So that indicates that something is wrong (Figure 18).

#2. Would the Air Layer Persist?

So the second question is "Would the air layer persist?" because my old observation was that the air layer will persist in a superhydrophobic surface. The main difference between regular superhydrophobic surfaces with droplets is, under the water drop, there is air around, always providing air under the water. But when submerged, this gas, once it's gone, it's completely gone. So it's much more difficult. Not only that, even theoretically, we have proven that even water or maybe 10 centimeters deep or deeper than 10 centimeters from the water surface, the gas of the surfaces will not even stay, even theoretically not possible. So it explains why it was not even possible to have drag reduction. I'm going to jump this more complex, more sophisticated result (Figure 19).

But the key is that even the nature does not allow the air to stay on the surface when you submerge under the water. So, in a way, we are trying to combat something where we have no chance of winning. So when the nature, when we know that the nature does not allow the gas to stay, the only way is to find the solution with engineering techniques (Figure 20).

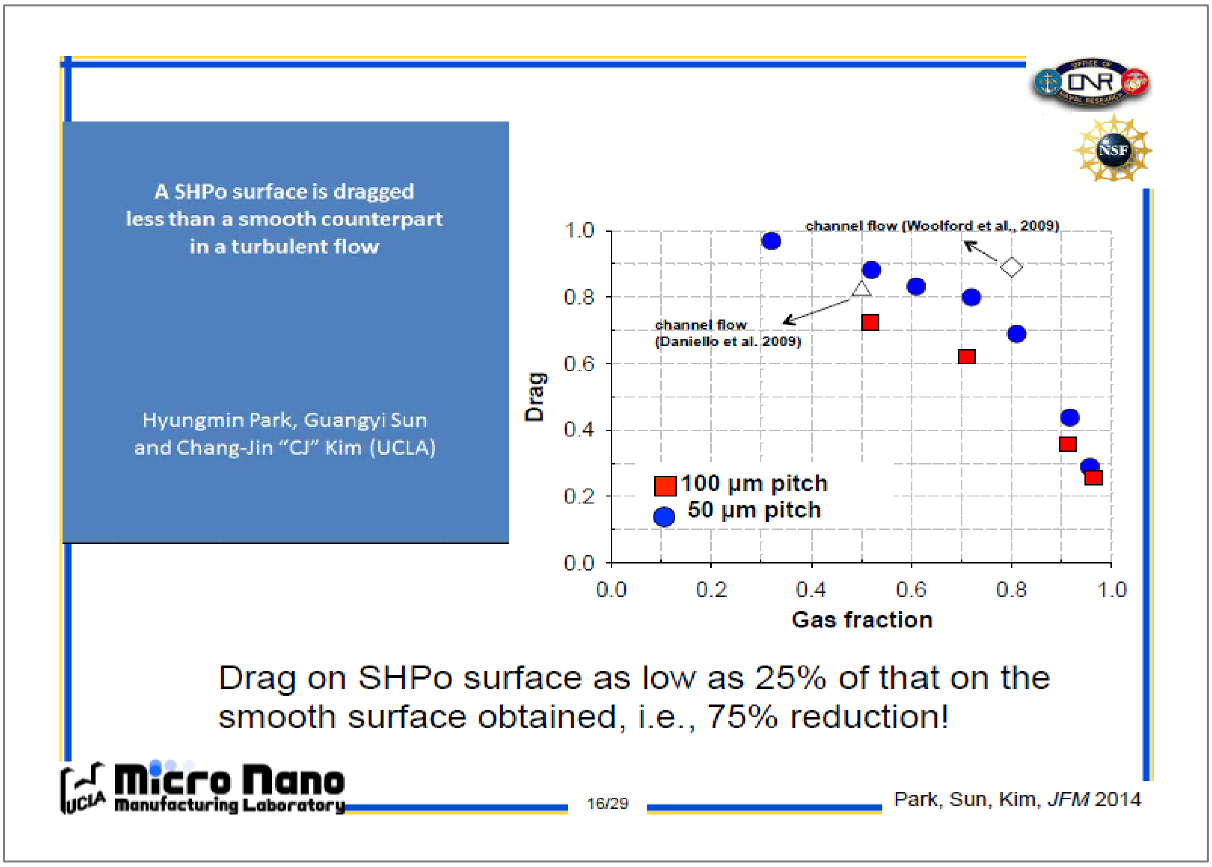


Figure 15. Drag on SHPo Surface as Low as 25%

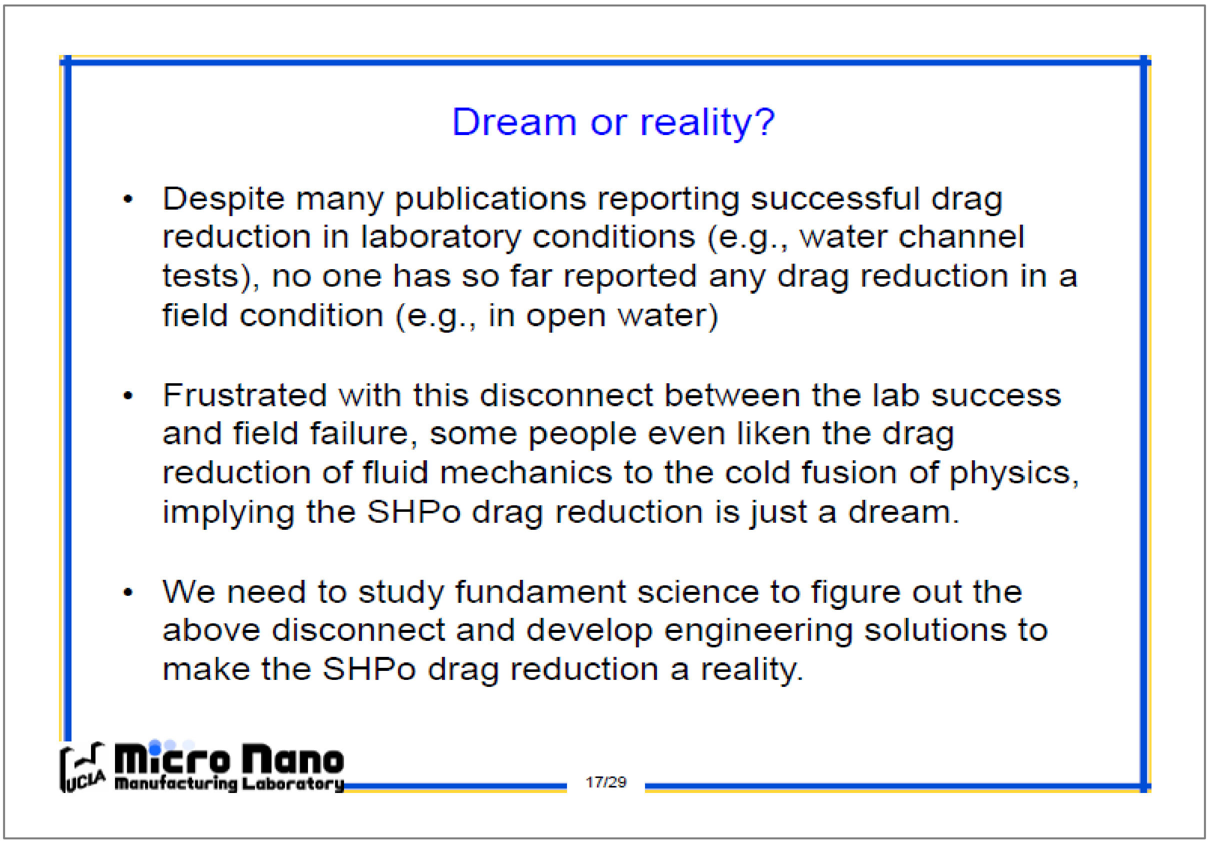


Figure 16. Dream or Reality?

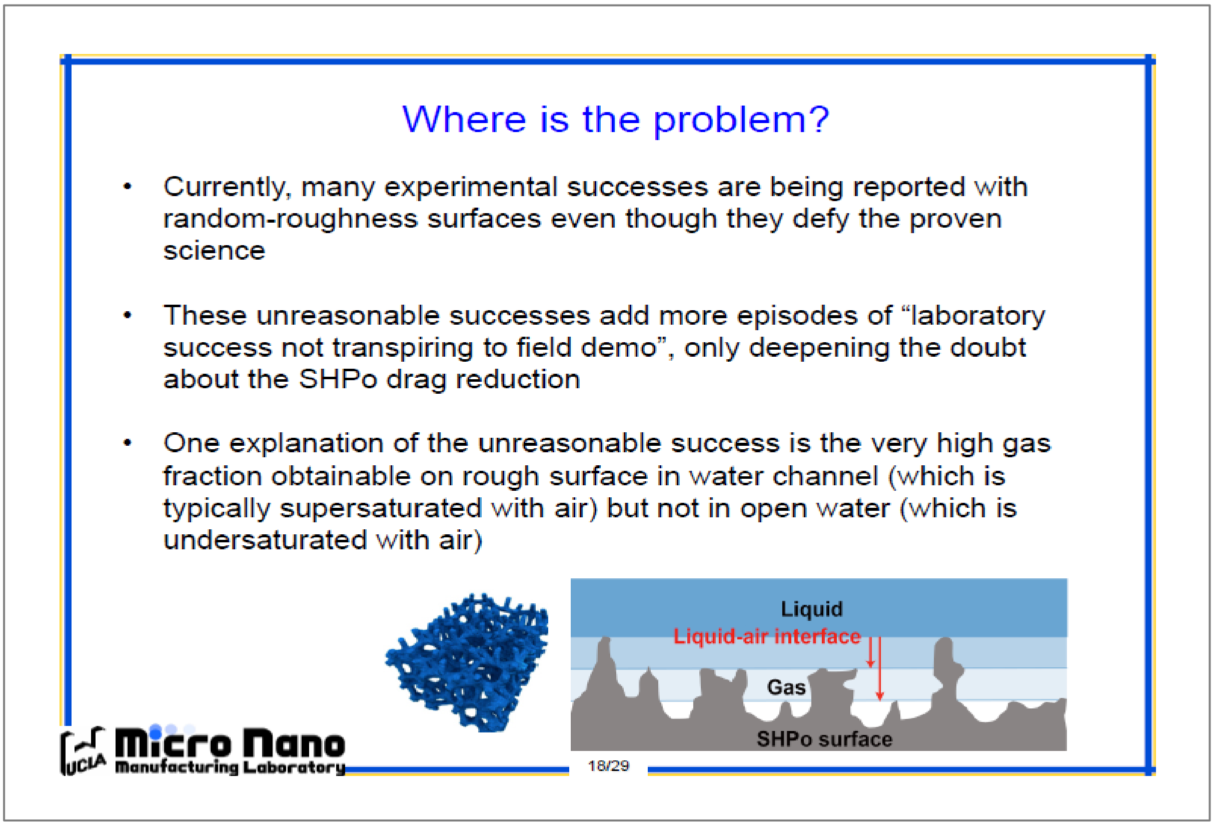


Figure 17. Where is the Problem?

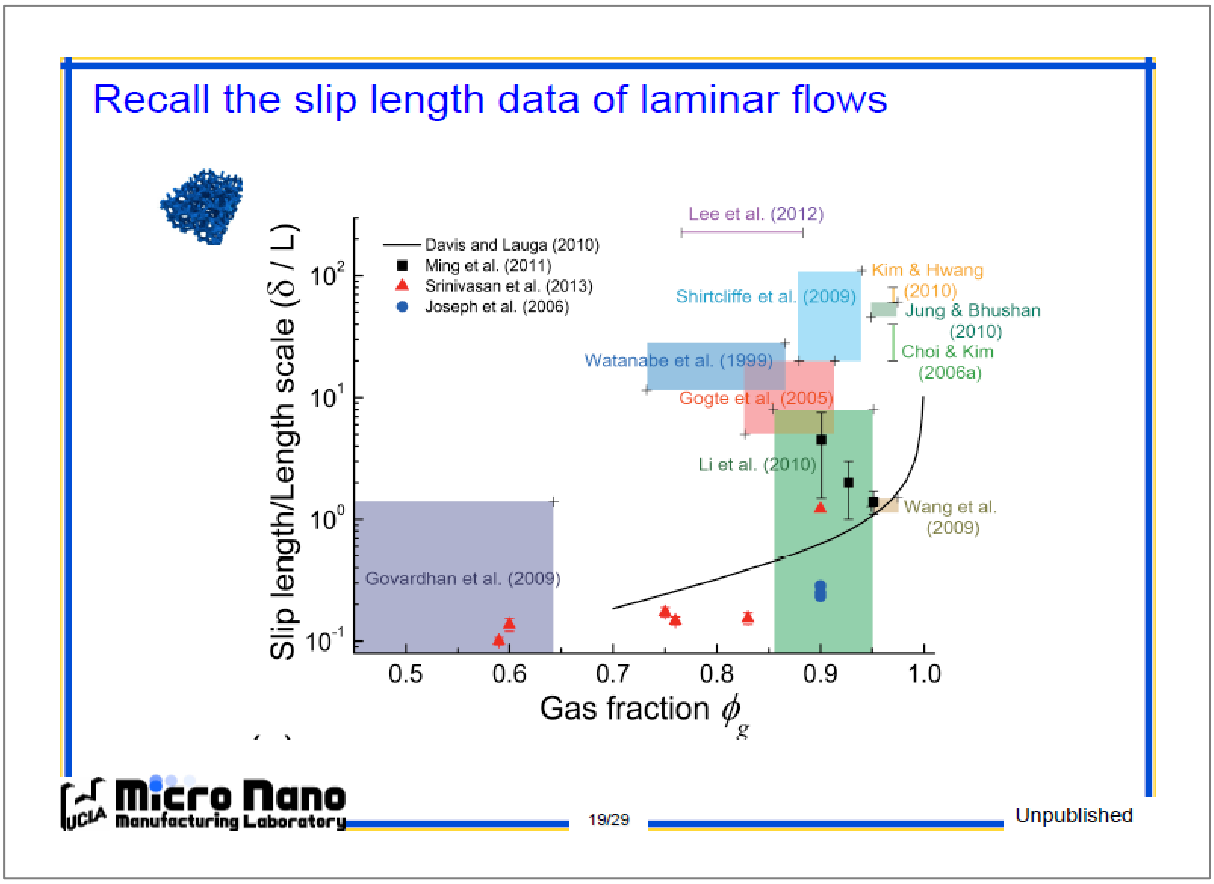


Figure 18. Recall the Slip Length Data of Laminar Flows

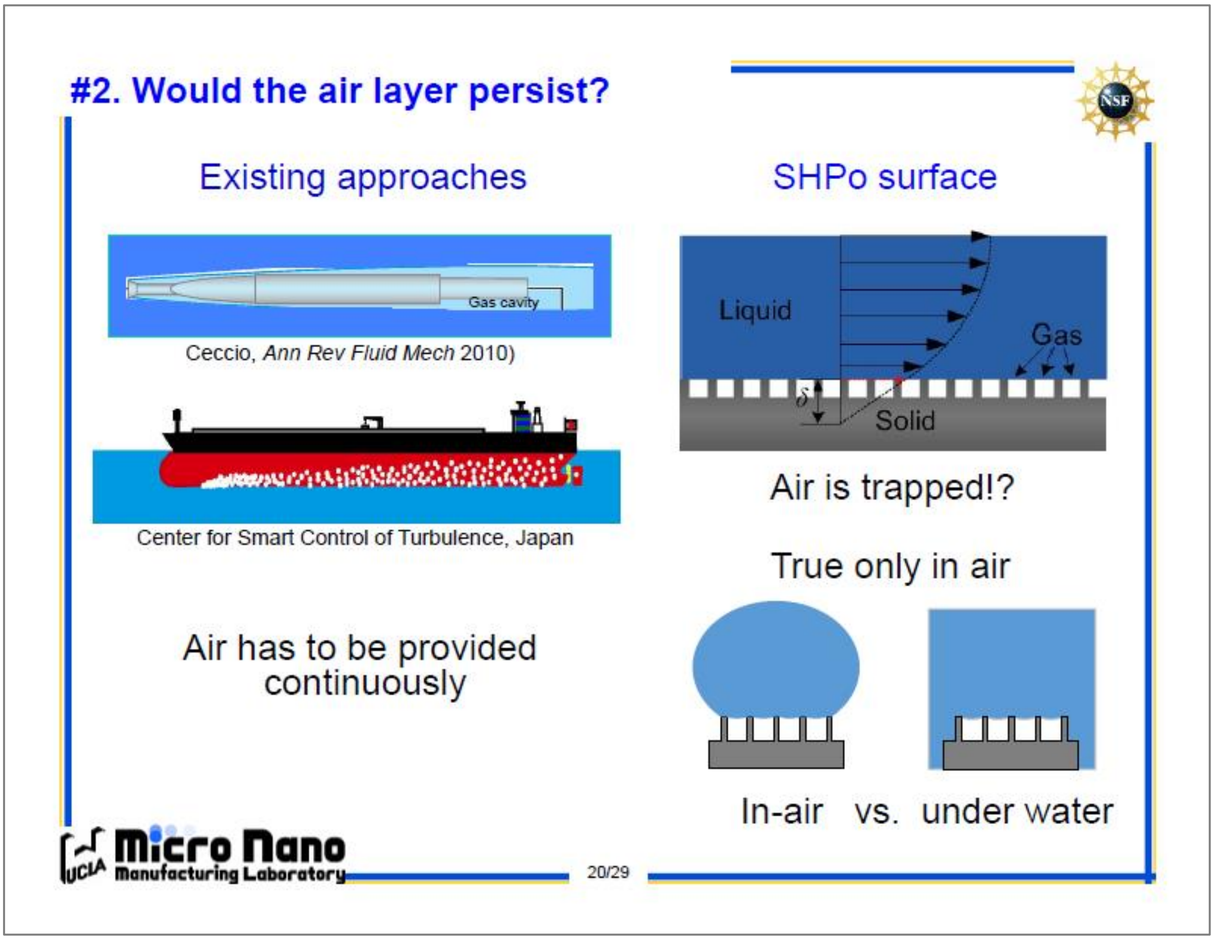


Figure 19. Would the Air Layer Persist?

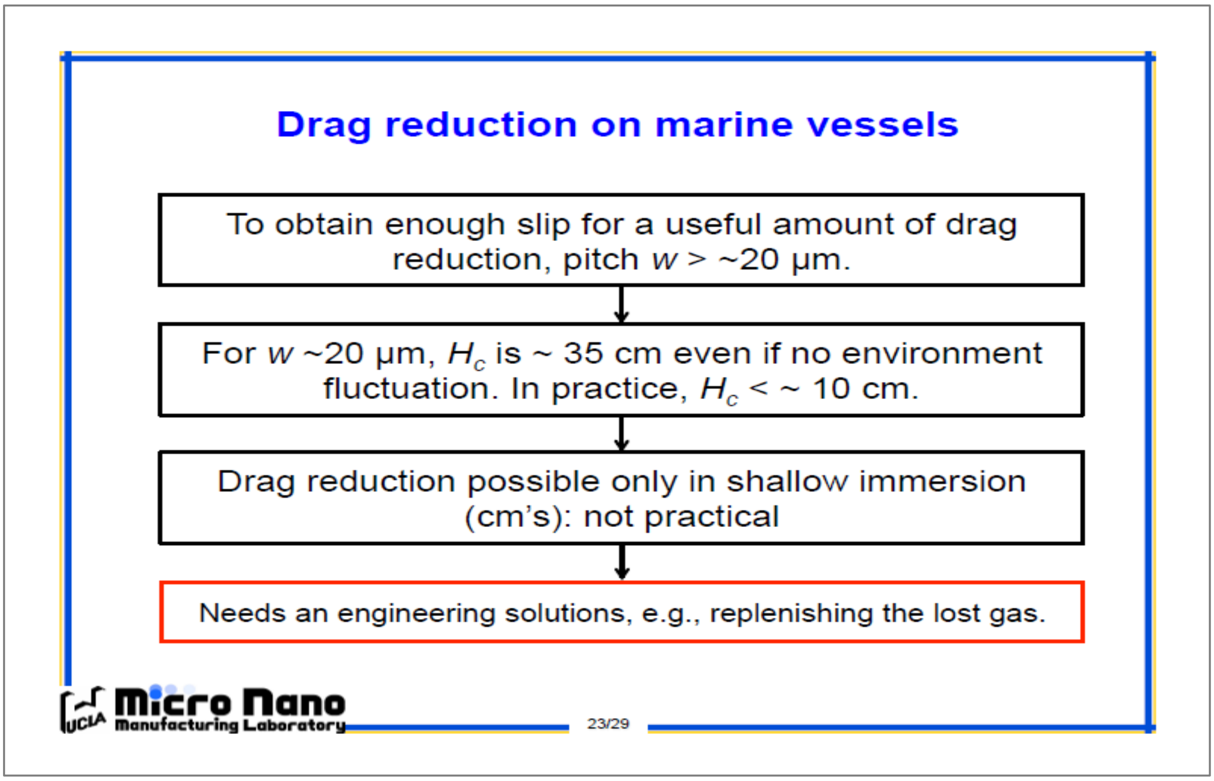


Figure 20. Drag Reduction on Marine Vessels

So this is our technique. So now we accept under the water, after a while, this gas layer, which is called a plastron, will be gone. We accept that. Instead, we apply voltage between your hull surface and conductive water. Now, if the water wets any of the structure and touches the conductive hull, what happens? Electrolysis happens. Gas will be generated. They will push the water away and return to the original condition. This will go back around without having any sensing mechanism or control mechanism. It's self-controlled. So yes, you lose, you use a little bit of energy—but a very small amount of energy—but you create large drag reduction (Figures 21 and 22). (I'm actually going to jump a little bit.)

I will show that, however, yes, conceptually things are always easy. Usually implementation is much more difficult. Even for the same structure, unless you do things right, yes, gas will be generated, but in this case, gas will be lost. Instead of spreading on the surface, gas will form as bubbles and leave. It's not successful. But, even if it looks pretty similar, if you do design things properly, scientifically right, then, as you can see, the gas is generated by electrolysis, self-controlled electrolysis, and spreads only sideways. So this way, you can recover the plastron on the surface without continuing to lose the energy. So this is our strategy to combat the nature that is against us (Figure 23).

So this is just last, one of the last videos showing. Well, so far, we are showing the gas is spreading on the top, but how do we know it actually recovers well the way we planned? This is the view from the side. So this is the water, and this is air within trench looking from the side using transparent material. As you can see, there is air. Soon, the air diffuses away to the water, and when the water touches the underneath, as you can see—it's real time, oh, sorry, it's 30 times fast, but—hydrogen is generated and recovered to the exact position so that you don't have to consume, continue to consume, the energy (Figure 24).

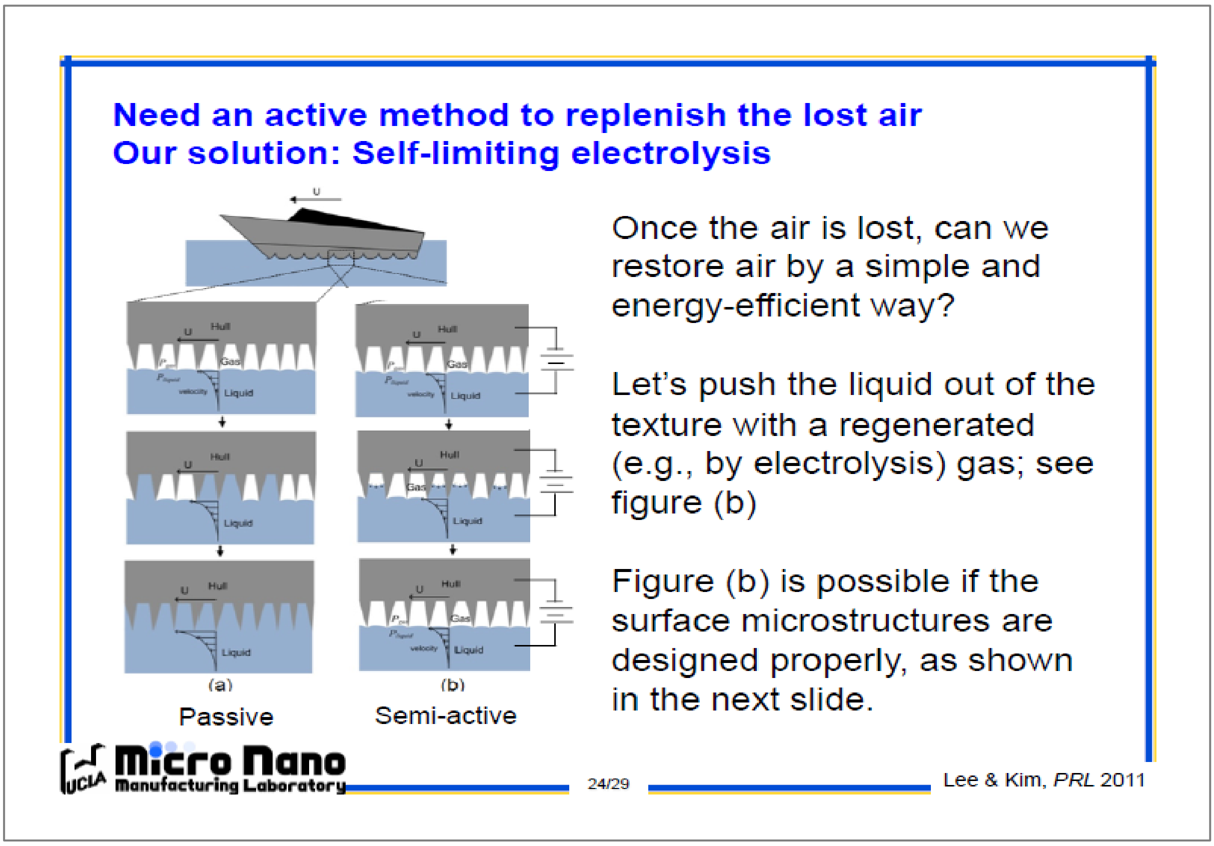


Figure 21. Need an Active Method to Replenish the Lost Air

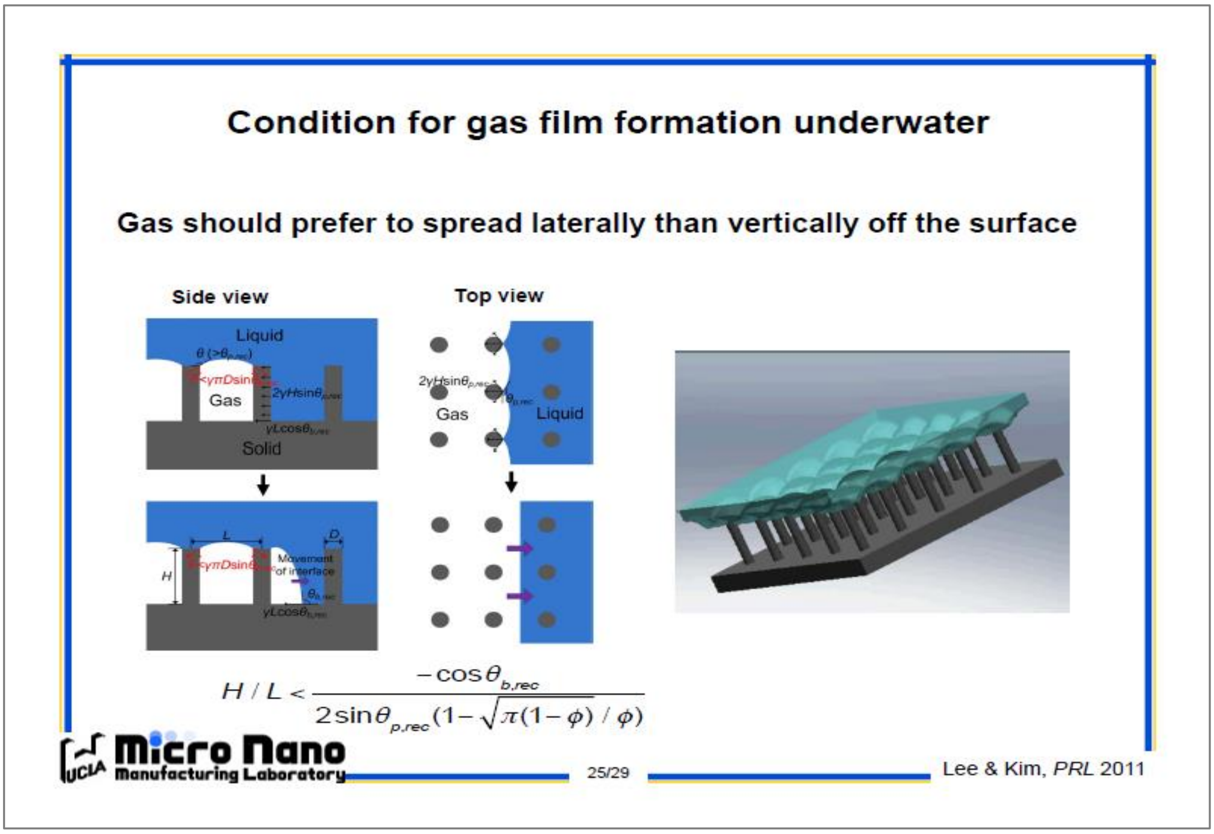


Figure 22. Condition for Gas Film Formation Underwater

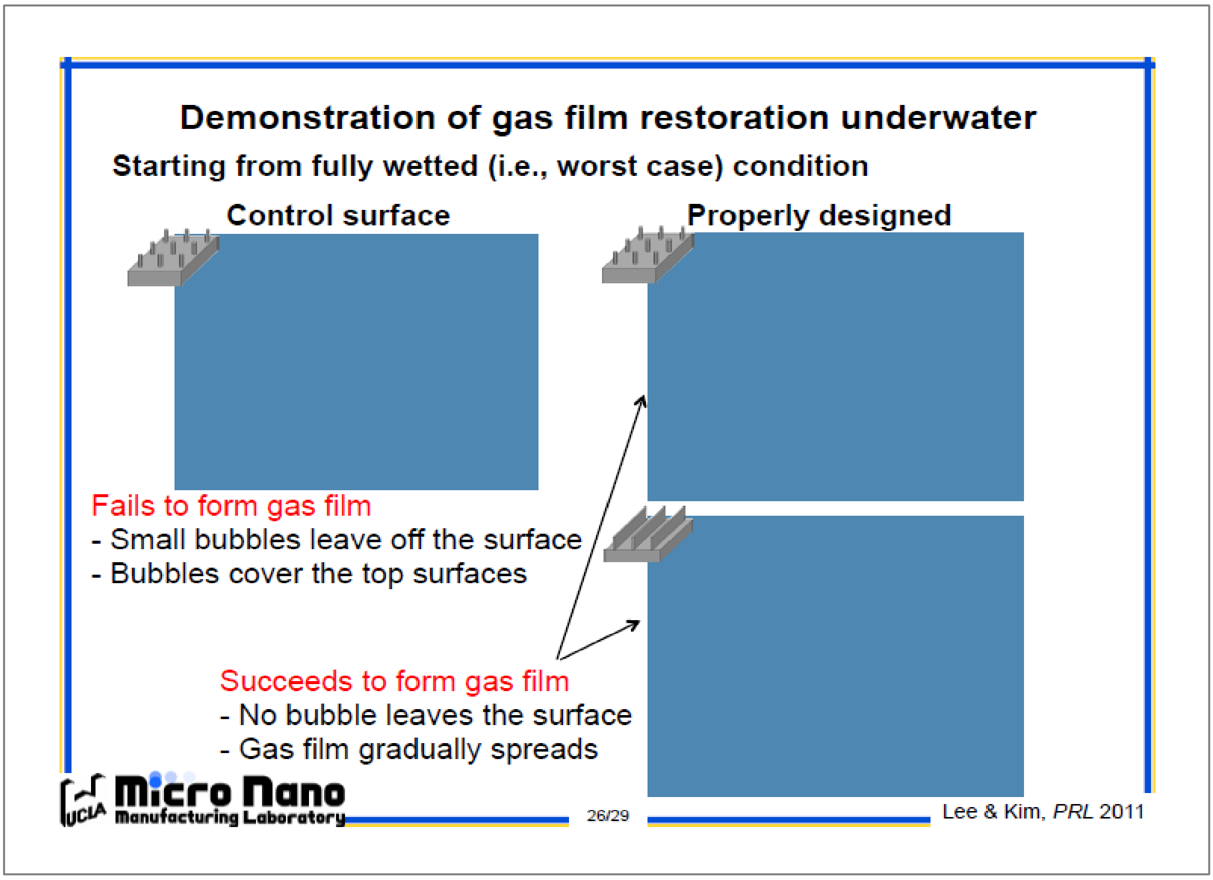


Figure 23. Demonstration of Gas Film Restoration Underwater

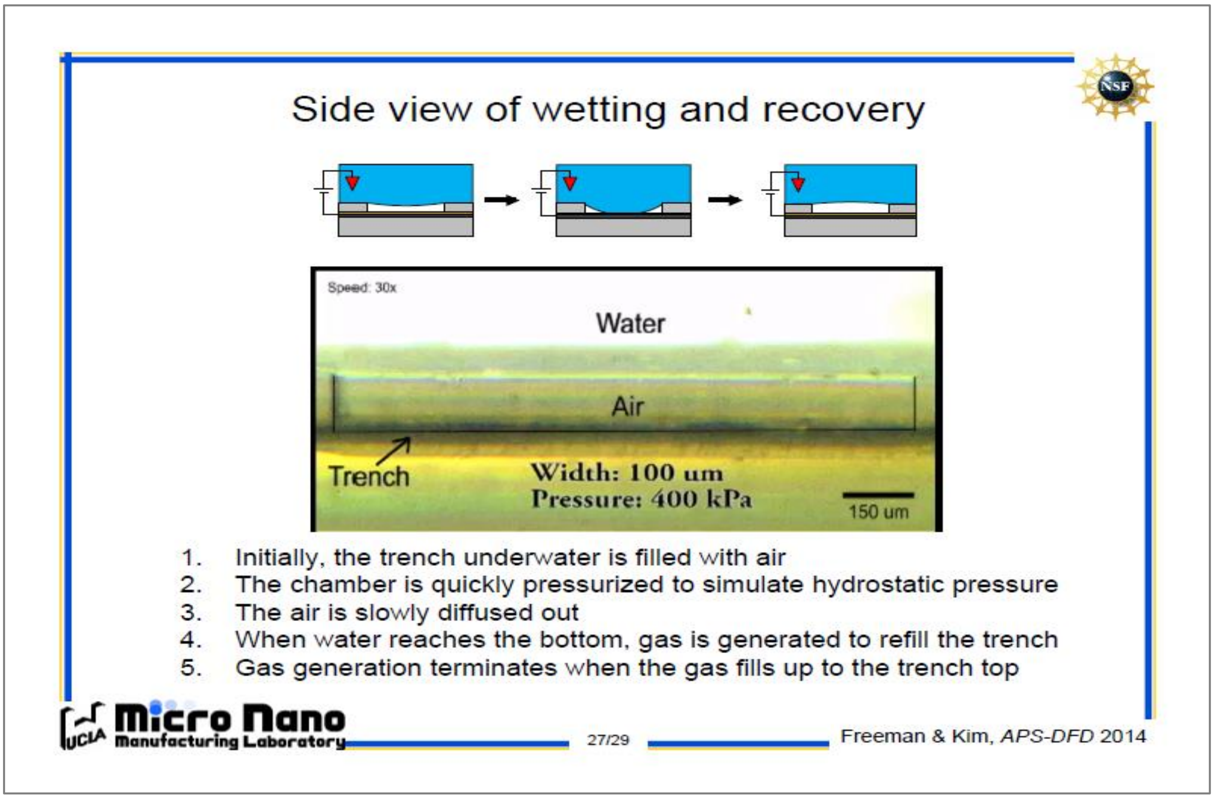


Figure 24. Side View of Wetting and Recovery

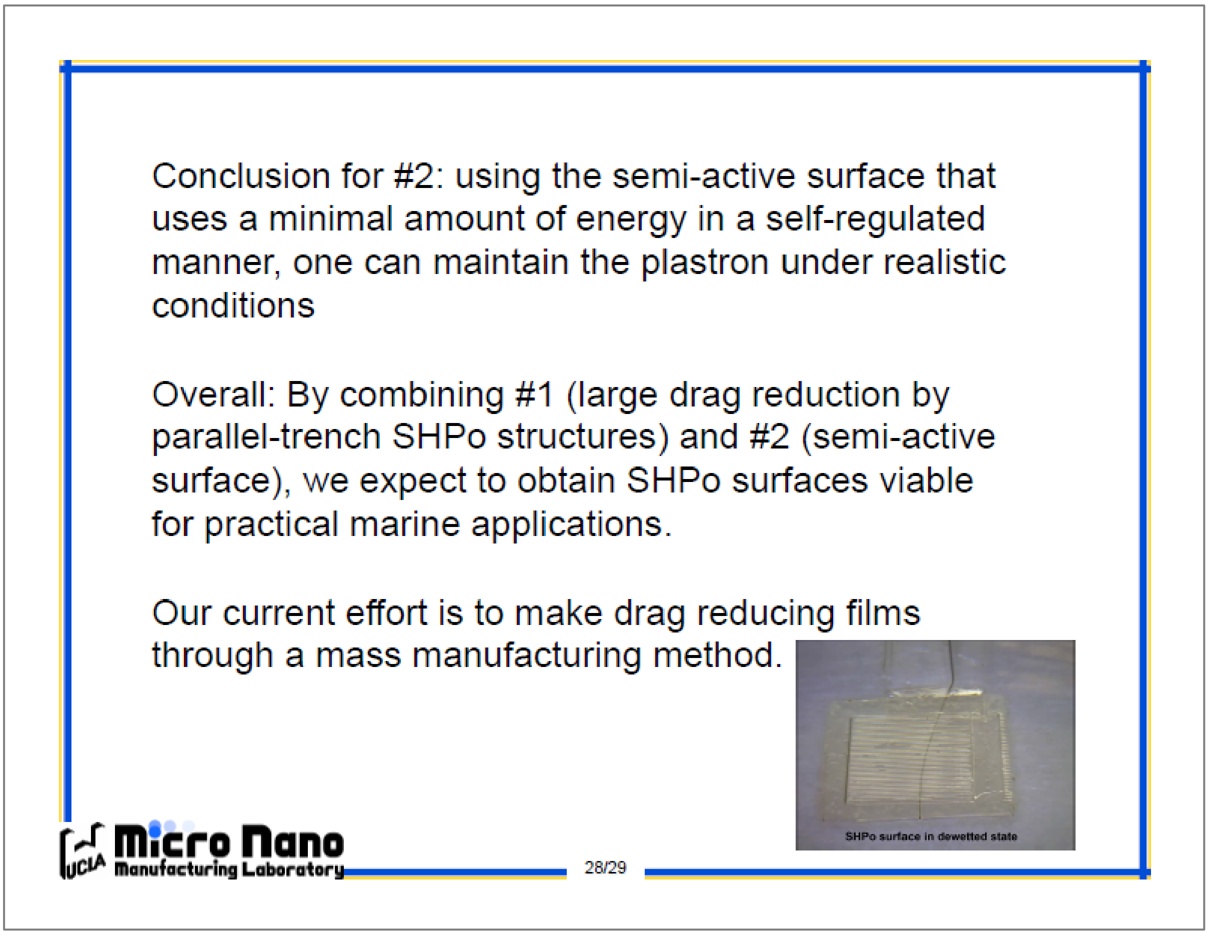


Figure 25. Conclusion

So the conclusion of number two is, yes, the nature does not allow you to keep the air. But engineering can solve the problem using the semi-active surface, what we call a semi-active surface that uses the minimum amount of energy in a self-regulated manner. One can maintain the plastron in the realistic conditions (Figure 25).

Conclusions

So overall, by combining condition number one which is proven now and number two which has been proven in concept but has more work to implement in real conditions, our effort currently is focusing on making drag reduction films, flexible films, through a mass manufacturing method. And this one shows one of our successes, showing that this is actually a flexible thin Teflon film, which has one wire, and showing that when it's wet, it automatically recovers the superhydrophobic state by generating the gas by itself without having any control (Figure 25).

So OK, overall, this is my philosophy. If we play the game the right way using the scientific knowledge properly, we can even apply microscale phenomena to large applications (Figure 26). Thank you.

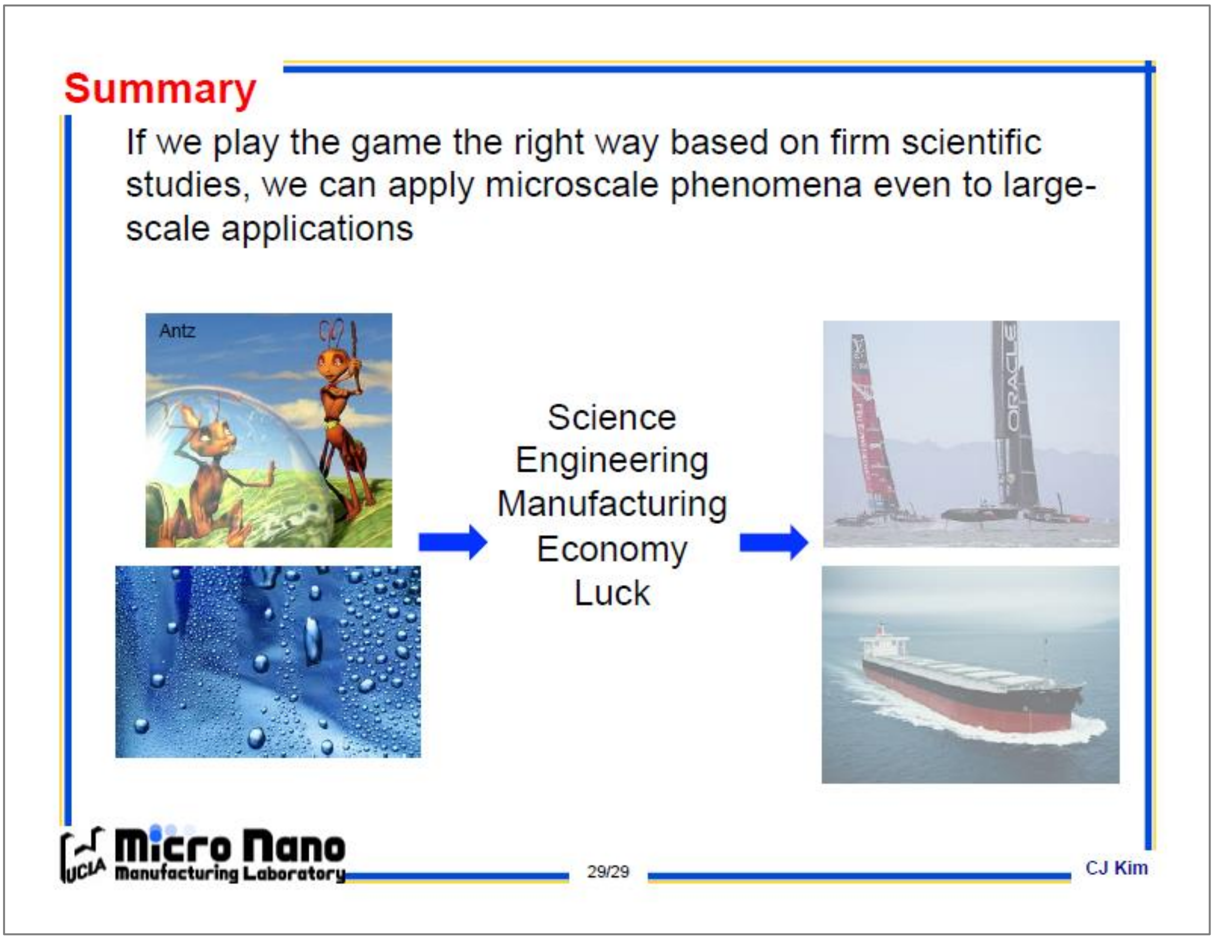


Figure 26. Summary

Back to Mechanics – How Nanoimprint Lithography Changed the Way

How We are thinking about Nanomanufacturing?

Helmut Schift

Head Polymer Nanotechnology Group

Paul Scherrer Institut

Good morning. When I was invited to come to IFAME, I asked myself what is the stage here to the audience to whom I should talk.

It's about advances in mechanical engineering. Now, I am not really an expert in mechanical engineering, although I did my Ph.D. in mechanical engineering; but I am an electrical engineer, and you will see I am also a microtechnology person. Therefore, the first thought was to give my talk the name, "The Renaissance of Mechanical Engineering in Nanoapplications," but then I changed it to "How Nanoimprint Lithography Changed the Way of Thinking about Nanomanufacturing." Nanoimprint lithography is my specialization since about 20 years, but at the same time, I also want to expand the field. I will not just show my own contributions to the field, but I will show you a little bit of the state of the art of the field and some kind of inspiration, I would say, for mechanical engineering.

Introduction

Now nanoimprint lithography was initiated by Stephen Y. Chou. Maybe you know him. He is Chinese but became American. And he is now in Princeton University, and he said when we had the 20th anniversary of nanoimprint lithography last year, "Until 20 years ago, nanolithography by mechanical methods was unthinkable." But I want to show you how mechanical methods are coming back again into microchip manufacturing. It's one kind of future which I want to present to you. And this is basically the machine which he was using 20 years ago. It's a very simple mechanical machine, and it's now in the technology museum of Munich as an example of how simple technical advances can begin at the stamps which he was using. When you see this grey and white picture, scanning microscopic pictures, that is 40 nanometers high, 10 nanometers wide, and the pitch is 40 nanometers as well. You can take this stamp and just press it into a soft polymer; then you retract it. We call it demolding, and you have these nano-holes in your polymer film. And this kind of resolution, you have to think about the fact that it's about 100 times of a single atom. It's one tenth of the size of a virus; therefore, it's really small, and it was unthinkable for many people that this can be done with this simple technology, particularly technology like this. It's just done like this: you press into the film, and you demold it (Figure 1).

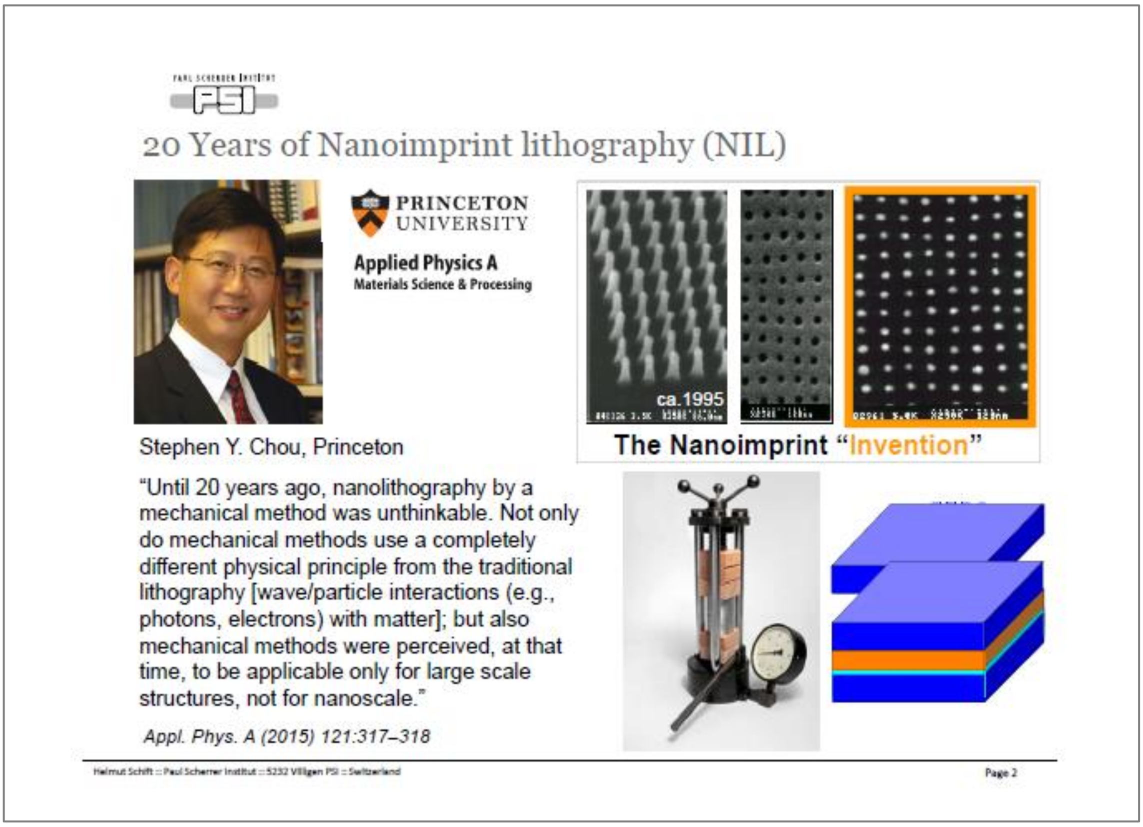


Figure 1. 20 Years of Nanoimprint lithography (NIL)

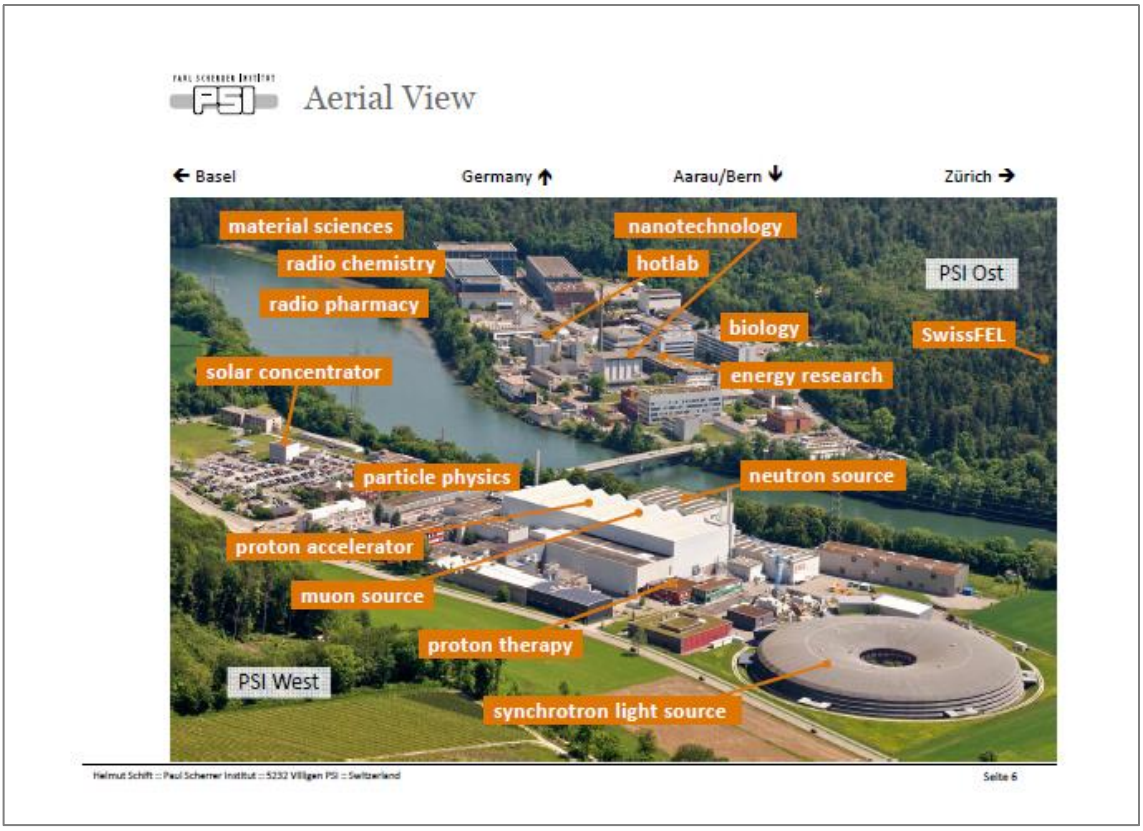


Figure 2. Paul Scherrer Institut (Aerial View)

Now, this is Paul Scherrer Institut (PSI). I want to shortly introduce Paul Scherrer Institut. It's in northern Switzerland. And you see it's a large compound with the river Aare (Figure 2).

We are a Swiss Federal institute, and these are the different government ministries. And this is the Paul Scherrer Institut, and you can see that we are on the same level as ETHZ and EPFL. These are two universities, but we are, like KIMM, a state institute (Figure 3).

And this is the Paul Scherrer just to show that it's a real person who was a good physicist who introduced nuclear technology in Switzerland (Figure 4).

And now again back to the Paul Scherrer Institut. We have built up nanotechnology in Paul Scherrer Institut. We have a large synchrotron light source (SLS) but soon a free electron laser for X-rays (SwissFEL). These are our large tools, and it was seen that nanotechnology has much to do with X-rays here in this synchrotron. But we have other techniques as well; therefore, it's not only nanotechnology (Figure 2).

And now most of the people who do research in a large institute like ours, they produce photons, protons, neutrons, and muons, and they shoot these kinds of probes and particles on matter. And then we take a kind of camera (or we call it microscope), and you take a microscopic picture and analyze materials (Figure 5).

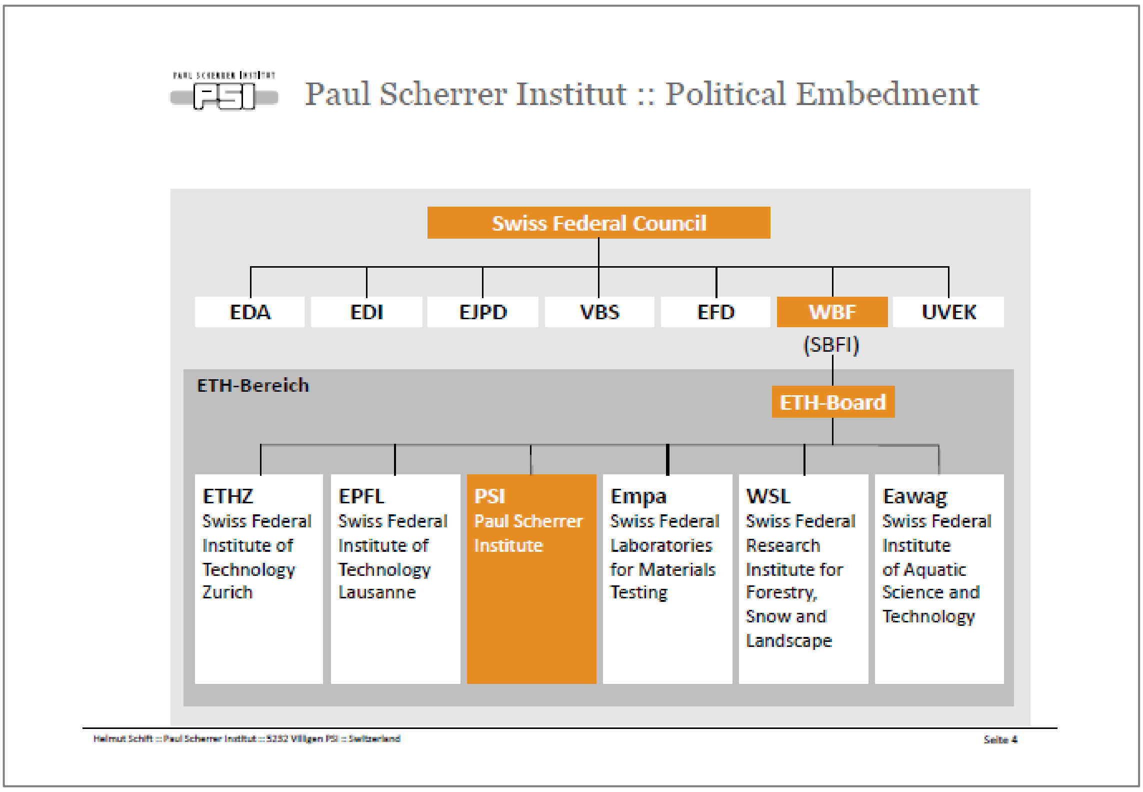


Figure 3. Paul Scherrer Institut (Political Embedment)

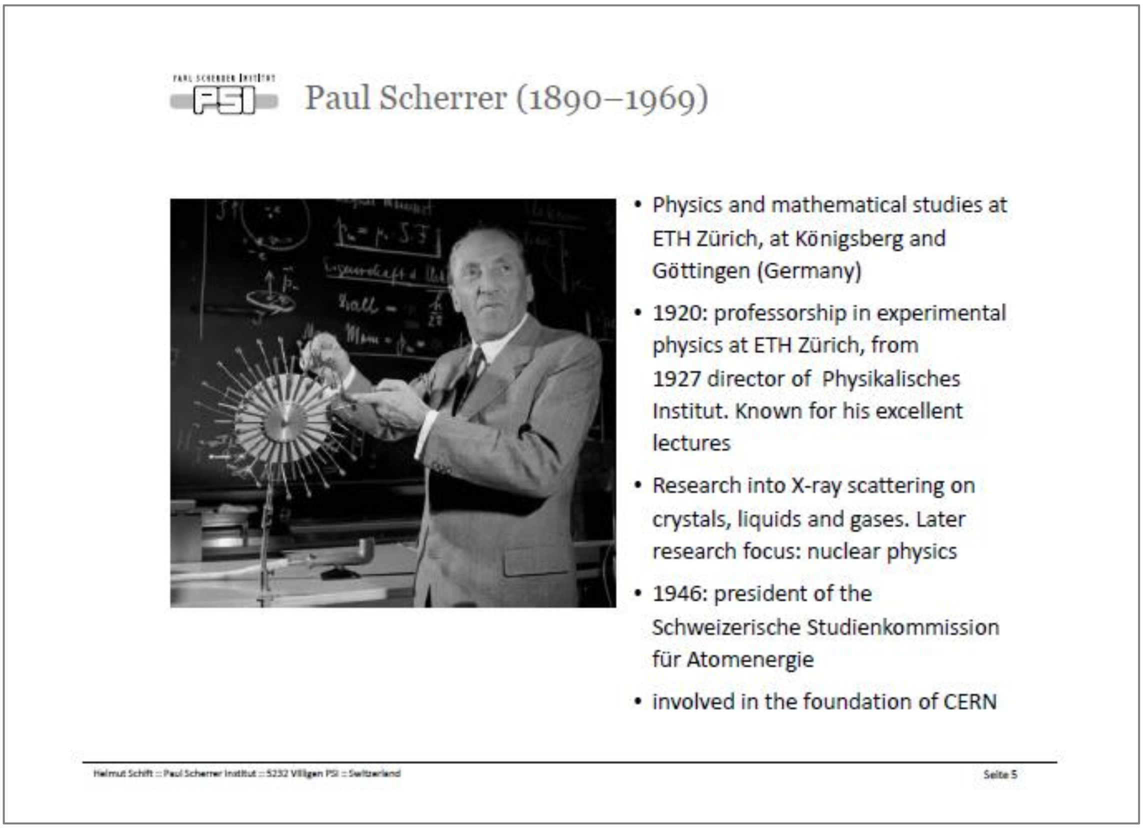


Figure 4. Paul Scherrer (1890-1969)

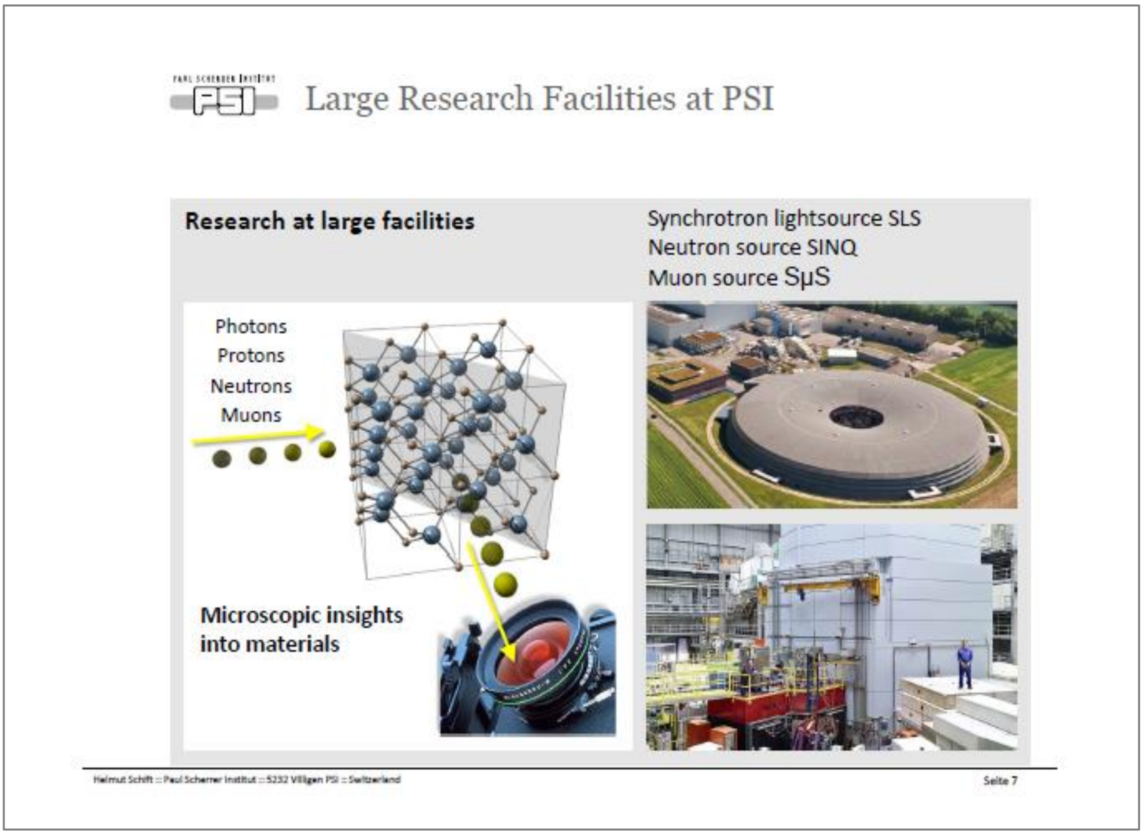


Figure 5. Large Research Facilities at PSI

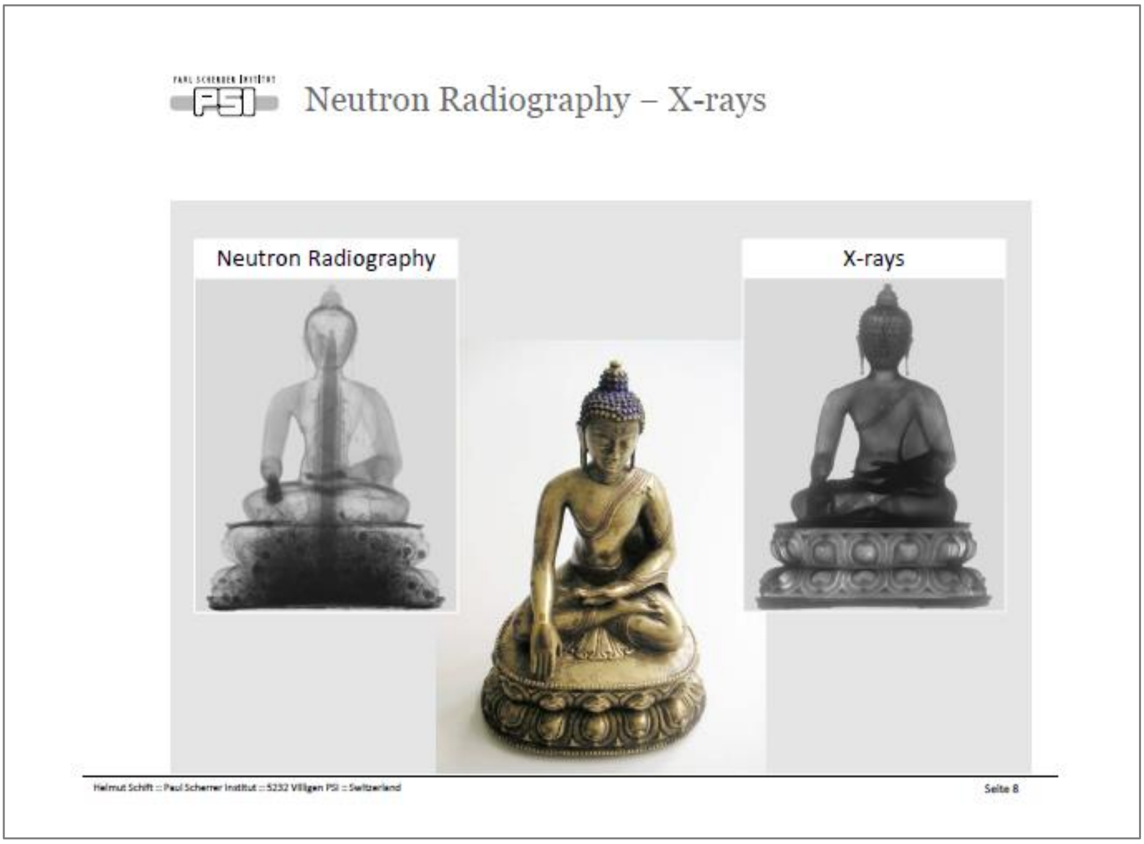


Figure 6. Neutron Radiography - X-rays

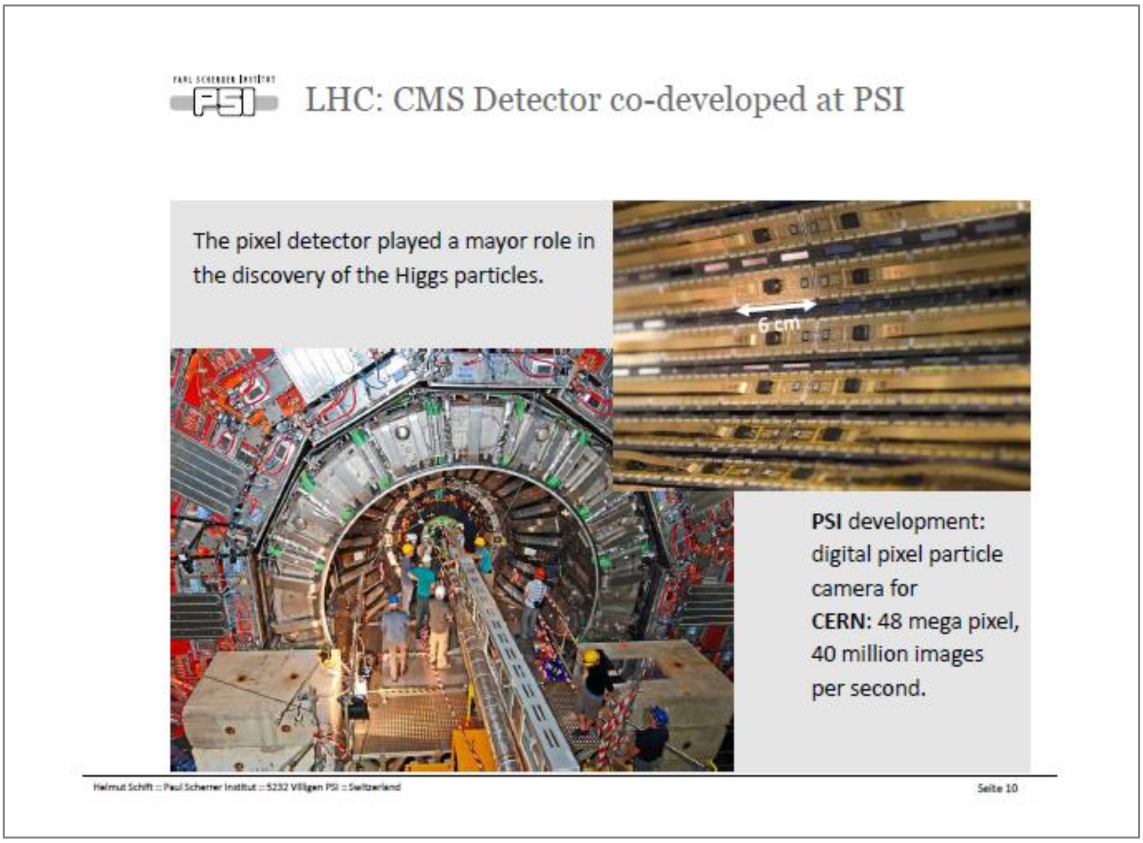


Figure 7. LHC: CMS Detector Co-Developed at PSI

Now just a kind of comparison, if you take this Buddha statue here, you can take neutrons; you can take X-rays. You see the contrast is totally different depending on the probes which you take (Figure 6).

Now we have something in common with CERN, which is located in Geneva. PSI is a state institute of Switzerland, and CERN is an international institute which happens to be on Swiss and French ground. Now we have something in common. We have high precision here and extreme energies, and where PSI comes into play is we are co-developers of the detector which is necessary to find the Higgs particles. Therefore, we are making these kinds of chips and, for that, we need clean room laboratories. And that's also the reason why I'm at the Paul Scherrer Institut, because we are developing lithographies for high-resolution manufacturing (Figure 7).

Nanoimprint in the Context of Advances in Mechanical Engineering

I begin with nanoimprint in the context of mechanical engineering. I want to come back to my initial slides and show you a process. Here I show a stamp which you press into a thin layer of material on a substrate. This is basically a mechanical process. And this is an additional process step; we call it pattern transfer. And with that, you do something which is called lithography; you pattern the substrate. And just to give you a kind of idea, this is real mechanics on the nanoscale (Figure 8).

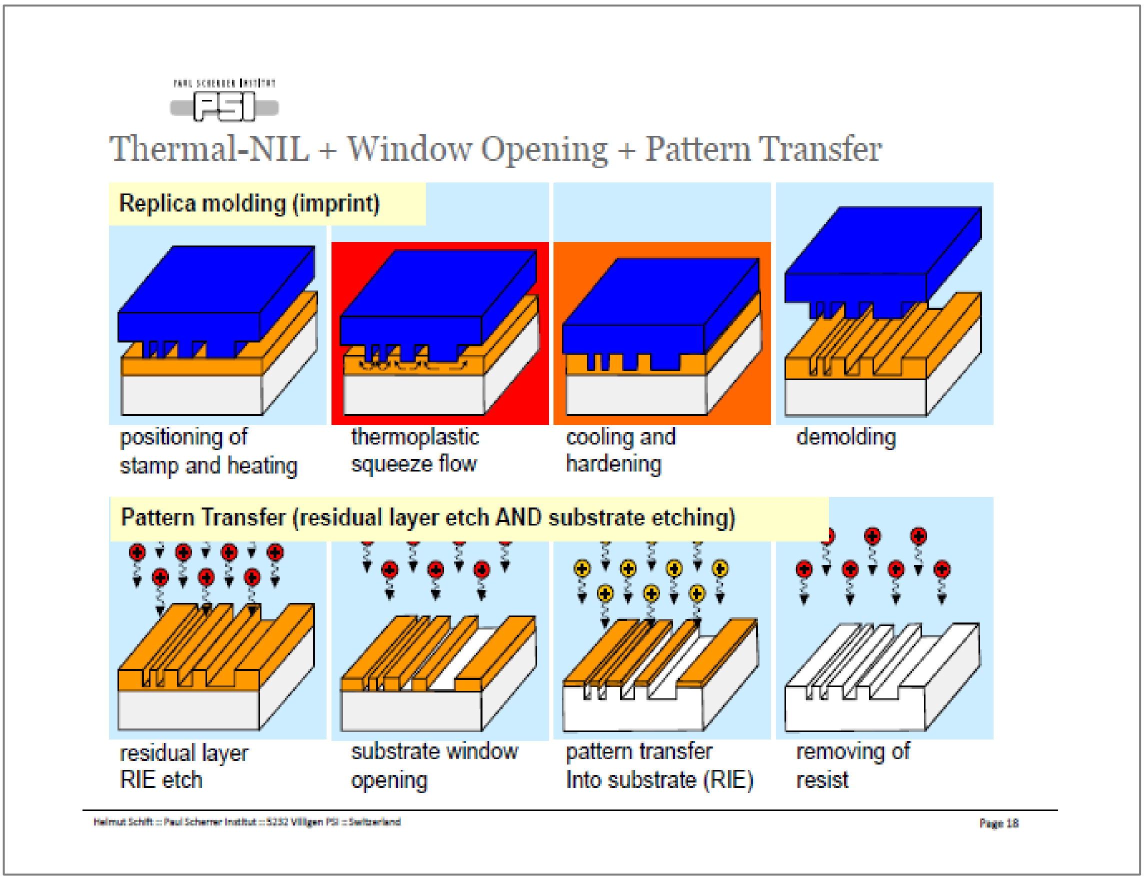


Figure 8. Thermal-NIL + Window Opening + Pattern Transfer

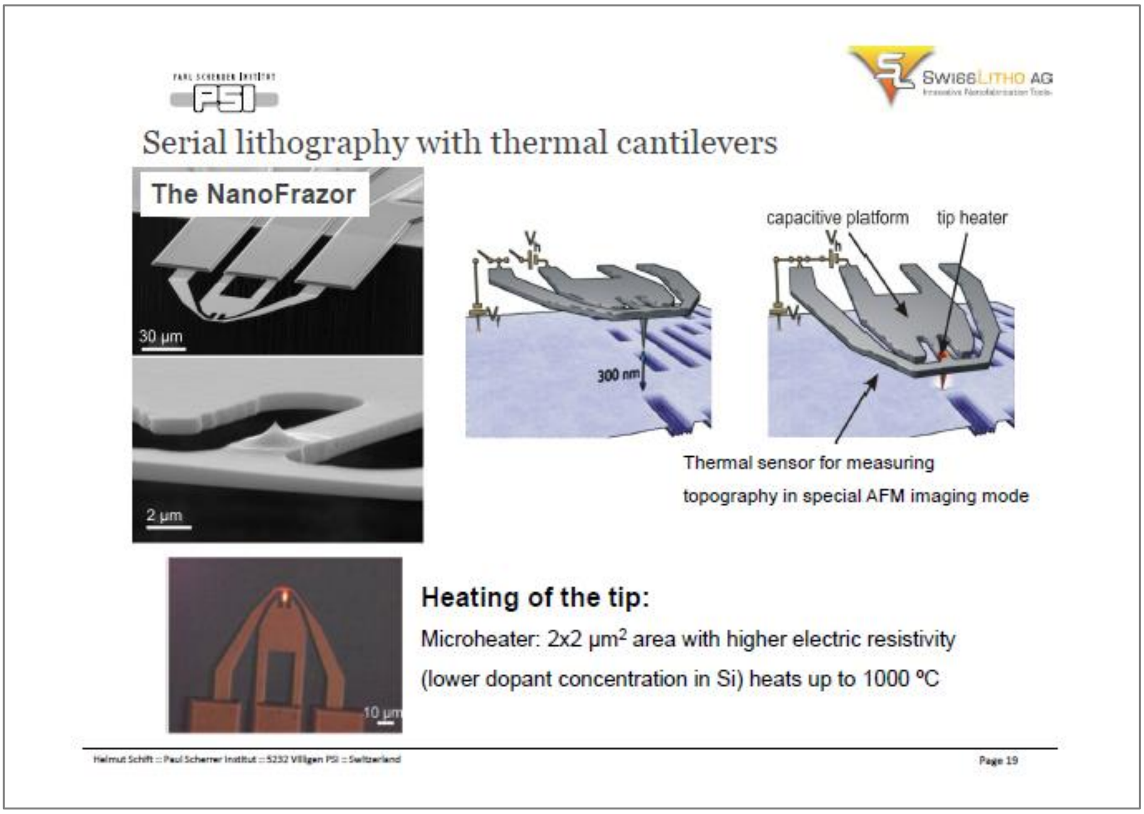


Figure 9. Serial Lithography with Thermal Cantilevers

For comparison, I show you a process which was commercialized by a Swiss company. If you have a single tip here, you can also do that in a serial way. That means you just impress into a certain surface, and you can also structure surfaces. And these are the new mechanical ways of structuring surfaces in the nano-range (Figure 9).

Now the replication technology has big advantages. You can take polymers as a template. 800 years ago did not use polymers but clay for the manufacturing of vessels, which can also be molded. You can do replication very fast. This demonstrated with an injection molding of a compact disk. It's a parallel process and one process cycle is done within 3 seconds. You can pattern it on large areas at the same time and achieve high resolution. And you can also do some additional things; you can make your own tools with this kind of replication techniques. You can copy stamps, for instance (Figure 10).

NIL Is a Next Generation Lithography - True, but Not Only!

Now what is next generation lithography? Well, again, it is about resolution, large area, and small tools. In the next slide you see a different tool, but it's a very simple tool. And with that, you can do most of the processes. In real production, you take different tools (Figure 11).

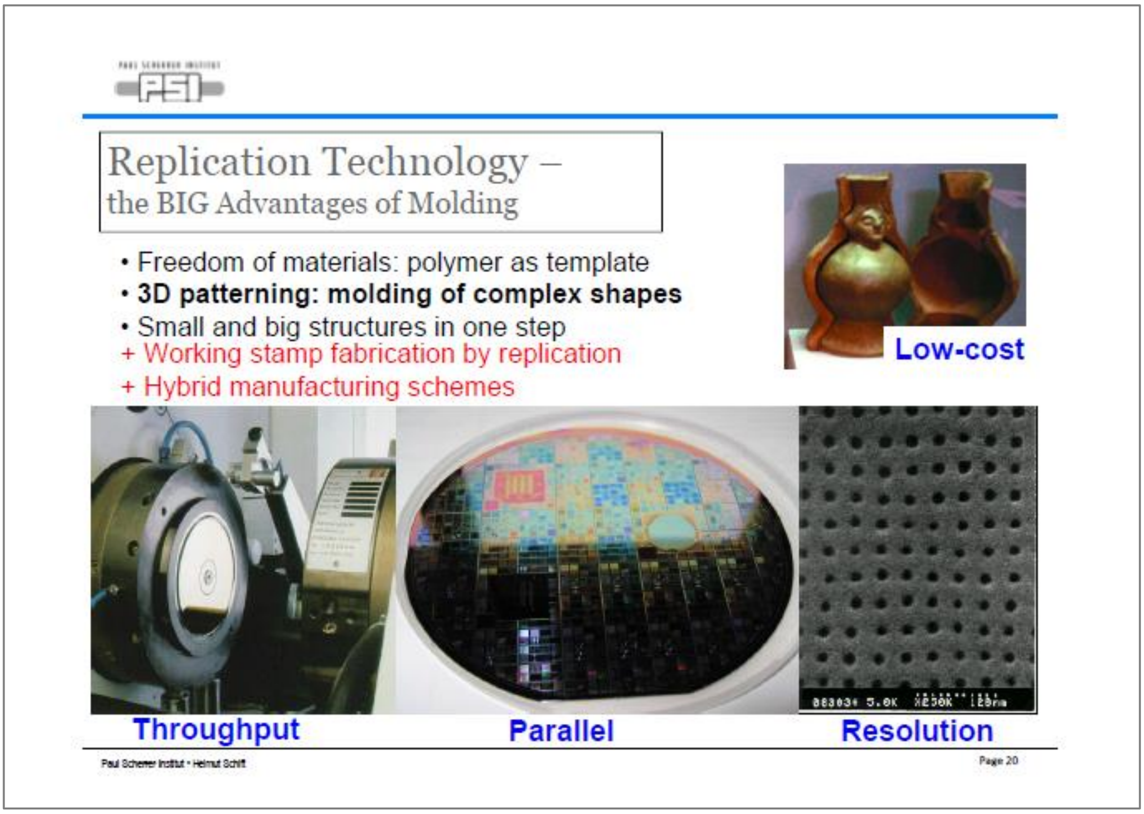


Figure 10. Replication Technology - the Big Advantages of Molding

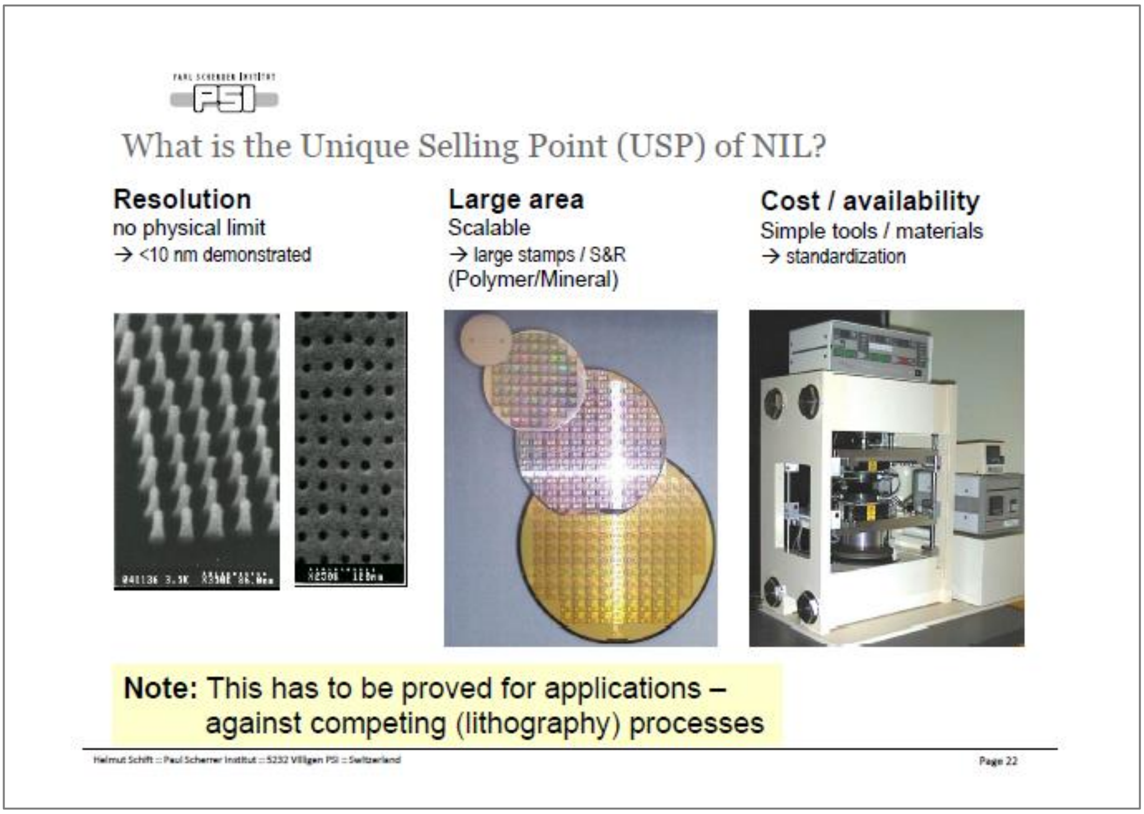


Figure 11. What is the Unique Selling Point of NIL

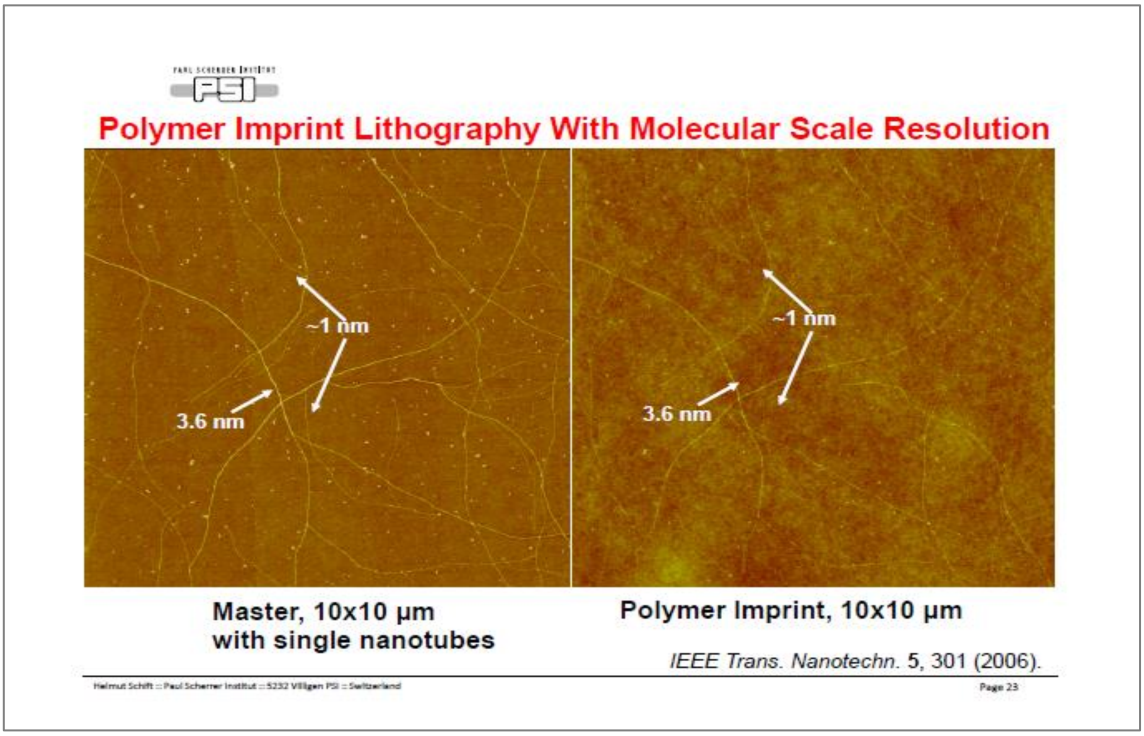


Figure 12. Polymer Imprint Lithography with Molecular Scale Resolution

And just to give you an idea about the resolution, John Roger's group at the University of Illinois who were using carbon nanotubes – that means very small tubes here on the surface which are molecular – they were replicating that and then finding them again. That means the resolution limit of this technology is in a range about one nanometer. That means it's really small (Figure 12).

And then again, this kind of tool, which you can buy for maybe 10,000 dollars or something like that. And this already does the job. You can imprint ten nanometer structures by a simple kind of process. In principle, you don't need expensive machinery. However, more expensive machineries sometimes make life much easier (Figure 13).

For instance, you can buy machineries like that. This is now an example from Austria, the EVG tool, and then you can imprint large areas in a clean room (Figure 14) and for instance 300 millimeter wafers like those here which were patterned in CEA-LETI in Grenoble, France. And they can be patterned. This is the stamp. And this is the silicon wafer with nanostructures on top of it (Figure 15).

And if you go one step further, here now KIMM comes into place. Also in KIMM, there is a big tool development for very advanced processes. We call it roll-to-roll or roll-to-plate processes because these are rolls here. KIMM has developed special solutions where you can replicate structures like those here, for instances, in a polymer film or even these small pits here with 100 nanometers or 140 nanometers into a polymer. Therefore, there's a lot of development going on, and KIMM is very good in making these kinds of mechanical tools (Figure 16).

Now what are the applications? Microelectronic chips are always the biggest application which people have in mind because here there's big money. But big money is also in the much simpler applications, like for instance, wire grid polarizers in hard disks, patterned magnetic media, and high brightness LEDs. This is the field where you might have a product at home which has already profited from nanoimprint lithography (Figure 17).

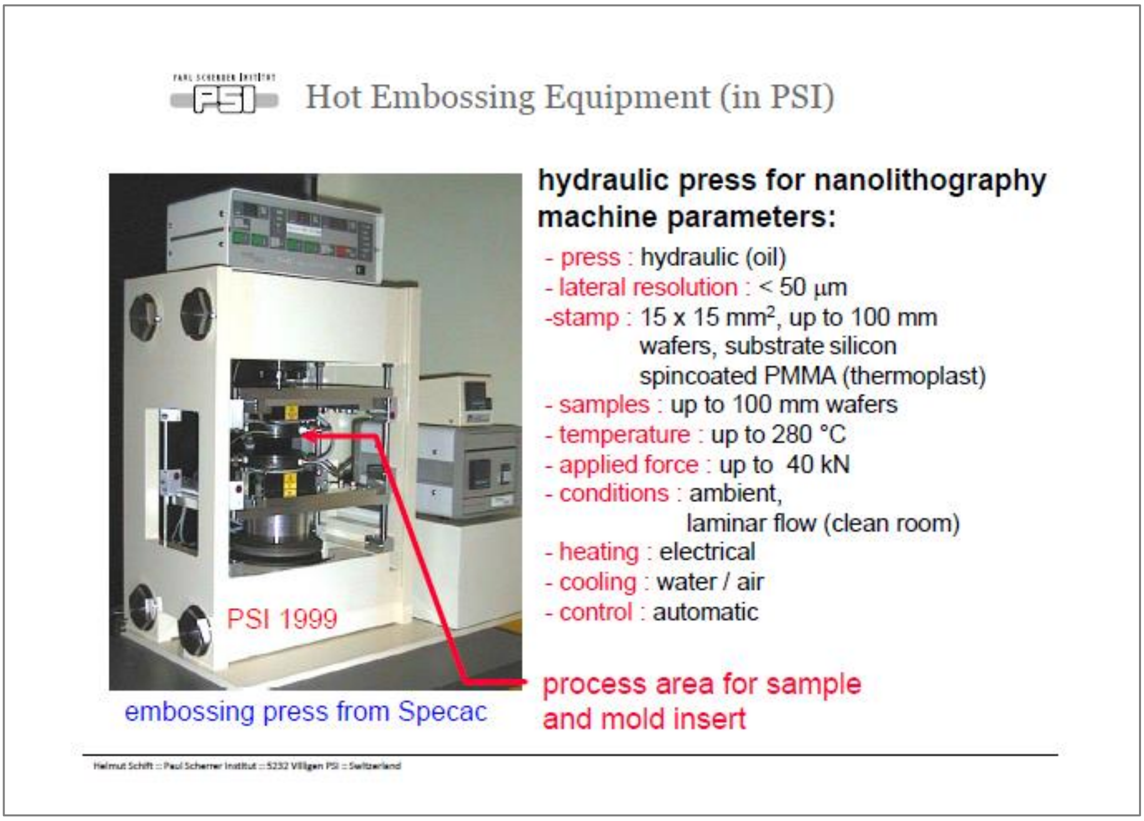


Figure 13. Hot Embossing Equipment (in PSI)

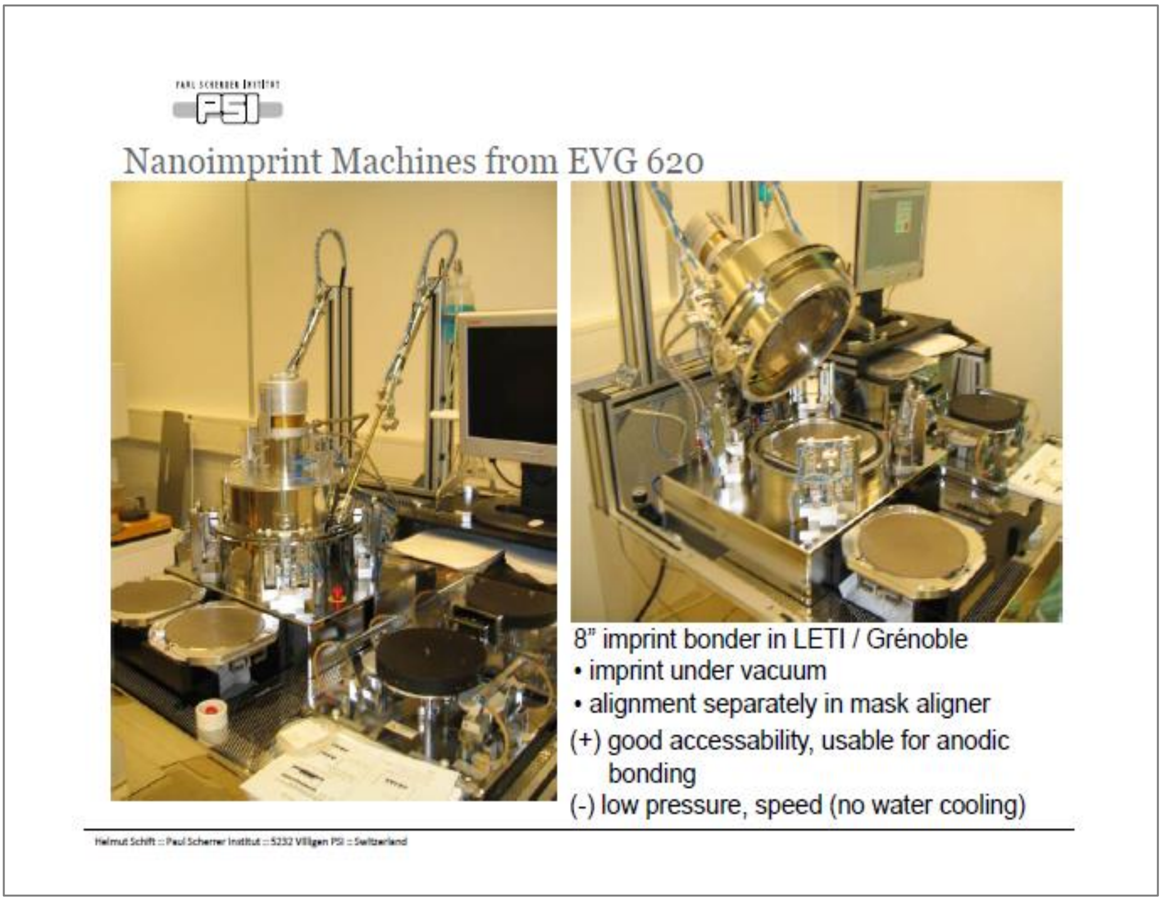


Figure 14. Nanoimprint Machines from EVG 620

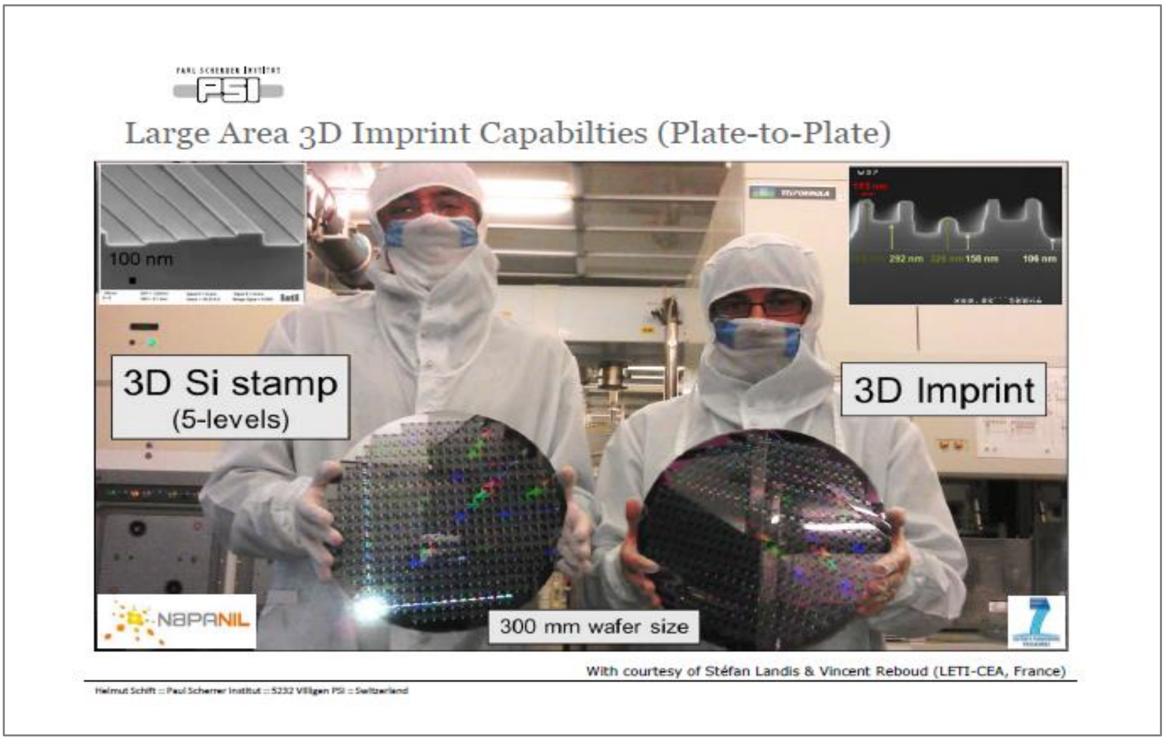


Figure 15. Large Area 3D Imprint Capabilities (Plate-to-Plate)

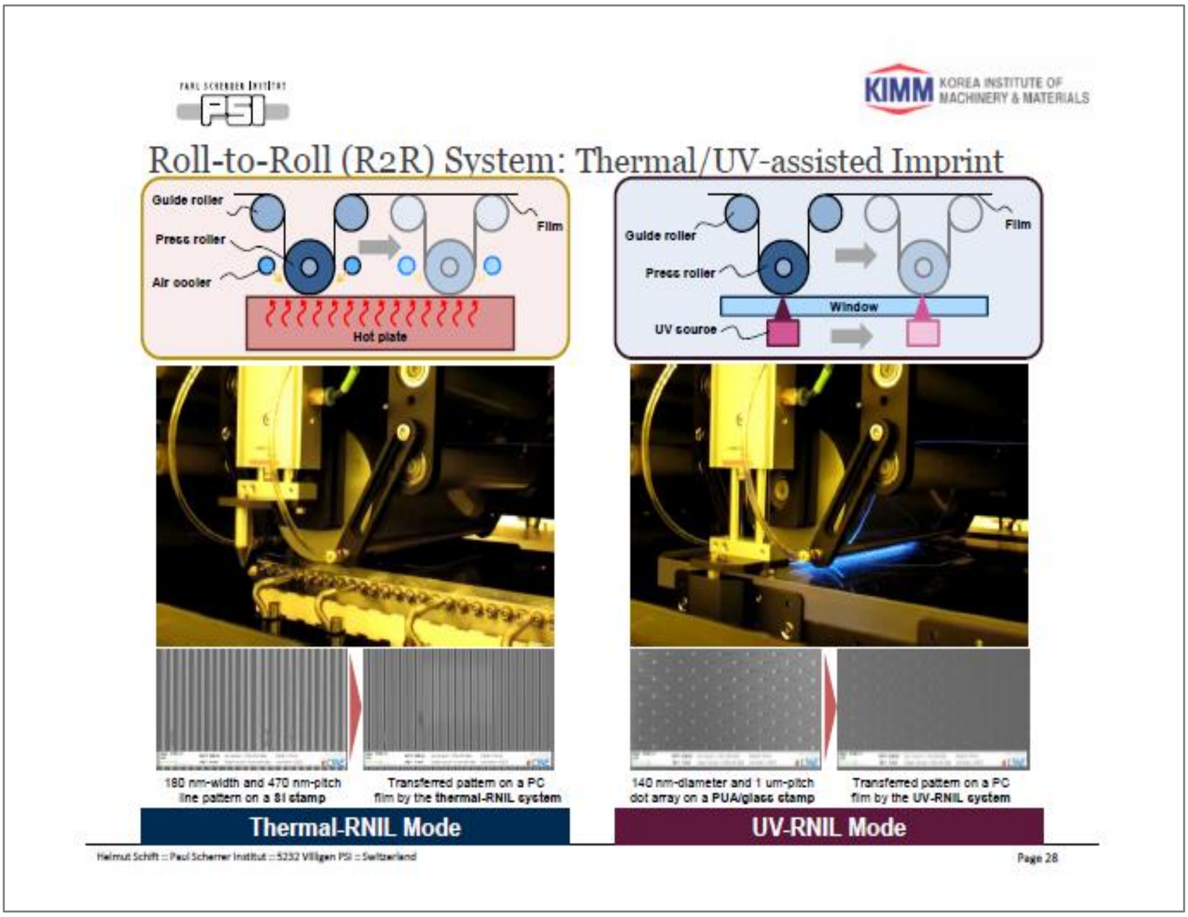


Figure 16. Roll-to-Roll (R2R) System: Thermal/UV-Assisted Imprint

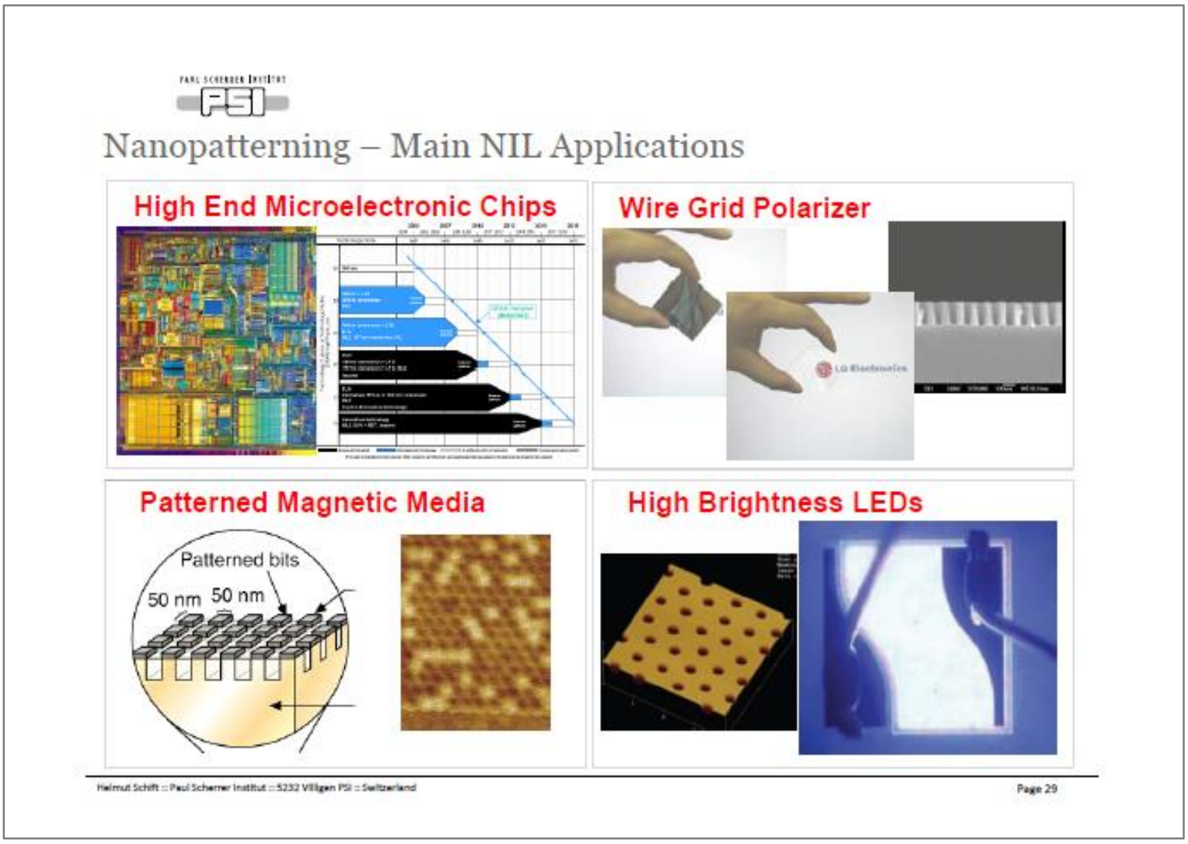


Figure 17. Nanopatterning - Main NIL Applications

Again, this kind of patterning here, it's a kind of process chain. You have the stamp you imprint, and you want to make something out of this polymer device. You have a kind of polymer here, and you have to make a pattern transfer into metal. That means you take this kind of structure, and you make a so-called "lift-off" for instance; and then you can generate small dots on the metal out of these kinds of structures here (Figure 18).

And there are different kinds of processes. I don't go into detail here, but you can do that with heat, for instance, just to make the polymer soft by heat. It's a viscous material then. Or you can take a viscous material and press a stamp into it which is transparent, and then you shine light through it; and you can harden the material just by chemical process. And then you detach the stamp, and then you have same result as here. The process is a little bit more complicated, but it can be done at room temperature, which is sometimes an advantage. And if you want to pattern large areas, you just do it several times, or you can take a roll. You bend your stamp around the roll, and you do this rolling here. And you can also take these kinds of processes (Figure 19).

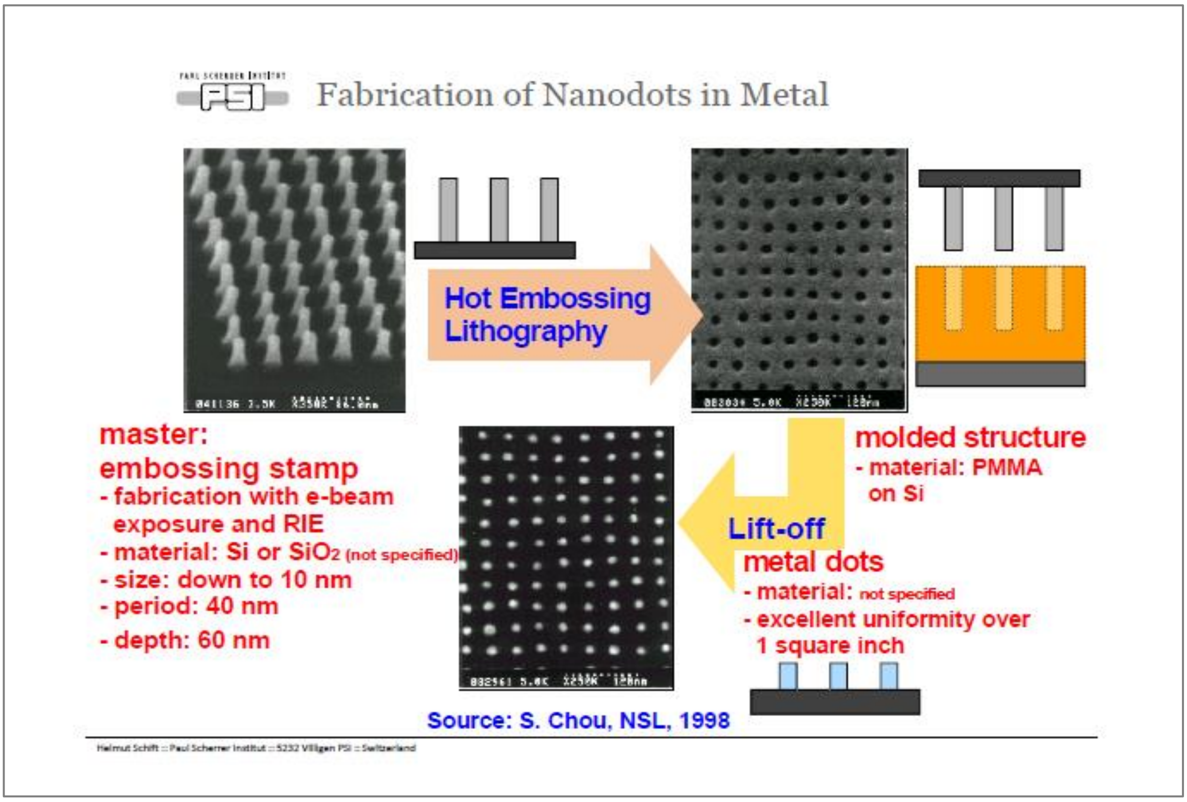


Figure 18. Fabrication of Nanodots in Metal

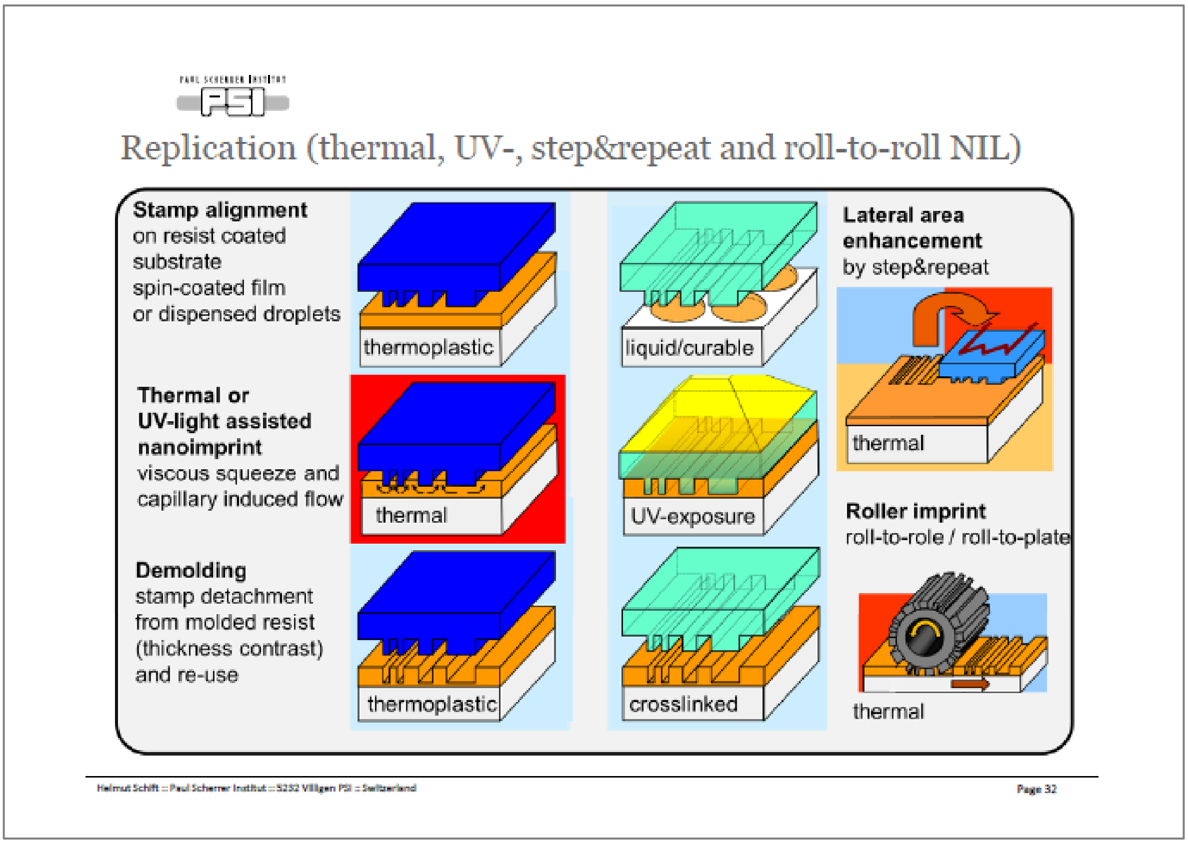


Figure 19. Replication (Thermal, UV-, Step & Repeat and Roll-to-Roll NIL)

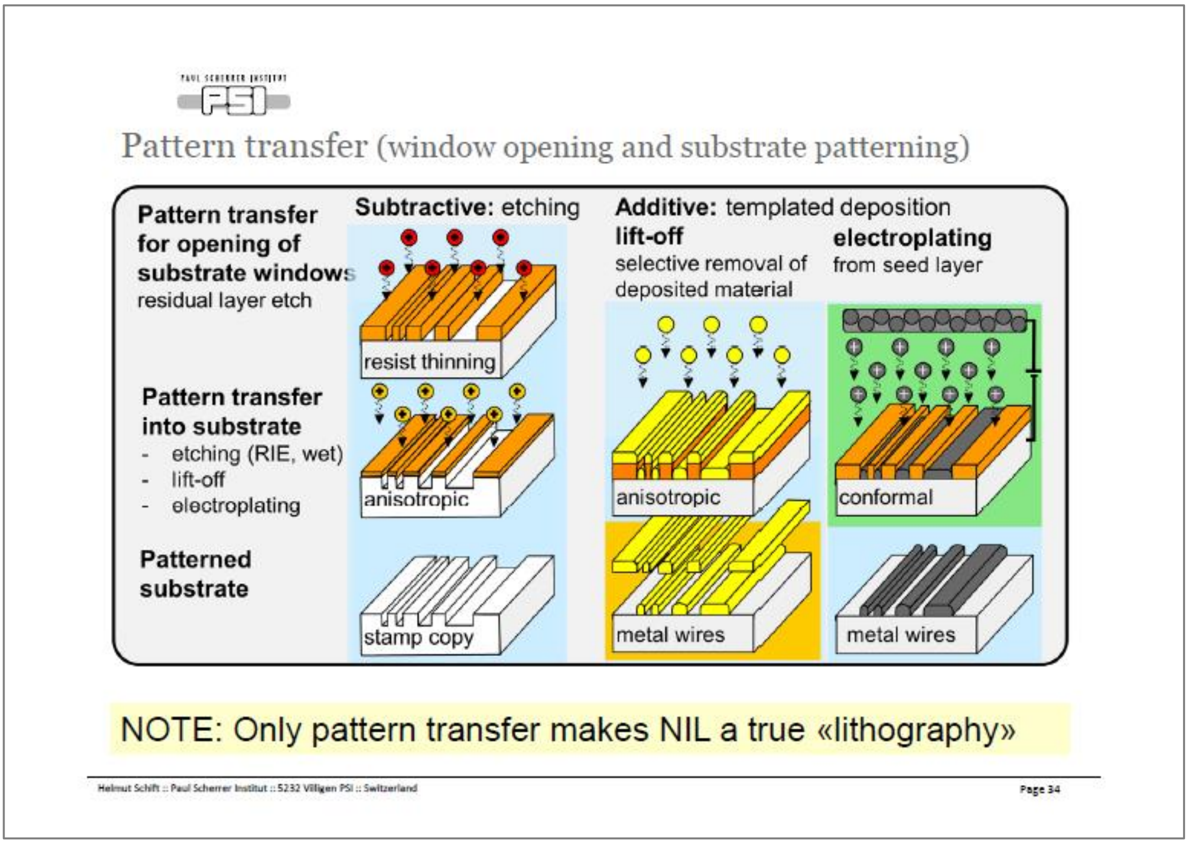


Figure 20. Pattern Transfer (Window Opening and Substrate Patterning)

And now look at this small film here. This is called a residual layer, and this is a little bit of a tricky part for nanoimprint. If you get rid of this layer, then you can use this kind of film as it would be in optical lithography. And how do we do that? We do that by resist thinning. You take plasma techniques, for instance, which are very directed to thin down the film. Then, you open these windows here, and then you can even etch down in the substrates. These are the processes which are needed for making chips. And there are different processes instead of subtractive processes. You can then take additive processes, and then you can make metal structures out of these kinds of resist films. It's just a kind of giving you a flavor about how these things are done. Only pattern transfer makes this nanoimprint (we call it NIL) a true lithography (Figure 20).

Now for mechanical engineers, this is not the only process. Injection molding is very much known to mechanical engineers because it is a manufacturing process used in different kinds of fields of applications. Also Switzerland is earning money with injection molding of polymer parts, for instance for biotechnology and for optics. Roll-to-roll processes are very important, for instance, for holograms and security features, which you have for your credit card. And micro thermoforming is, for instance, used if you want to have medicaments embedded in blister packages. Therefore, these are real mechanical processes, but I have just shown you that this is also a field where mechanical processing is at play (Figure 21).

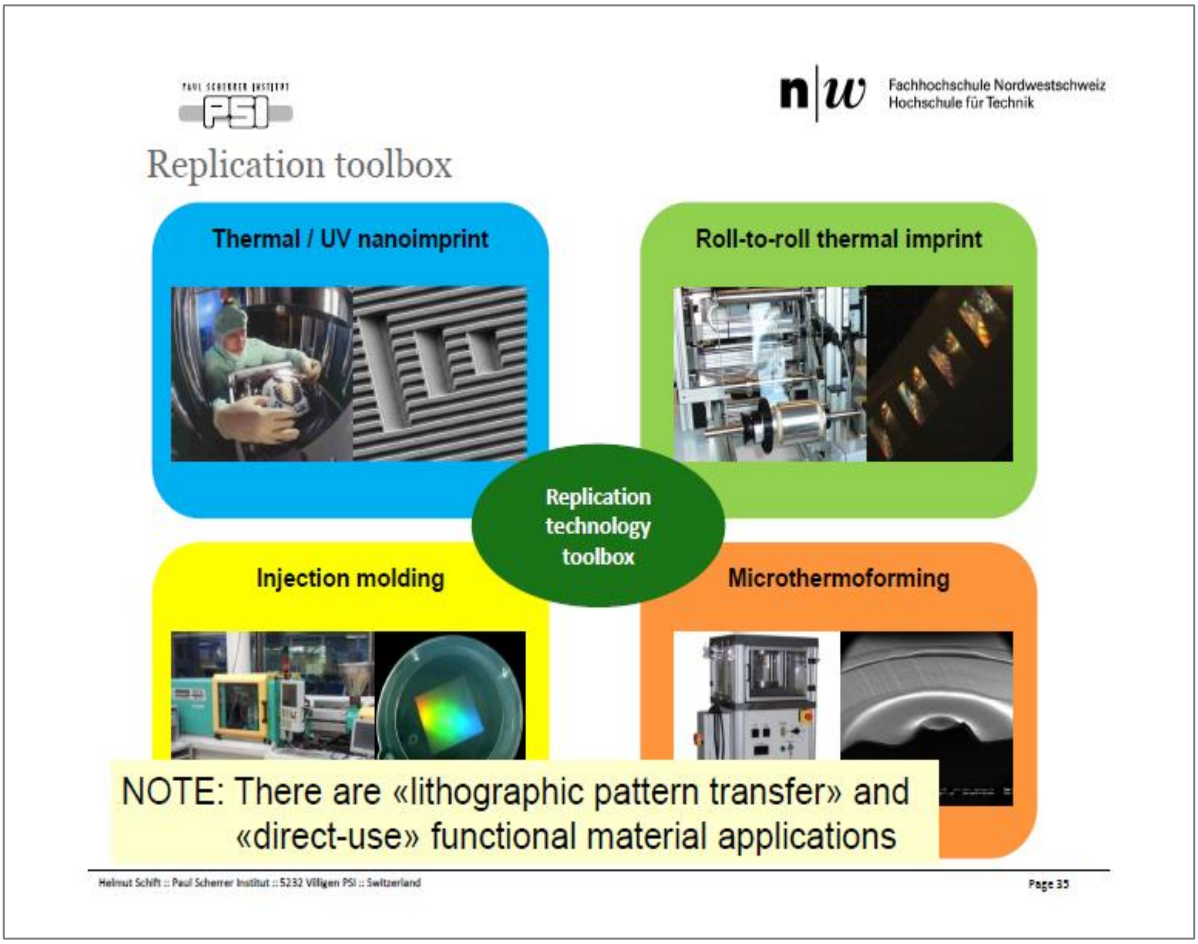


Figure 21. Replication Technology Toolbox

Is NIL More Moore or More than Moore?

Now here, you see "More Moore or More than Moore?" What do I mean with that? Well, Gordon Moore was the boss at Intel 50 years ago. And his economic law is "If you are not selling chips every year, we will be out of business." And why do you sell chips? If chips become better and better, then people will buy new chips. Therefore, the chips have to become better, and the number of transistors has to double every 18 months. If you are not doubling the number of transistors every 18 months, we are out of business. And therefore, Moore was putting pressure on engineers. They are forced to make technological advancements. This is sometimes not so easy for engineers if somebody from the economics department comes and tells you that you have to make your devices and processes better, otherwise we will be out of business (Figure 22).

And then people from the marketing department would come up with this roadmap and say like "OK, this is the resolution, and the number of transistors is growing in this direction. And the roadmap projects the time when a technology has to be ready." And if you look here at 2016, we have this kind of technology. White means it's in production, and blue means we are still in the testing phase here. And you see that there are different kinds of technologies which are competing with each other. And nanoimprint was introduced in 2006 into this kind of technology roadmap, and the other technologies are non-contact technologies. That means these are the big competitors, but here you have mechanical process which gets into high volume manufacturing. And currently nanoimprint is tested out for the manufacturing of chips (Figure 23).

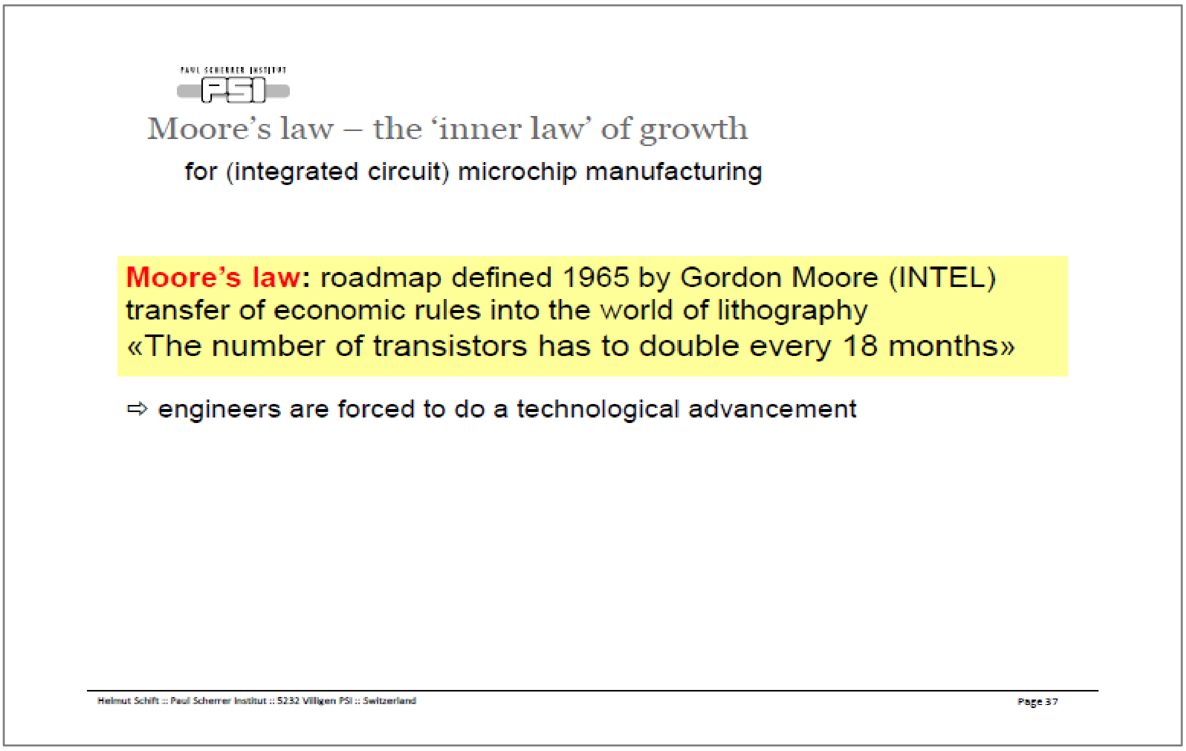


Figure 22. Moore's Law - the "Inner Law" of Growth (1)

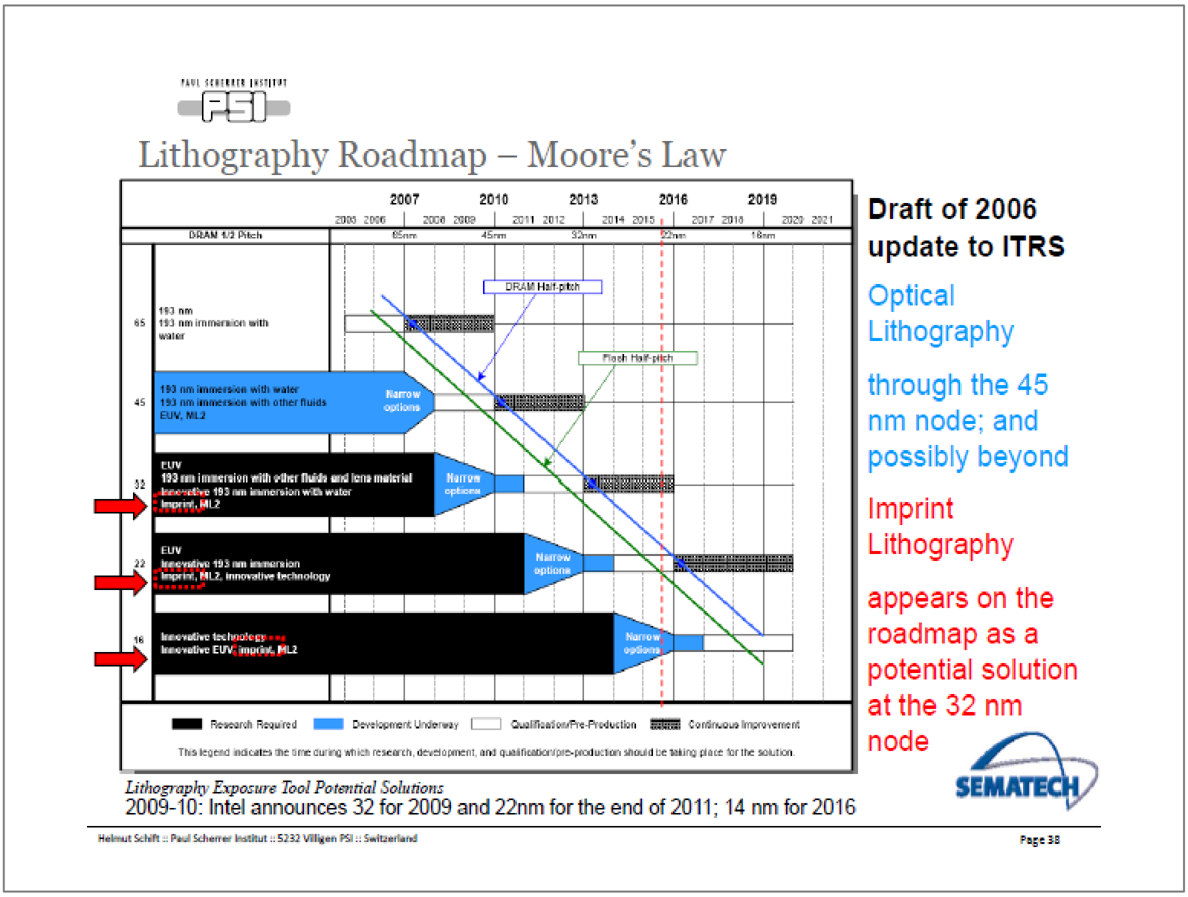


Figure 23. Lithography Roadmap - Moore's Law

And you see that here, for instance, this is a roadmap, and these are, for instance, structures which you can take here. They look a little bit different than that which I have shown you. Nanoimprint is, therefore, called one of the ten emerging technologies that will change the world. Whether it is true, I cannot say to you, but we all hope that this will come true within the next few years (Figure 24).

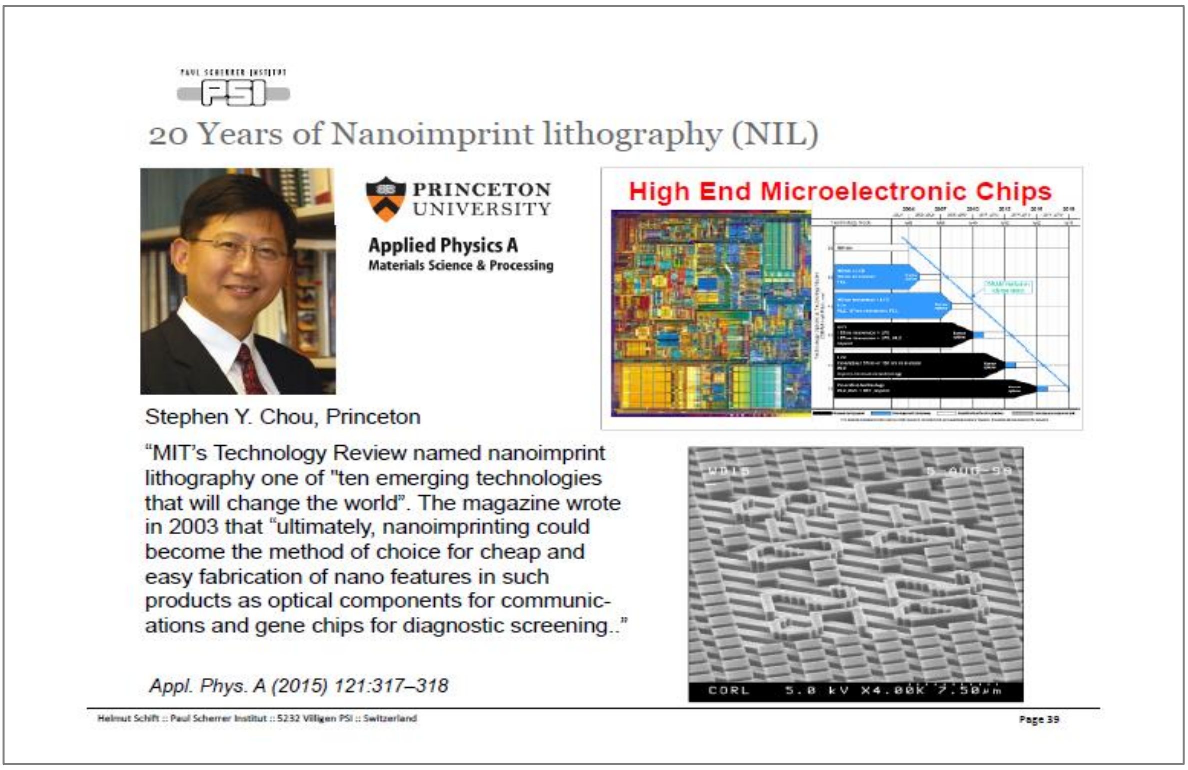


Figure 24. Twenty Years of Nanoimprint lithography (NIL) – High End Microelectronic Chips

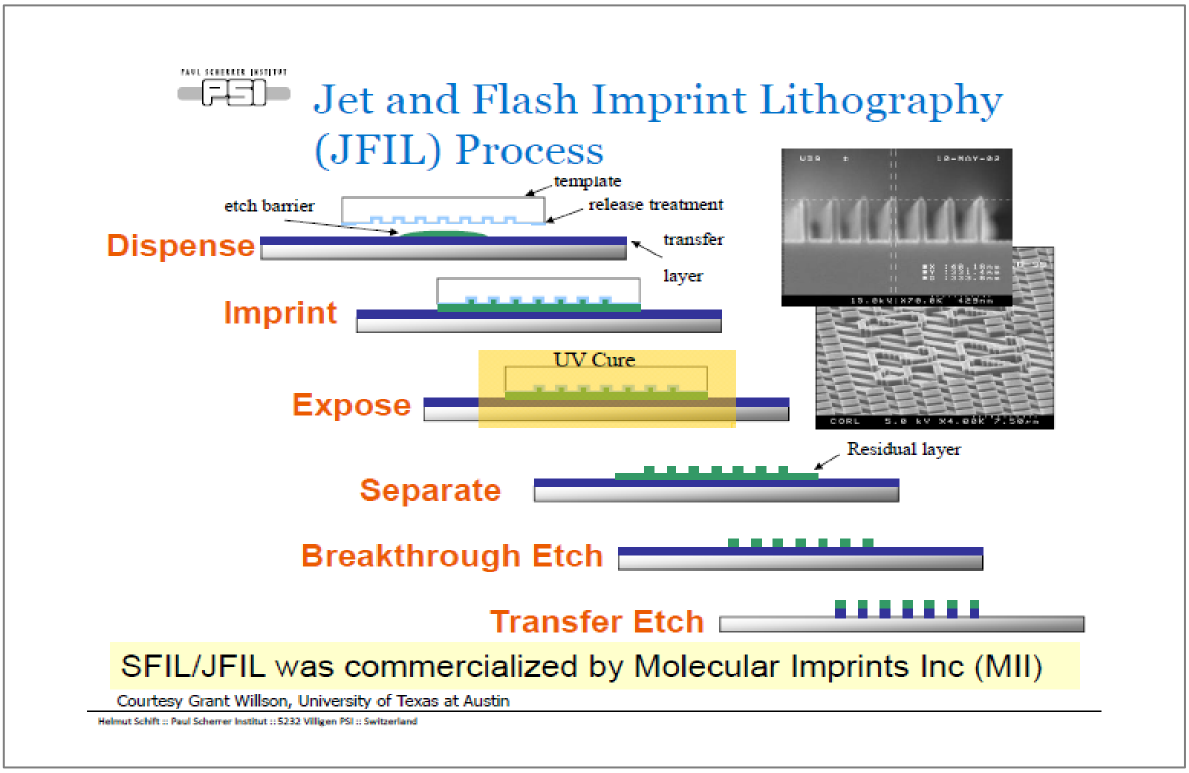


Figure 25. Jet and Flash Imprint Lithography (JFIL) Process

And the processes are looking a little bit different. I do not go into detail here. It’s called SFIL, Step and Flash Imprint Lithography. Or they even changed the name to JFIL, Jet and Flash Imprint Lithography. And the most important is that there was a company in Texas which was commercializing this kind of specific process, and that was called Molecular Imprints, Inc. (MII) (Figure 25).

And just last year Canon acquired Molecular Imprints, and they want to manufacture together with other industries NAND flash memories, and also other companies are joining in. As always, this is one possible road to go down to make 60 nanometer chips here, but this is, for instance, a 200-millimeter wafer which could be patterned by this. Now people need large machines to do that. For instance, if you have a cluster of four machines, you can make this kind of 60 wafers per hour, which are needed to really be competitive with other techniques (Figure 26).

Now we come to “More than Moore.” We are doing more than Moore if we add some kind of cleverness to the process which is just not simply a replacement of other technologies, but the new technology. Replacement sometimes means you just do the same thing with a different process, but what we want to do is we want to use the advantages of nanoimprint in order to make the process even more effective. And that can be done, for instance, if you are not just replacing single lithography steps but by reducing the number of steps which are necessary to make a product (Figure 27).

For instance, Hewlett-Packard, it was already long ago, but they came up with a solution with a self-aligned imprint lithography. Instead of having one structure made at one time and a second structure made at the second time, they just take a stamp which has two structures in the same stamp. And here if you make one imprint after the other and do not do it right, you might have a misalignment here. If you have here a kind of imprint, it will always be like that. And if you have a misalignment, the transistor will just be shifted a little bit from one side to the other (Figure 28).

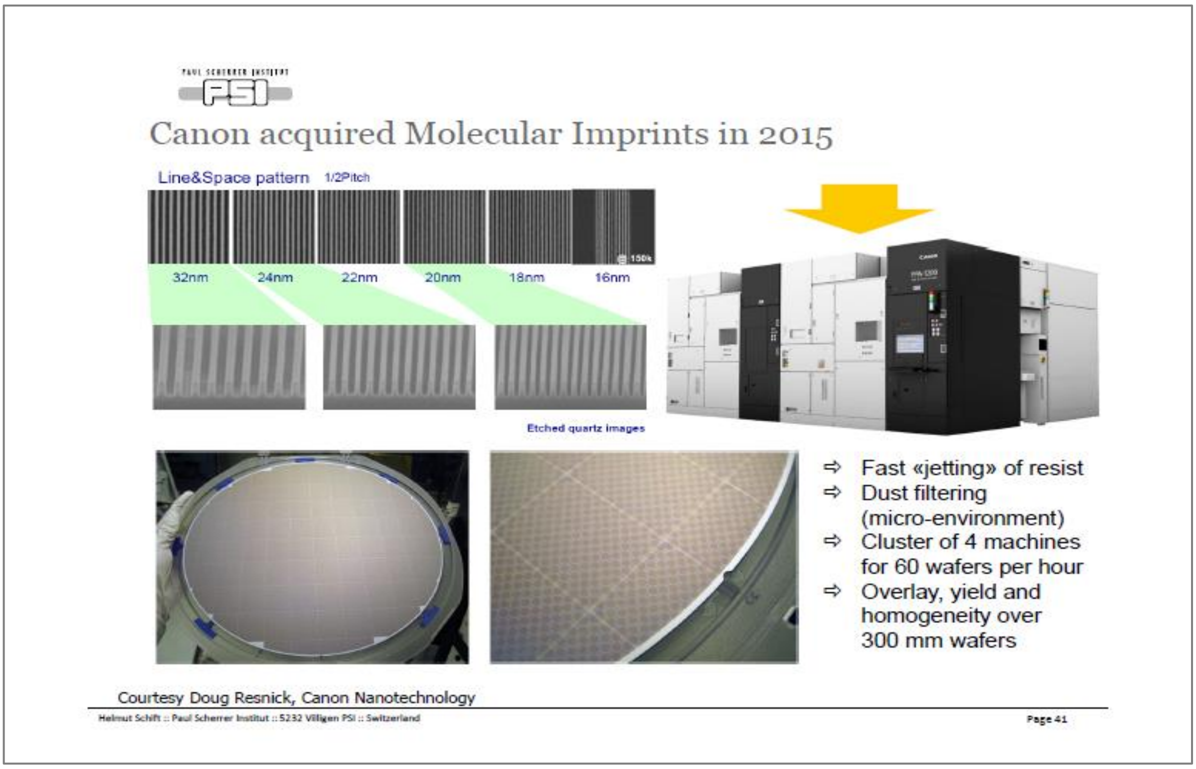


Figure 26. Canon Acquired Molecular Imprints in 2015

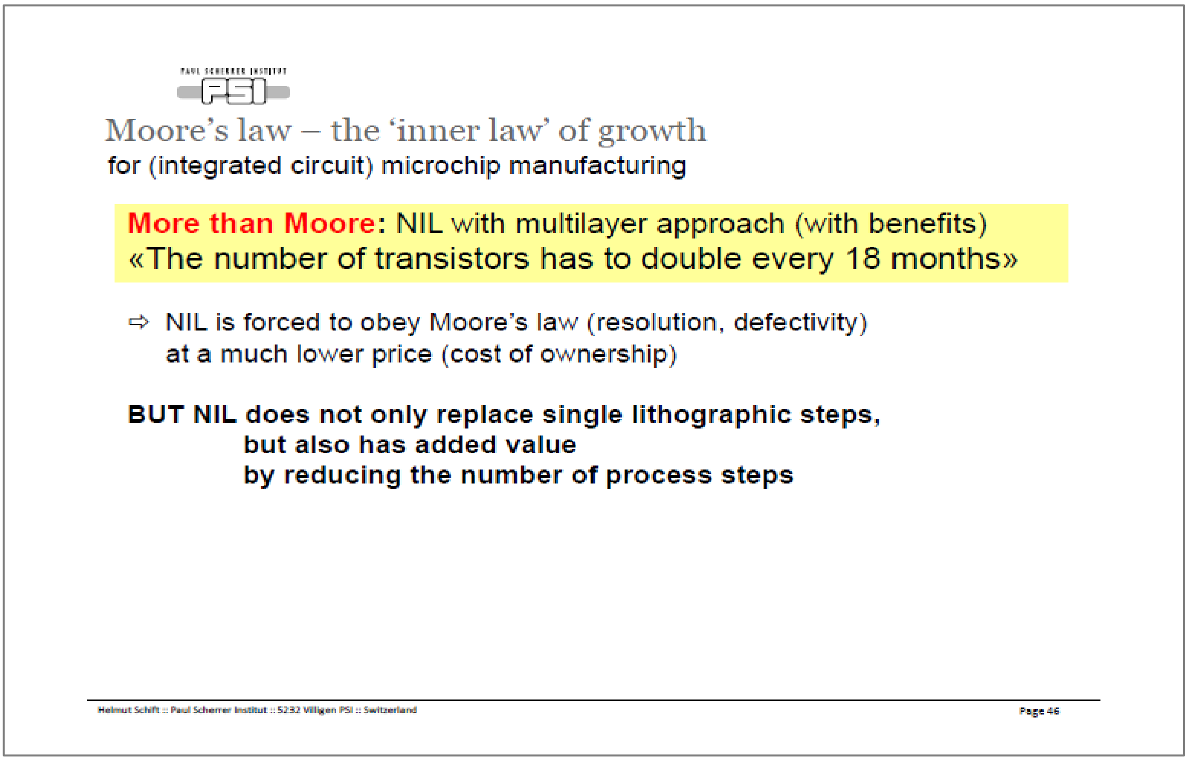


Figure 27. Moore's Law - the Inner Law" of Growth (2)

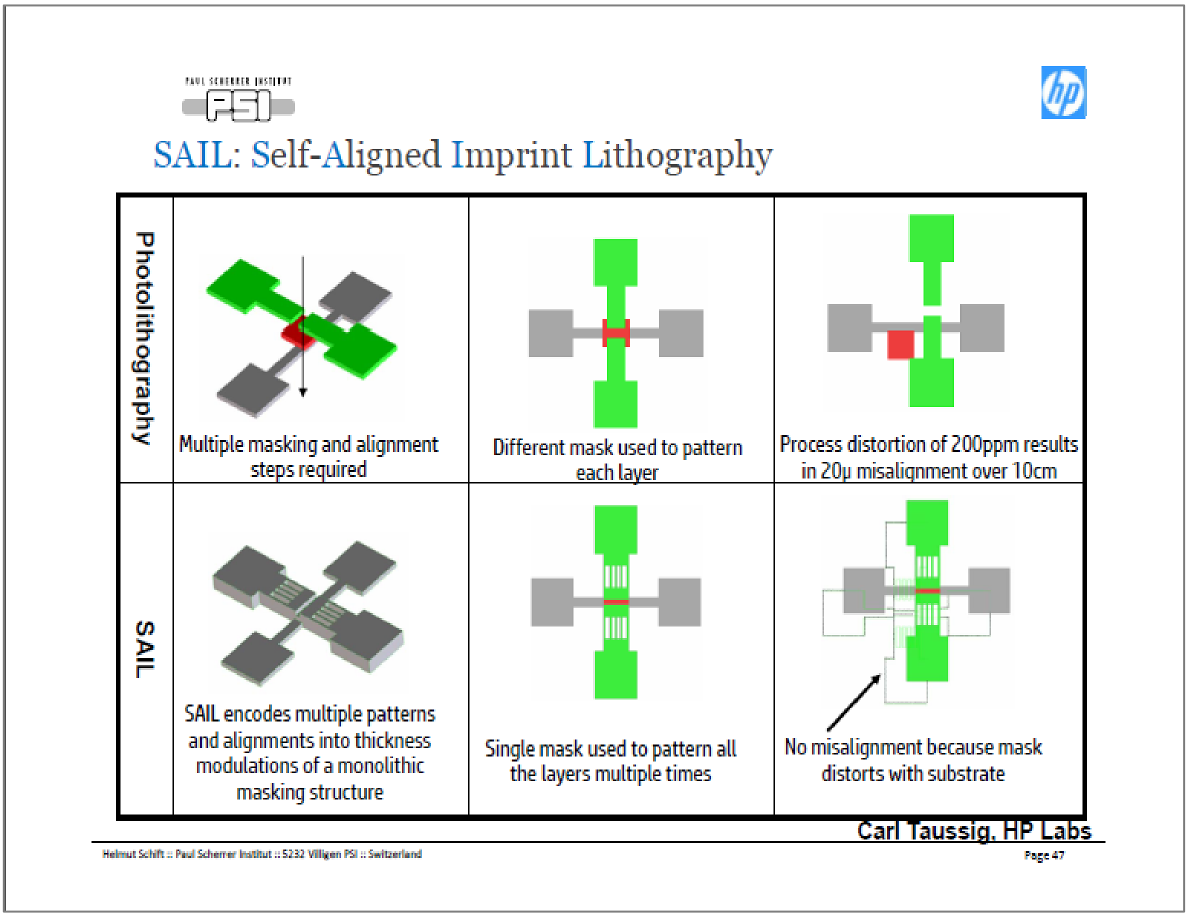


Figure 28. SAIL: Self-Aligned Imprint Lithography (1)

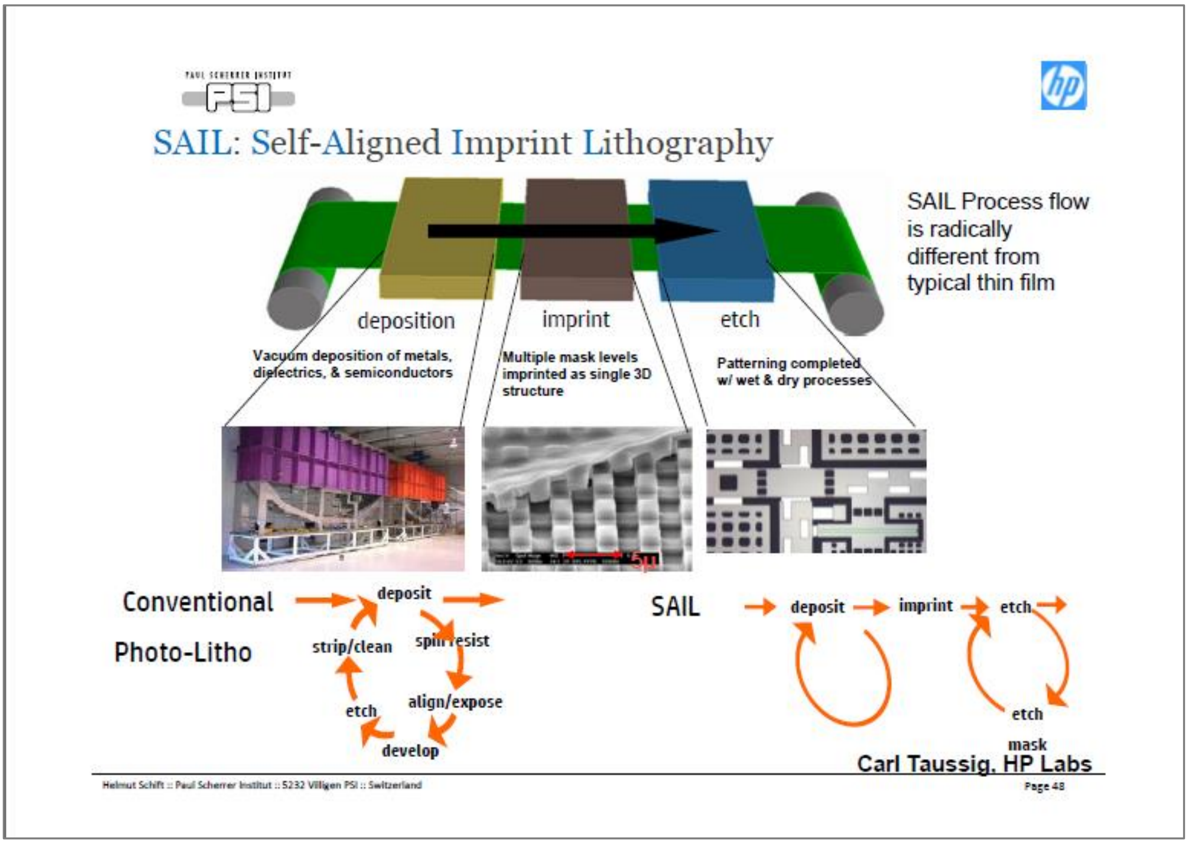


Figure 29. SAIL: Self-Aligned Imprint Lithography (2)

And then you can take roll processes which are typically not very precise, and then you can, for instance, imprint structures on the surface. And you have a clever etching process, and then you can do the patterning of the surface which typically would not be so easy to pattern with the right precision. I cannot go into detail here, but I just can tell you that the main message here is that you really have to think in a clever way in order to advance technology; it's not simply copying of things that are already there in the industry (Figure 29).

Non-IC Applications, More than Moore – Front Runners

- **Wire Grid Polarizer**

And now I come to the applications, the non-IC applications, which are more than Moore. And I come to this wire grid polarizer. I know that the vice president of LG is here. And I have to tell you already a few years ago, about ten years ago; LG was advancing the technology by going in this direction of wire grid polarizers. You have screens. And these kinds of screens always have a kind of wire grid polarizers. They are large area, but you do not see the polarizer at all. But it makes lights possible and makes this kind of bright colors possible (Figure 30).

And for instance, you also start with a glass substrate. It has a layer of aluminum on the top. You coat a thin layer of resist on top of it and take a stamp and imprint into it. Then you do the etching process to end up with aluminum gratings (Figure 31).

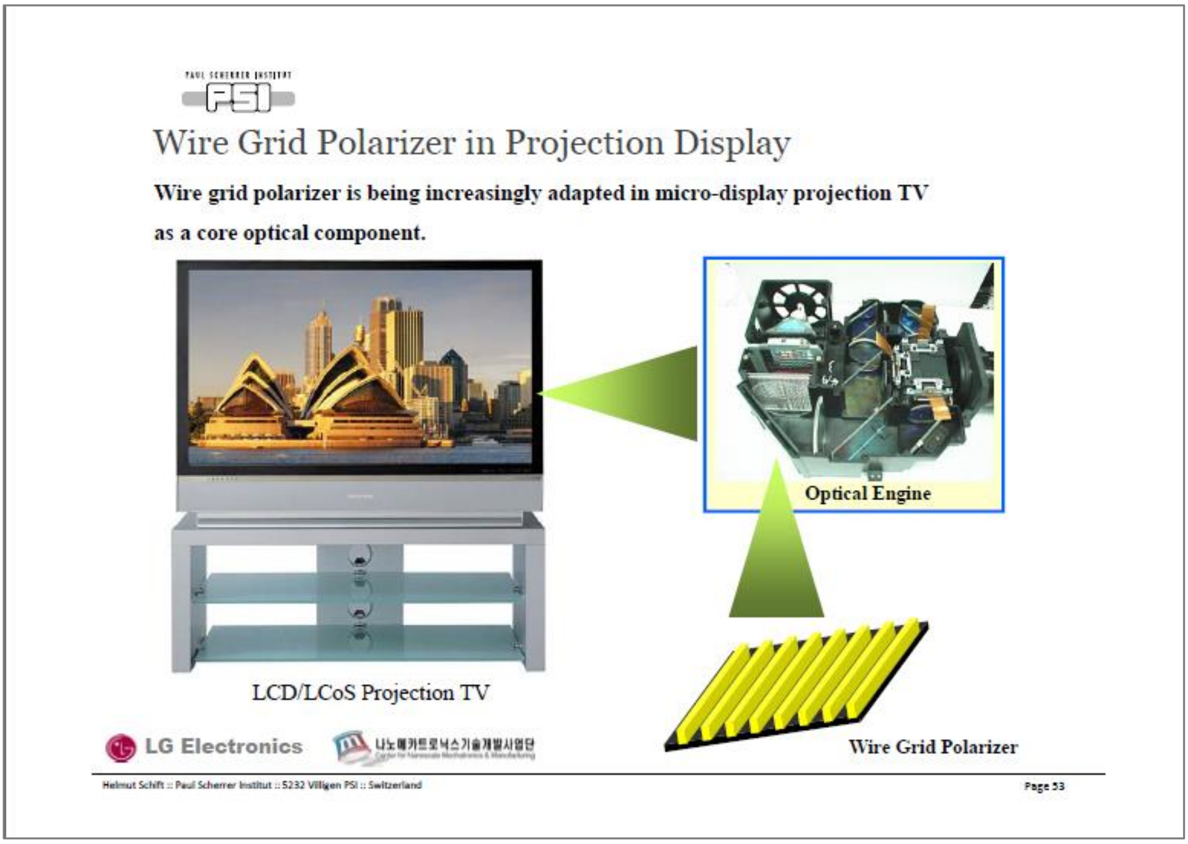


Figure 30. Wire Grid Polarizer in Projection Display

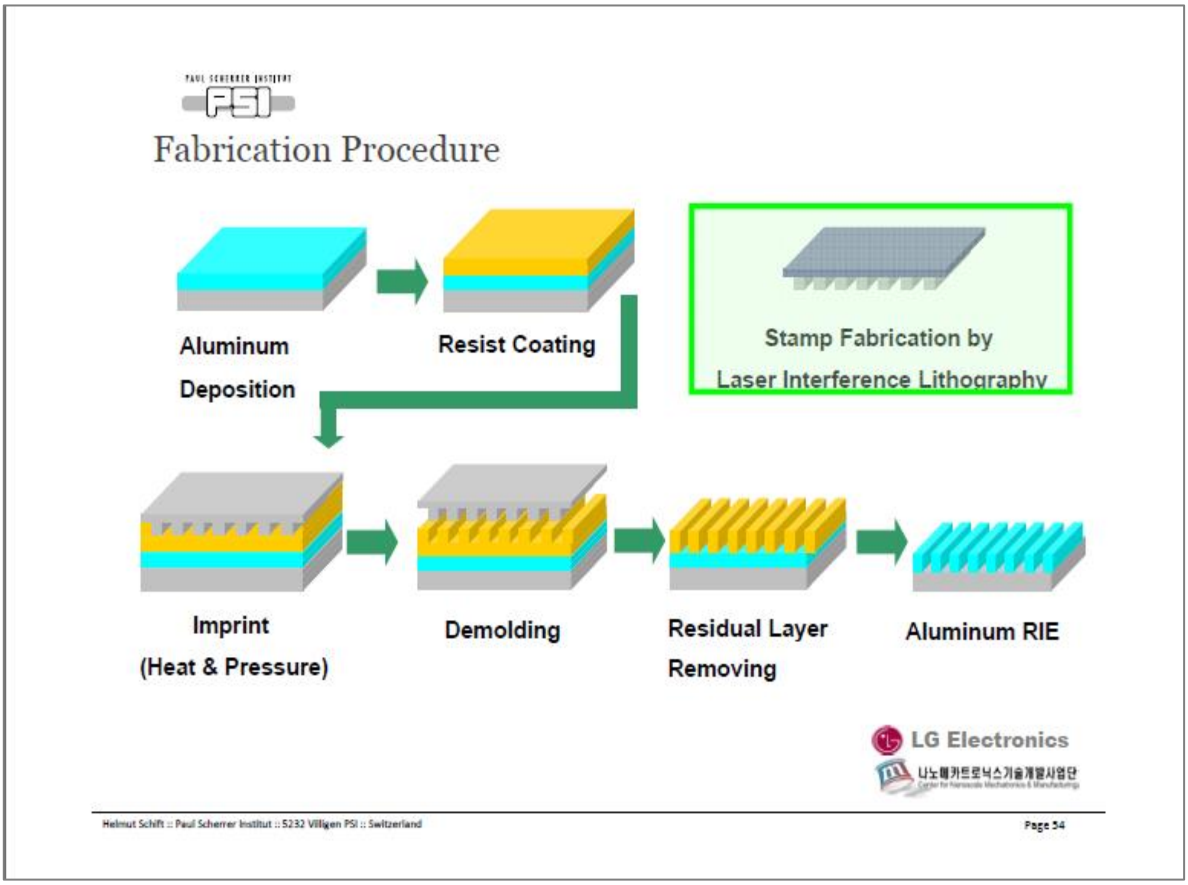


Figure 31. Fabrication Procedure

And this is just scanning electron microscopic pictures in which you see the process. Here you see the 50-nanometer resolution structures which are about 100 nanometers high. And now instead of having most of the area gray, which would be the case if we covered it with aluminum; you see in this picture, the whole grating here has about 50% of coverage (Figure 32).

The whole surface here looks transparent. But if you turn the whole grating by 90 degrees, you can make it opaque; that means it's not transparent anymore. And this is what polarizers are used for. You have transmission of 85%, and the extinction ratio of 2000. At the moment, I do not really know whether LG is still working on that, but it is still a highly attractive field where many companies were gaining some kind of experience (Figure 33).

Products which are done in a similar way are, for instance, the EyeFly 3D Screen Protector from Nanoveu. That is a Singapore company. And they were making structures like this here which can be put on your iPhone, for instance, and they are able to see 3D movies on this kind of iPhone. And that is basically done by putting a kind of lens structure here on top of your iPhone. It's a kind of foil which you can glue on top of it, and then by clever software, you can make these kind of movies 3D compatible (Figure 34).

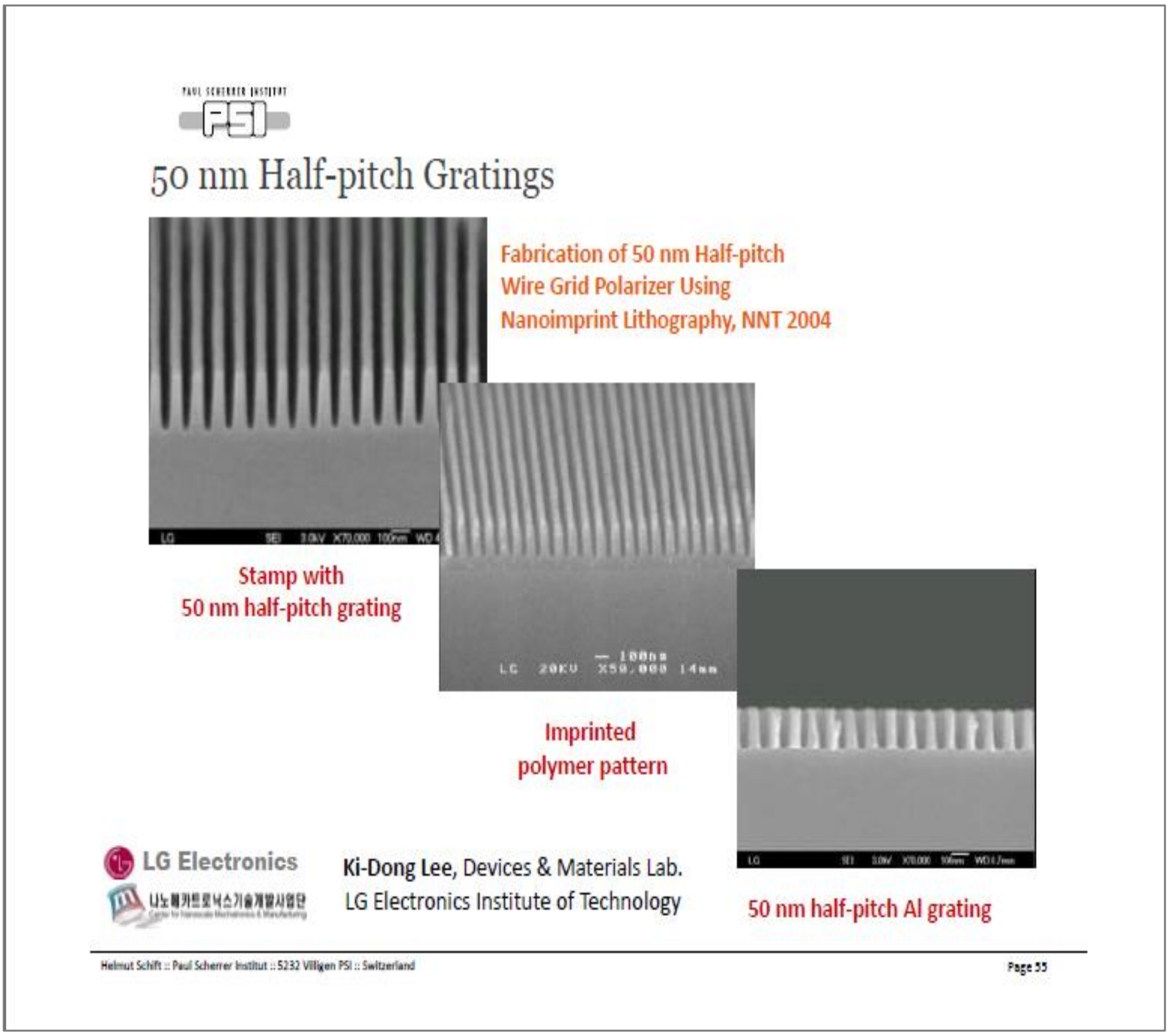


Figure 32. 50 nm Half-Pitch Gratings

Figure 33. Performance of Fabricated Polarizer

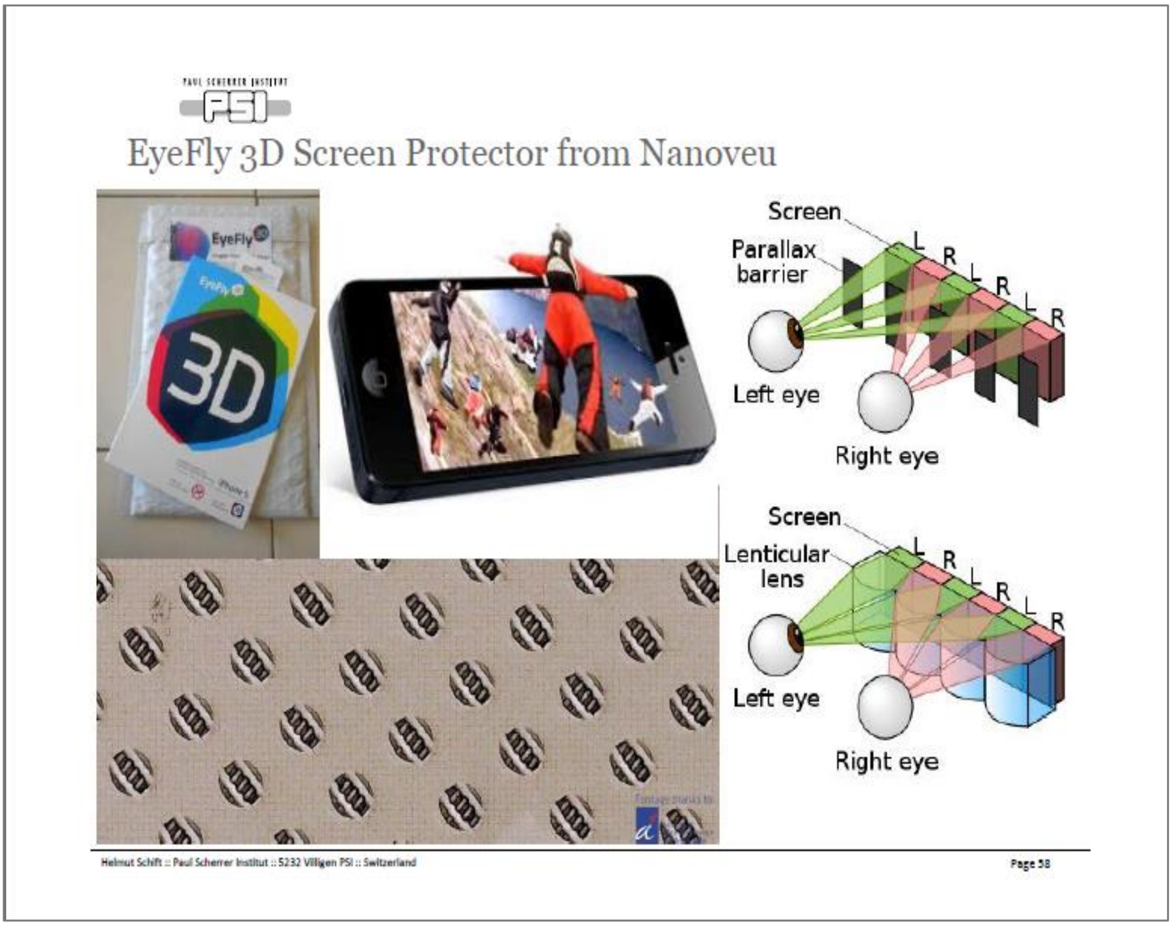


Figure 34. EyeFly 3D Screen Protector from Nanoveu

- **Patterned Magnetic Media**

Now, let's come to the patterned magnetic media. Until recently, this was a hot topic in nanoimprint. You have basically a hard disk, and if you open it, you would see these kinds of disks here. But on the disk, you have a lot of small dots, but normally these dots are simply in stripes in a layer of magnetic material. Like here, for instance, you go to smaller and smaller dots. This is not feasible anymore; you need to separate the individual dots with their magnetic domains. This here would be one. This would be zero. You can do that by mechanically separating these kinds of dots here by small pillars. That means the reduction of the magnetic interference is between the pillars and between tracks or islands can be done if you do a mechanical patterning of the surface before you put magnetic film on it (Figure 35).

And to give you a kind of idea about how this is done, you take a stamp here, and you imprint into a surface. First you make a copy of your stamp; then you imprint into your resist. Here again, on a kind of aluminum plate, you have a resist here. You print in this, and you etch again into the surface. And then, you coat a magnetic film on top of it. And now the interesting point is these kinds of dots are mechanically separated by the next dots. Therefore, if this dot decides to interfere with the other dot, there is a kind of boundary in between. And if this will be on the same height here, there would be an interference possibility, and the small dots will not be stable anymore. Therefore, here, the mechanical separation of the dots makes it possible to put more data on your magnetic disks (Figure 36).

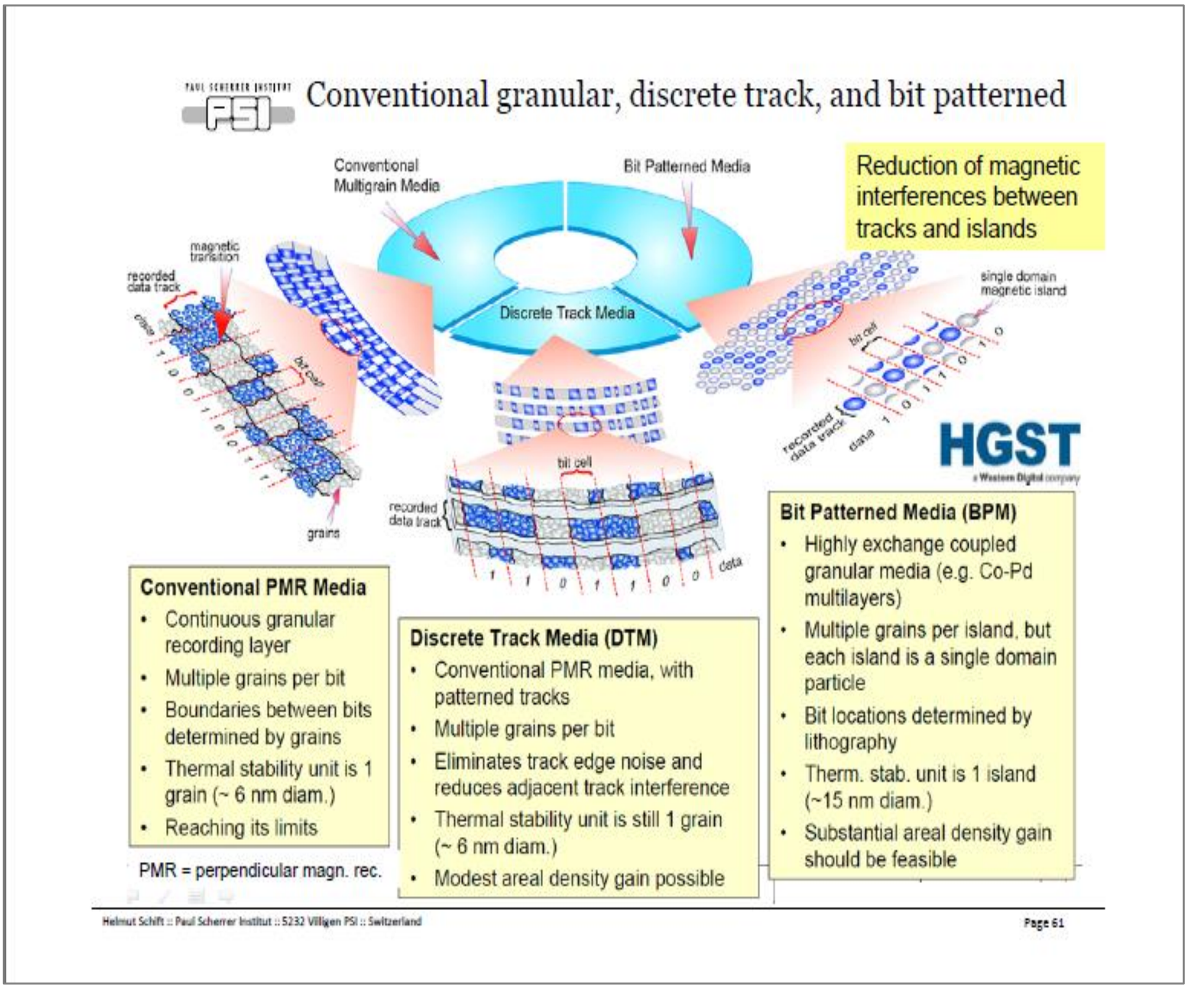


Figure 35. Conventional Granular, Discrete Track, and Bit Patterned

Now this can be introduced into existing process chains, and that was done by, for instance, Western Digital here. They were able to show, at least, that these kinds of processes are feasible for next generation patterned media (Figure 37).

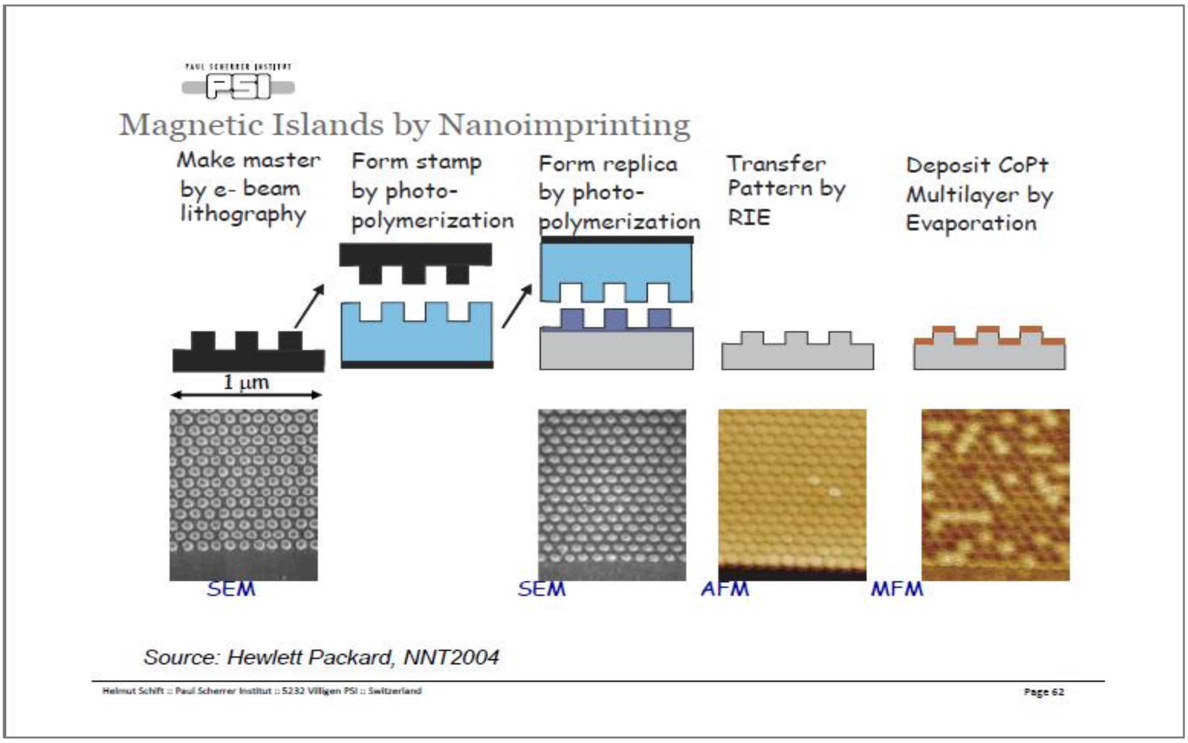


Figure 36. Magnetic Islands by Nanoimprinting

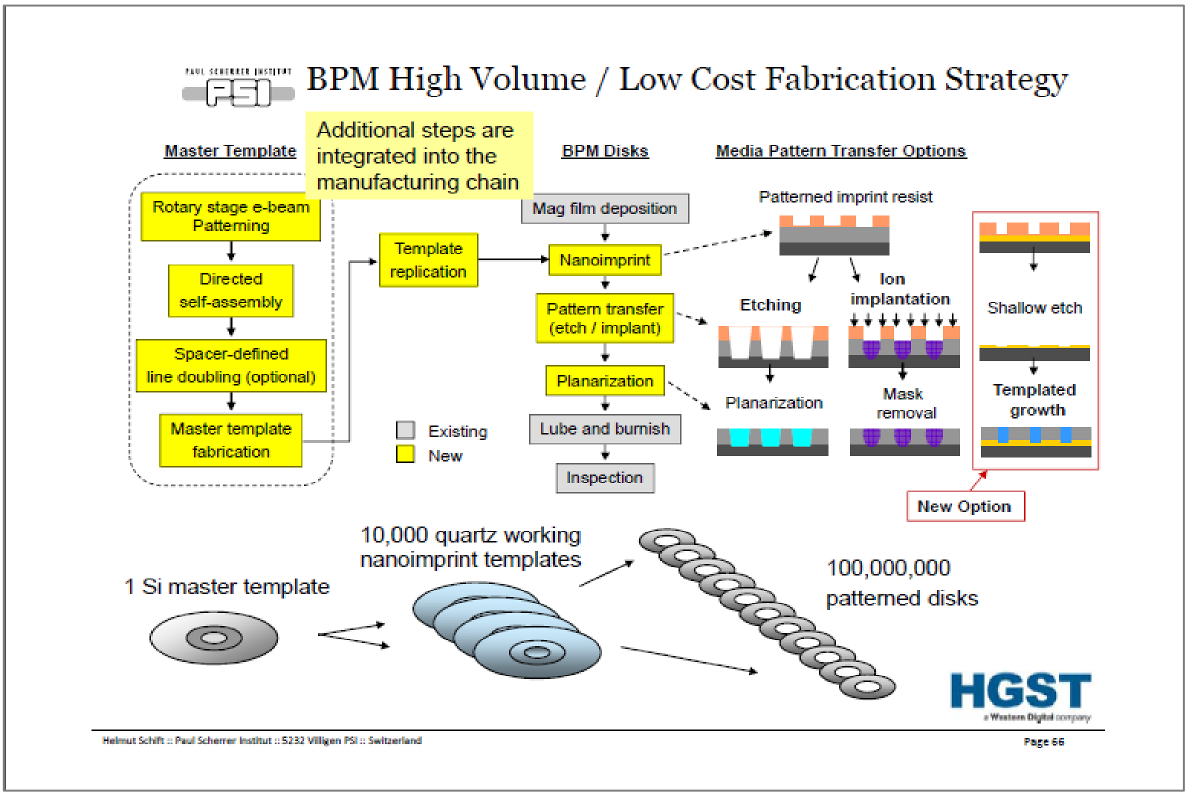


Figure 37. BPM High Volume / Low Cost Fabrication Strategy

Now the current state of the art is that Western Digital has put this kind of technology and has developed it at its own hold. They have made a large publication in 2015, and also in here a large publication in 2015. This is about here. That means people have developed the technology, but it's currently not introduced yet into the production because other technologies have gained more importance, and it's currently foreseen that this will be in production in about 2019 or 2020. Therefore, I can tell you that the technology has been developed, but sometimes the decisions on whether they are to be introduced or not, are a little bit tricky; that's done by management (Figure 38).

- **High Brightness LEDs**

I just want to tell you that LEDs profit a lot if you can pattern surfaces of these LEDs (Figure 39).

That means you simply put a nanostructure photon on top of the LEDs. These are small chips of 100 to 200 micrometers. And then if you have this nanostructure on top of your LEDs, you can enhance the brightness of LEDs. Brightness means you get more light out of your LED, and the light is not confined inside the chips when it's generated. That is currently something which is put into production in different countries (Figure 40).

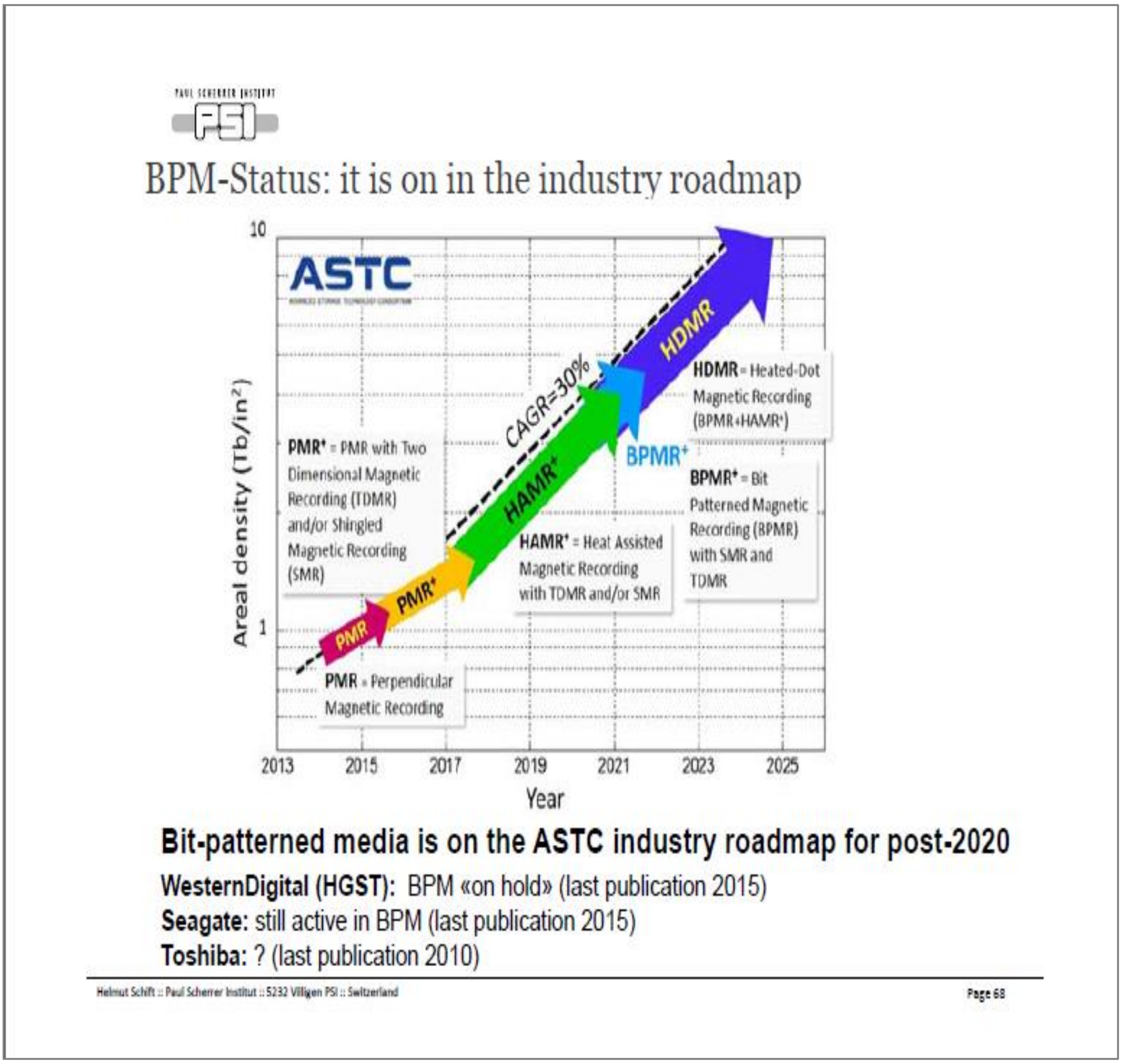


Figure 38. BPM-Status: It Is on in the Industry Roadmap

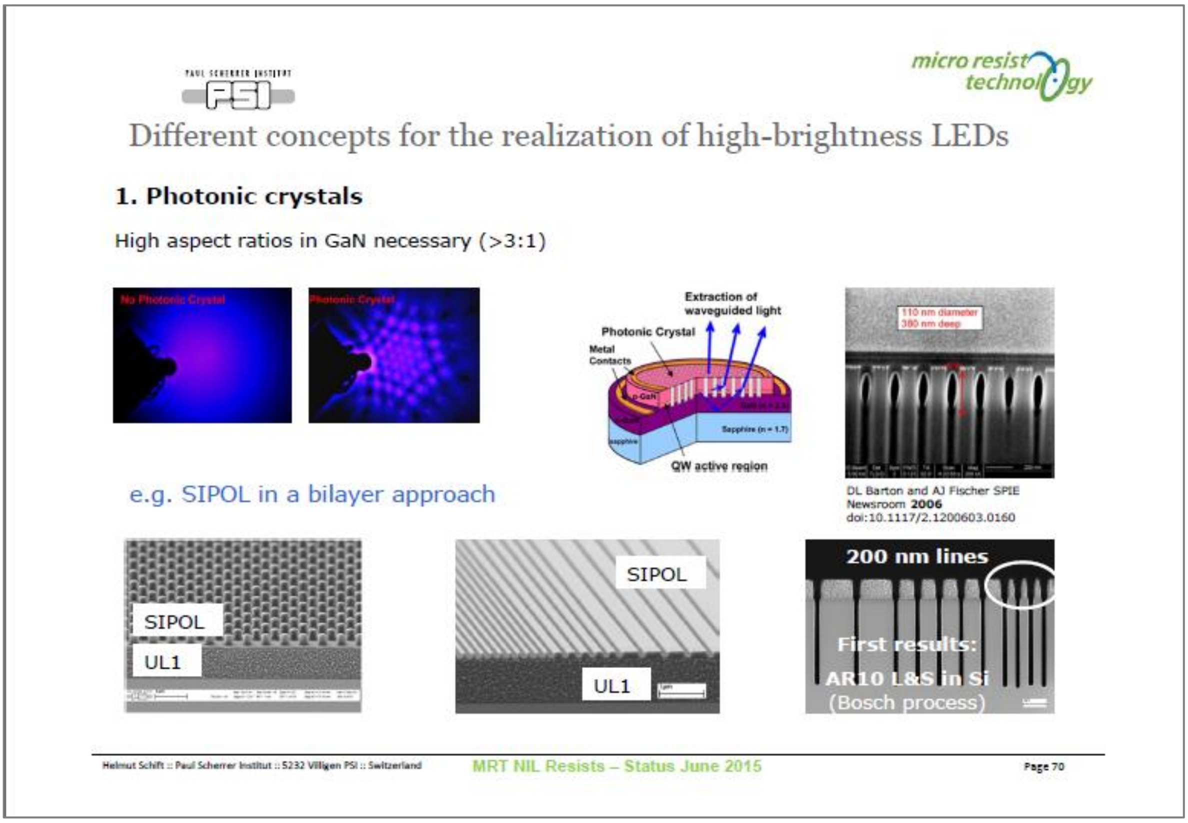


Figure 39. Different concepts for the realization of high-brightness LEDs

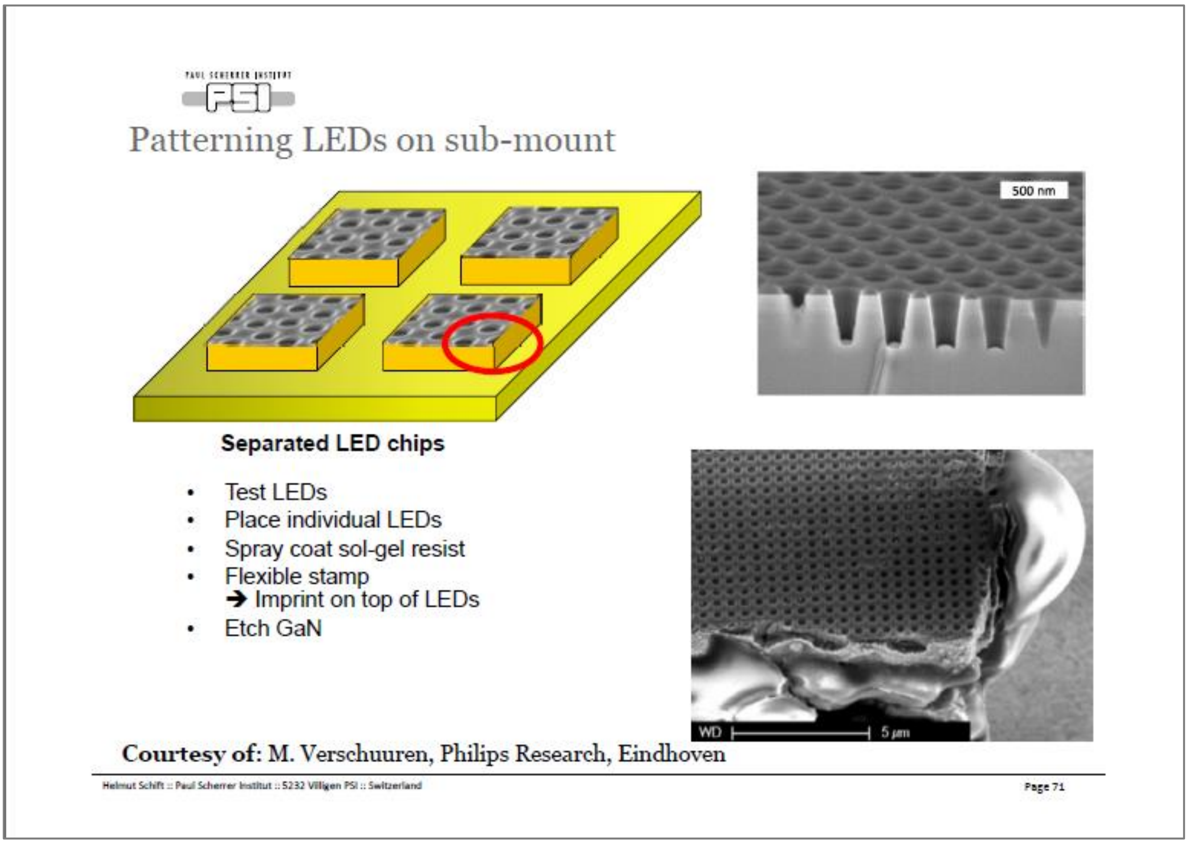


Figure 40. Patterning LEDs on Sub-Mount

If you look at the different application fields where these mechanical techniques are used, I have presented semiconductors, I have presented data storage, and I have presented the lighting. But you also see that, for instance, for pharmaceutical, solar energy, and MEMS/NEMS, and for biotech, there is a large market foreseen where nanostructuring of surfaces plays a role. Therefore, the message here which I want to give to you is, even if this seems to be the frontrunner in the moment, think about the other areas here where most of the money is involved. All these combined for instance, you can also see that there is a lot of money involved in other areas as well. And these numbers are only, I would say, first guesses. Therefore, it could be that this is enhancing quite a lot (Figure 41).

What a Researcher Can Contribute

So now what else do we, researchers, contribute? Sometimes there are areas where I would say development is done which is not yet in production (Figure 42).

And these are just fields, a little bit more elaborate, where I would say structuring can play a role. And I'll just show you photovoltaics, transparent electrodes, backlight display waveguides, and nanofluidic devices, which can profit from this nanostructuring as well. I will just go shortly through it (Figure 43).

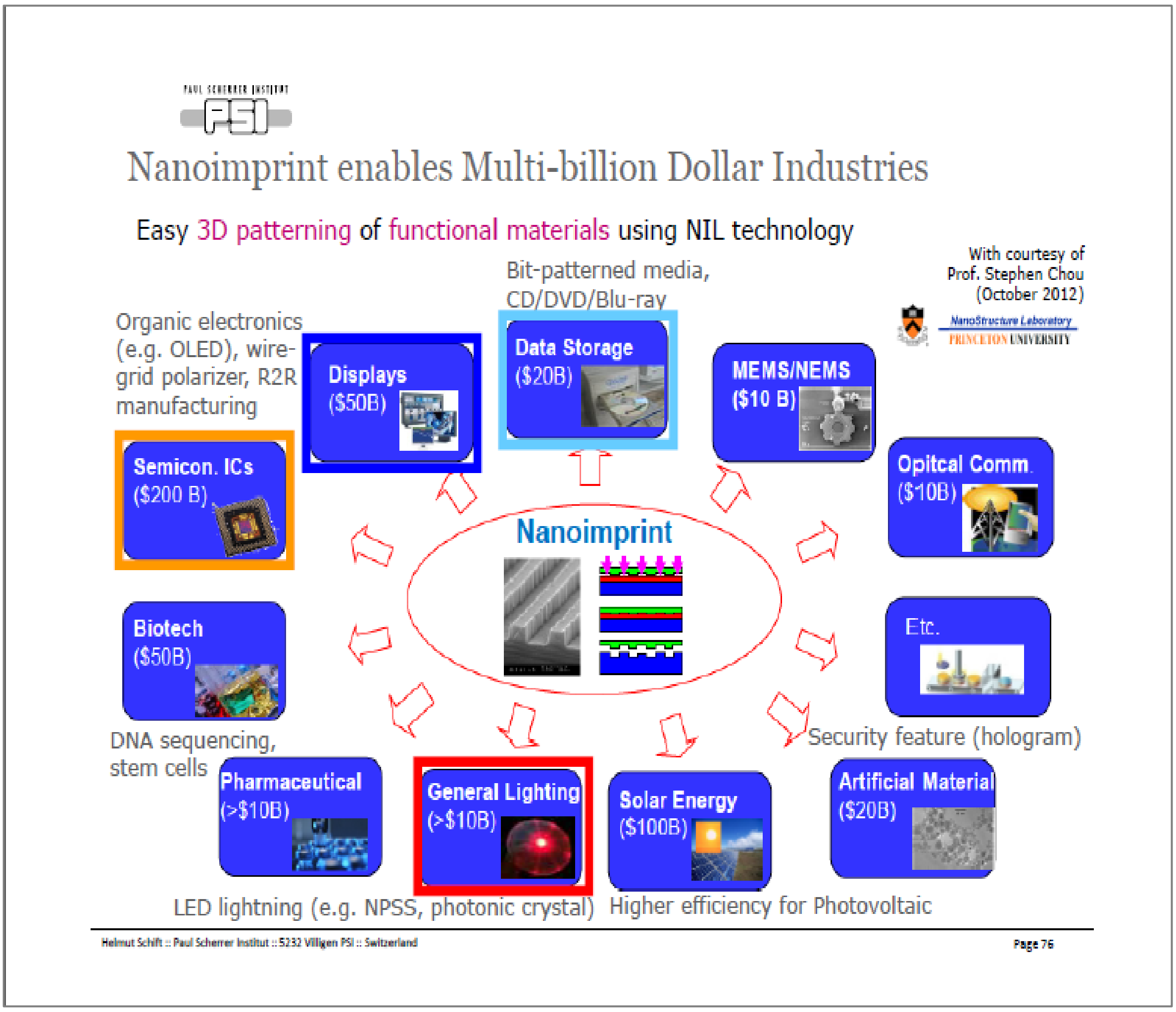


Figure 41. Nanoimprint Enables Multi-Billion Dollar Industries

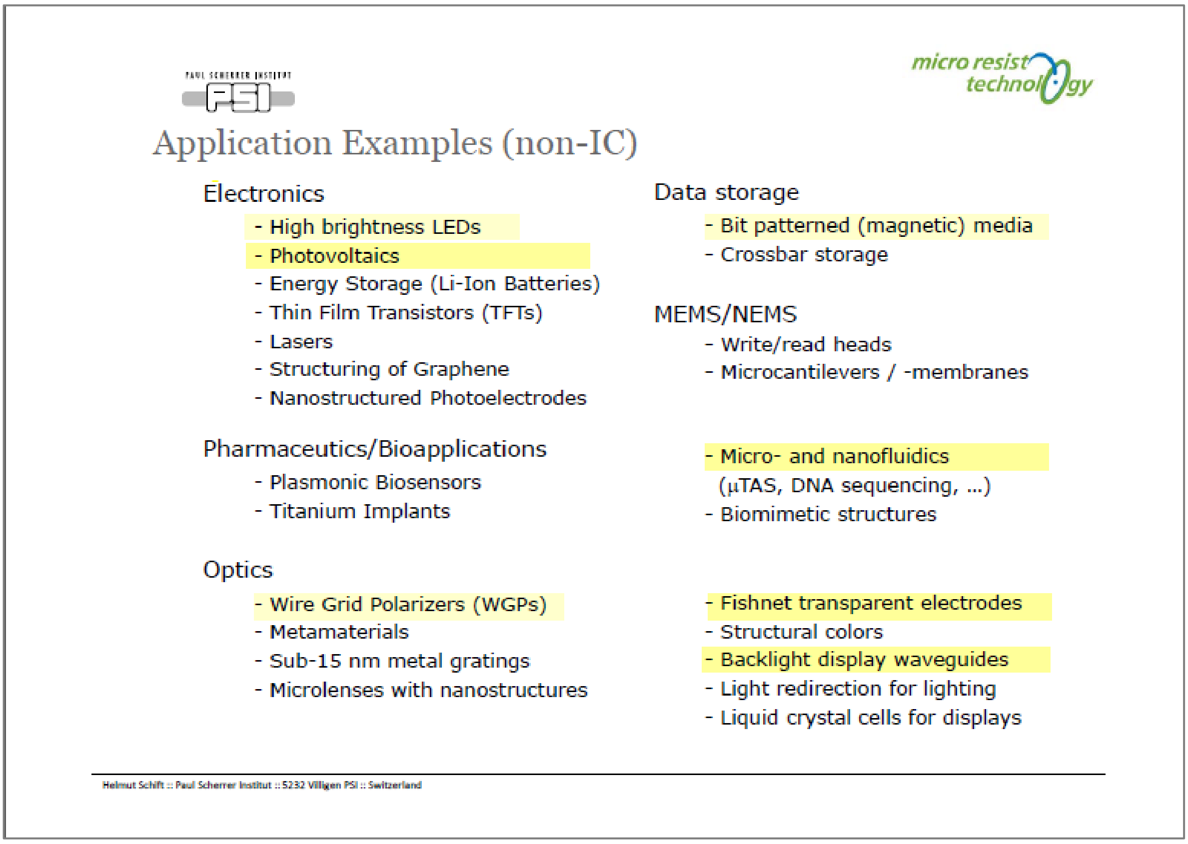


Figure 42. Application Examples (Non-IC)

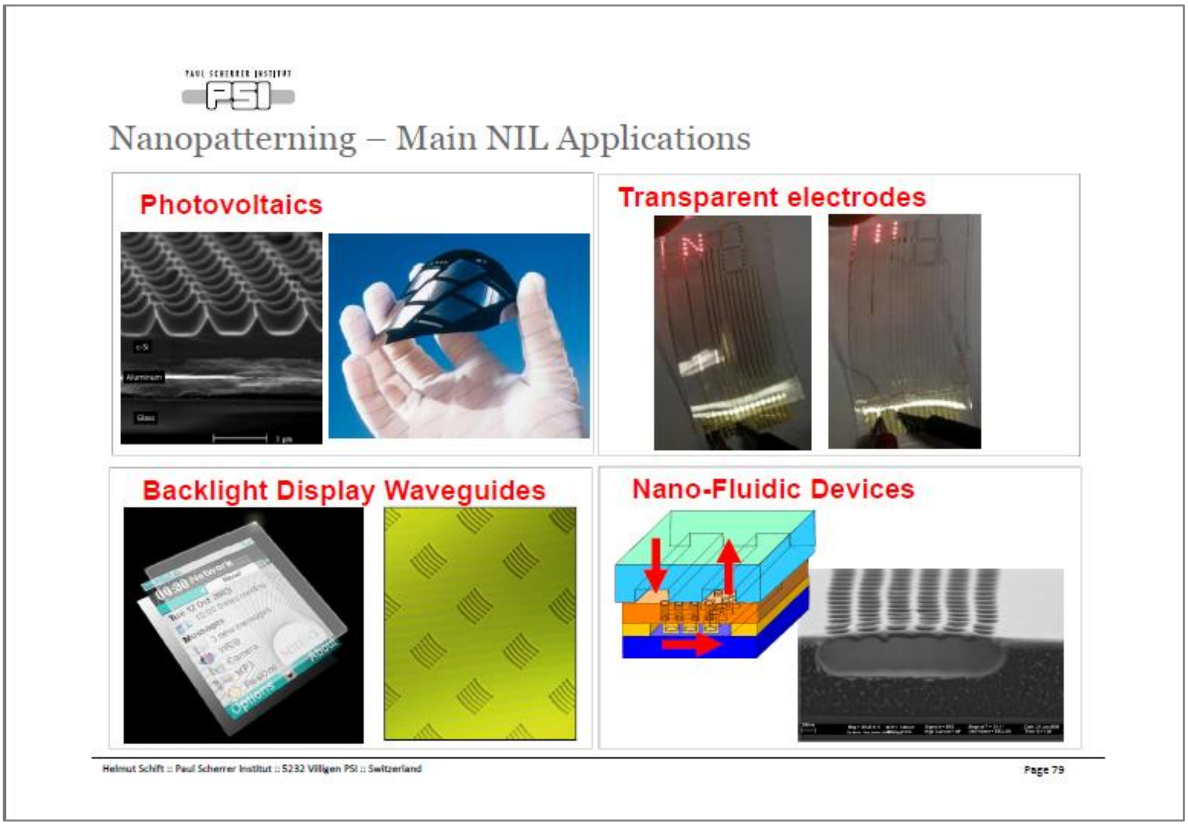


Figure 43. Nanopatterning - Main NIL Applications

- **Photovoltaics**

If you have a solar cell, which a test solar cell might look like this, if you put this honeycomb structure on top of the surface, you can also enhance the absorption of the light. That means the light is somehow deflected inside the solar cell, and then more light is absorbed. And you can enhance the efficiency of the solar cell (Figure 44).

And the wafer thickness is going down and down. It means you currently have 160-micrometer-thick wafers here, and this might go down in 2022 to 100 micrometers. And if you think about how thin a wafer is and how fragile it is, it's about the thickness of this kind of plastic which you have in this bottle here. It's about 100 micrometers or 50 micrometers. And plastic is much more robust than a silicon wafer. Therefore, you have to have very gentle mechanical processes in order to make this kind of processing possible (Figure 45).

For instance, the Fraunhofer Institute ISE in Freiburg, Germany, they were developing a roll process with which you could pattern a whole solar cell that typically has a size of 156x156 mm². And they have a kind of soft imprint on the surface with which they could replicate these honeycomb structures, meaning this would be the resist on the surface. And afterwards, it's etched into the silicon, and then the absorption can be enhanced (Figure 46).

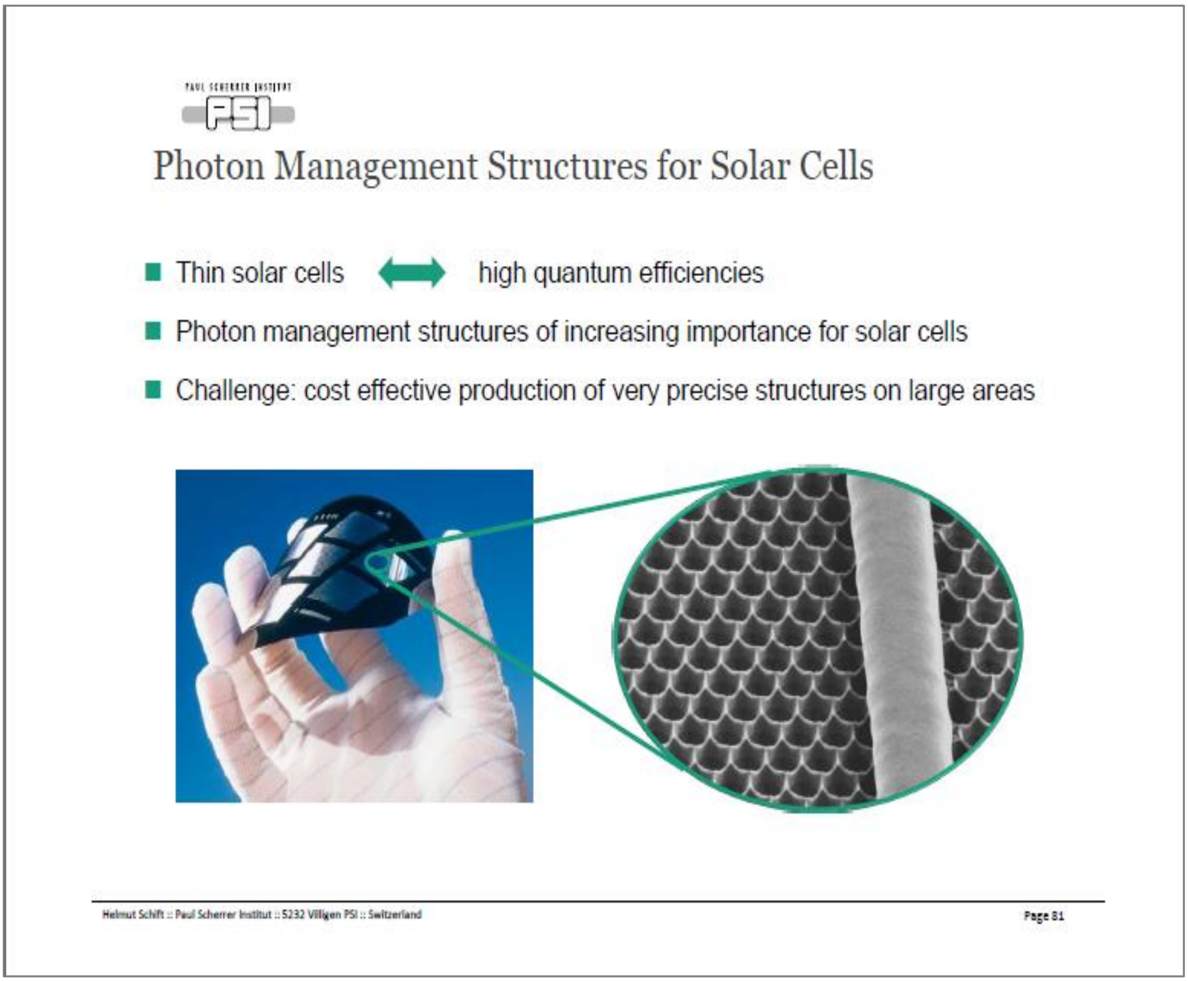


Figure 44. Photon Management Structures for Solar Cells

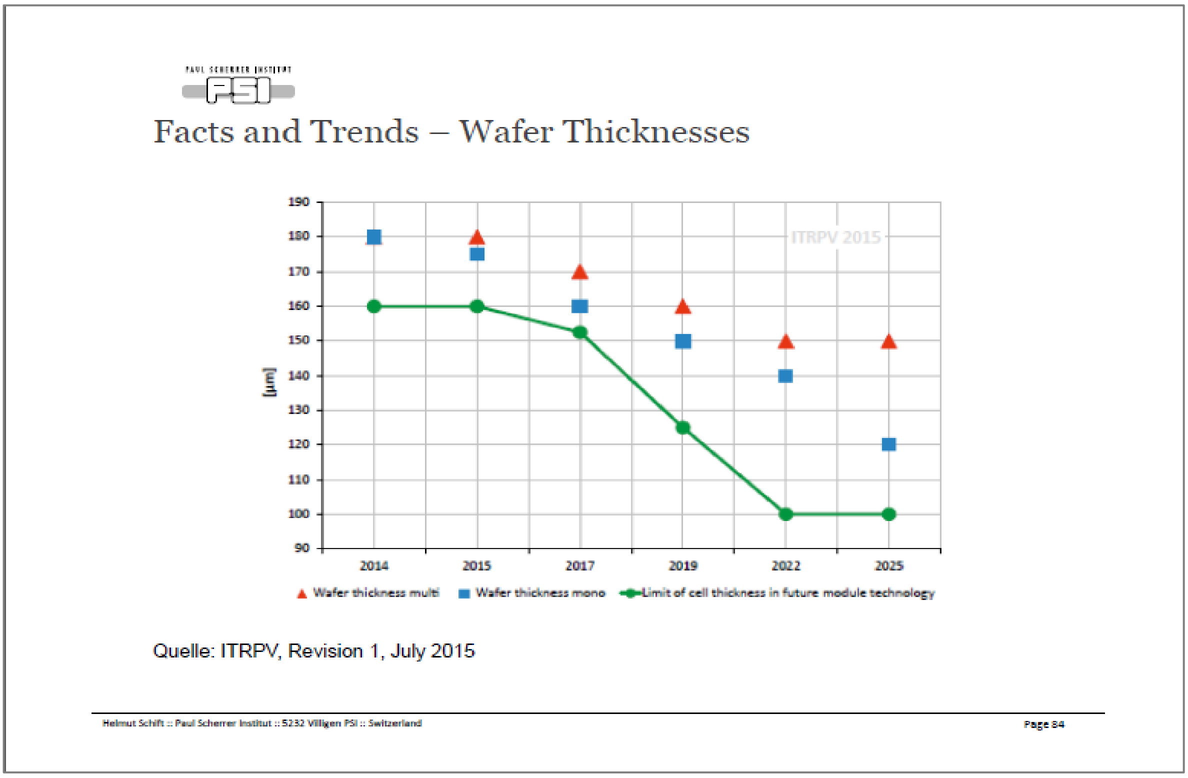


Figure 45. Facts and Trends - Wafer Thicknesses

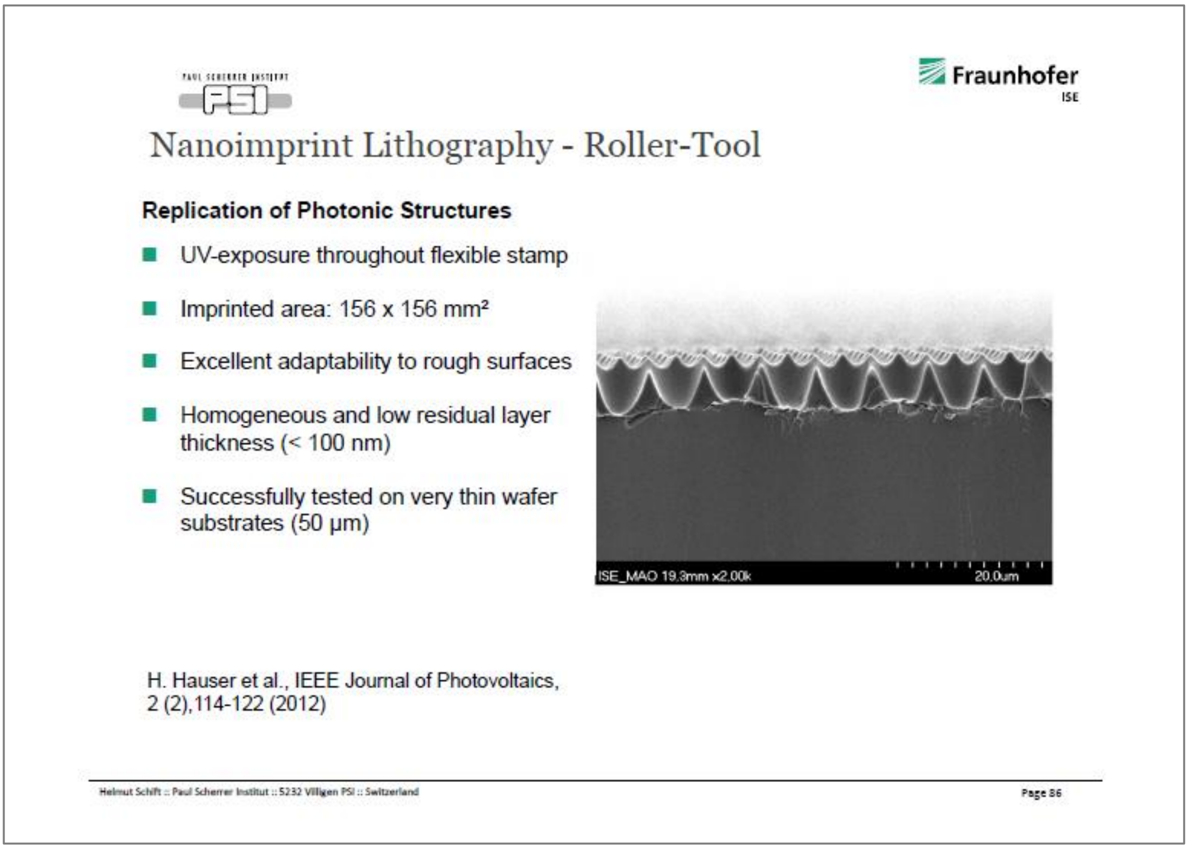


Figure 46. Nanoimprint Lithography - Roller-Tool (1)

And this is just a kind of a flexible wafer, which you can see that this is a 160- or 140-micrometer-thick wafer that is easily bendable. You see from the coloring here that there is a nanotexture on the surface. This is a kind of optical interference structure (Figure 47).

Therefore, if you compare different kinds of structuring on the surface, for instance, these honeycomb structures, you see that the reflectance of the surface can be greatly reduced. And in the visible wavelengths, most of the light is absorbed. And if you lower the reflectance, the absorption will be higher, and you get lighter converted into electrical energy by your solar cells. Therefore, they made a clear comparison with these kinds of techniques and even with other techniques and even with a plain reference, which would have a reflection of about 40 percent (Figure 48).

- **Transparent Electrodes**

Now people also think about "head-up displays," for instance in cars, where a certain kind of structuring might help. You want to integrate active devices here. This was a project together with Fiat CRF here with which we had in a European project (Figure 49).

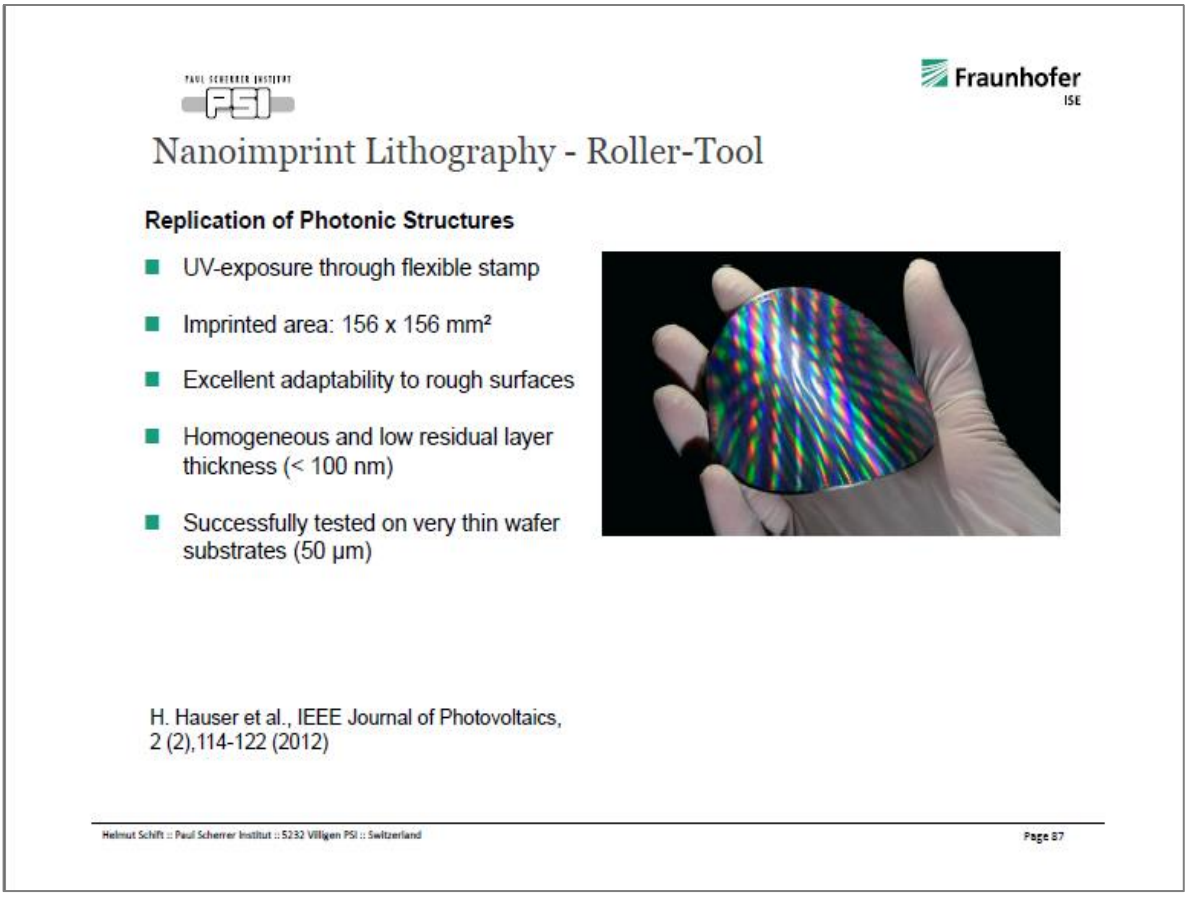


Figure 47. Nanoimprint Lithography – Roller-Tool (2)

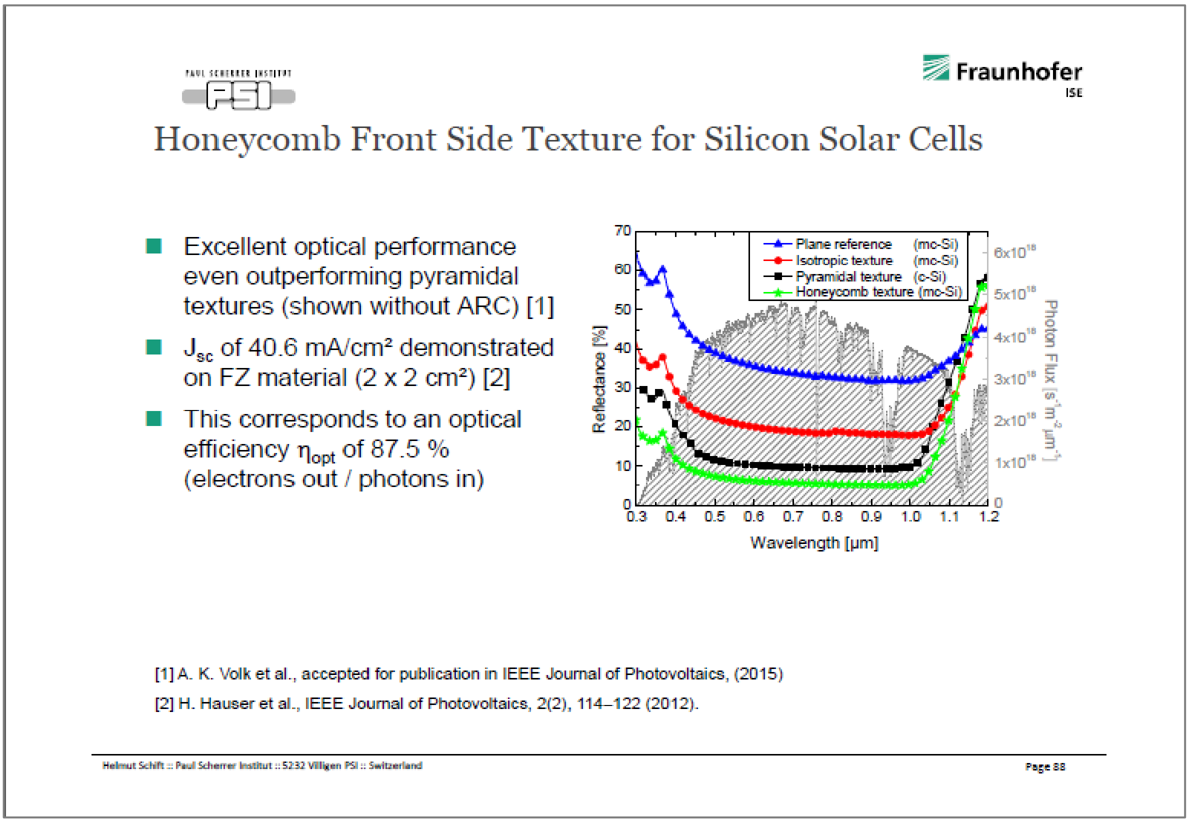


Figure 48. Honeycomb Front Side Texture for Silicon Solar Cells

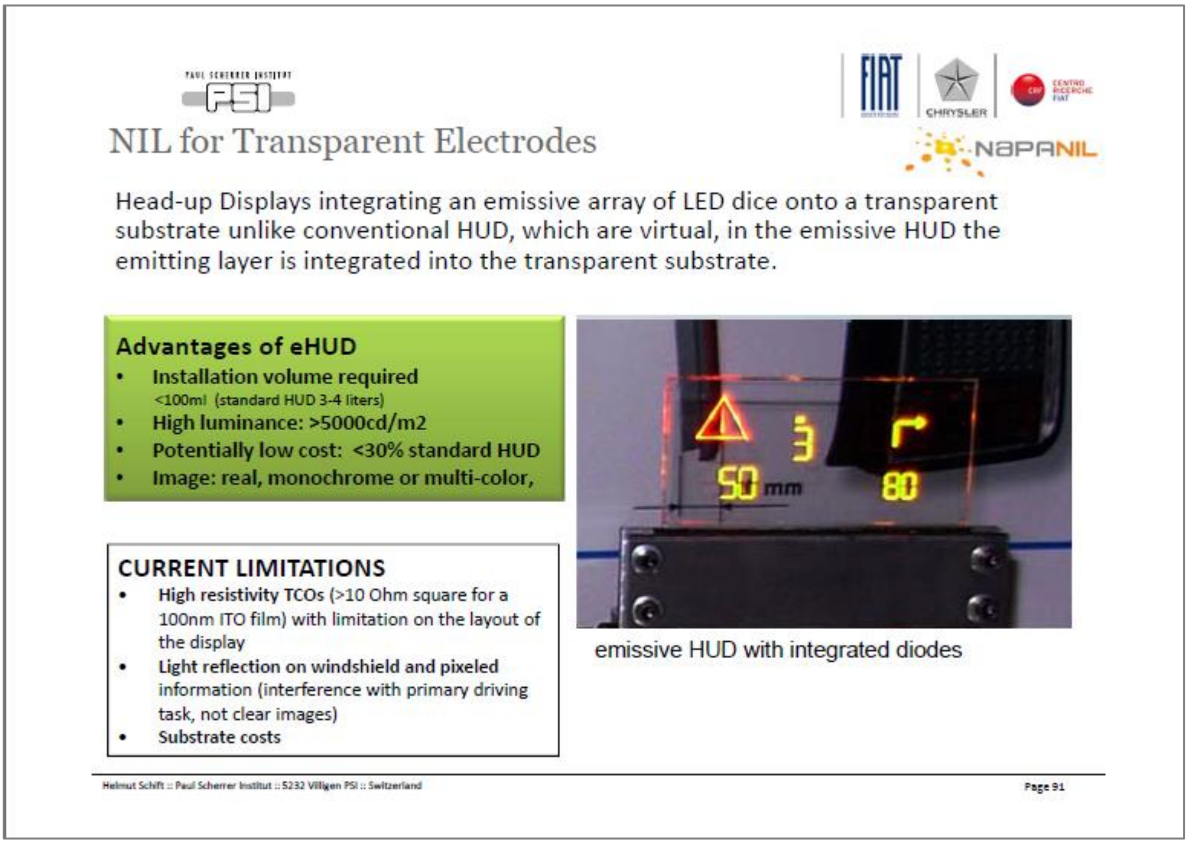


Figure 49. NIL for Transparent Electrodes (1)

You need several kinds of structuring at the same time. You want to have the front side patterned with these nanostructures. I think we will have a talk about antireflective structures next, or the talk afterwards will be about this. There are also structures on the backside where you want to have electrodes patterned which are transparent. And you want to have holes on the surface in which you can place LEDs. This is a little bit of complex structuring, but in the end, you simply want to have one structure put on one side of some kind of glass substrate and have the other structure put on the other side of the substrate. And this can be done by two separate nanoimprint processes (Figure 50).

And just to give you an idea about how transparent electrodes look, if you would make electrodes out of gold, which would be solid, then you would see these kinds of lines here and that would, for instance, inhibit your view through the screen. But if you have, for instance, nanostructure which has the same kind of conductance as these lanes here, you reduce the visibility of your lanes quite a lot. And then you have a transparent screen through which you can look in the car screen. So, also here is another structure. This can be still reduced further. Therefore, it's still very visible, but if you have done it in the smaller structures, you can get rid of this kind of visibility (Figure 51).

- **Backlight Display Waveguide**

So I come to the field where I was involved in. Not in the manufacturing of Kindle Paper White, but Paper White is using a similar technique. If you have the Paper White with electronic ink, it was not typically usable in dark light because there was some kind of self-reflecting screen. And to use in dark light, or when there is no light, you need to have some kind of illumination. And how is illumination done? You include a kind of light guide into your structure. Therefore, if this is your Kindle here, the light guide has to be a sophisticated structure. Here you see the side view. Here is the LED, and if you shine light through it, the light is somehow reflected on this kind of display and then gets back to your eye. To introduce a very thin light guide into this kind of component, a kind of nanoimprint lithography was used (Figure 52).

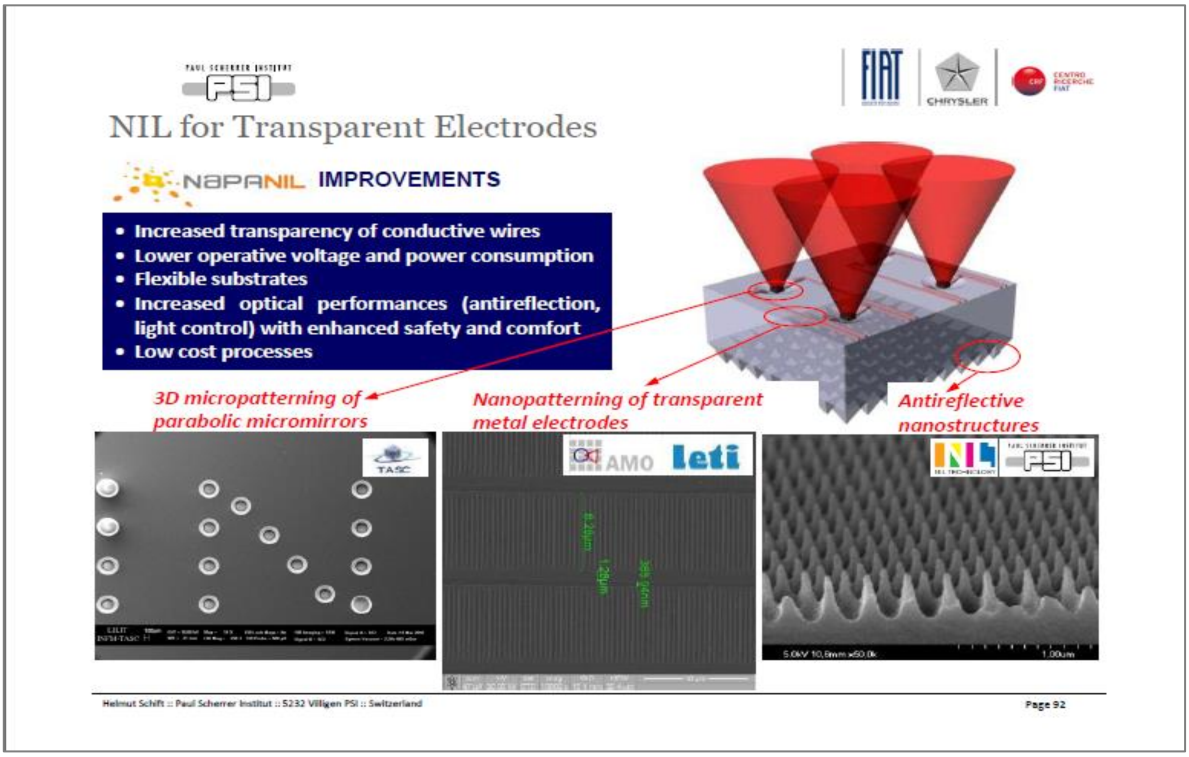


Figure 50. NIL for Transparent Electrodes (2)

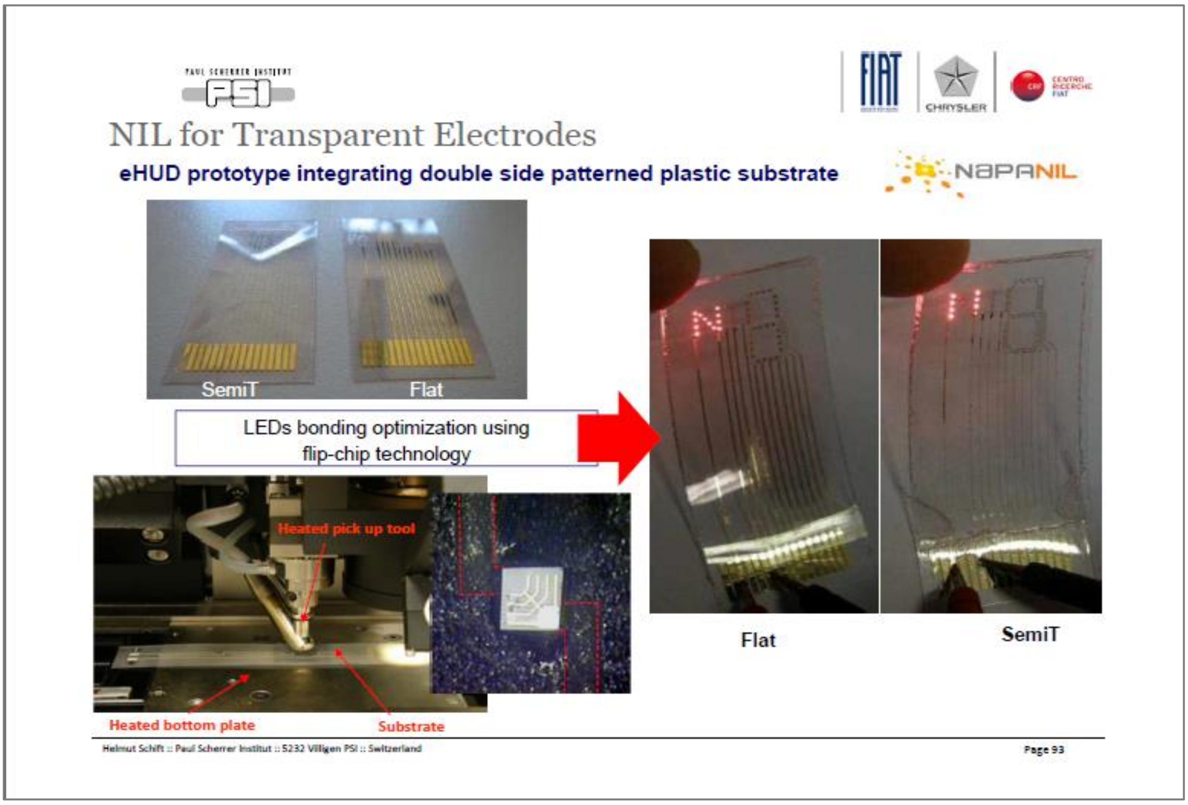


Figure 51. NIL for Transparent Electrodes (3)

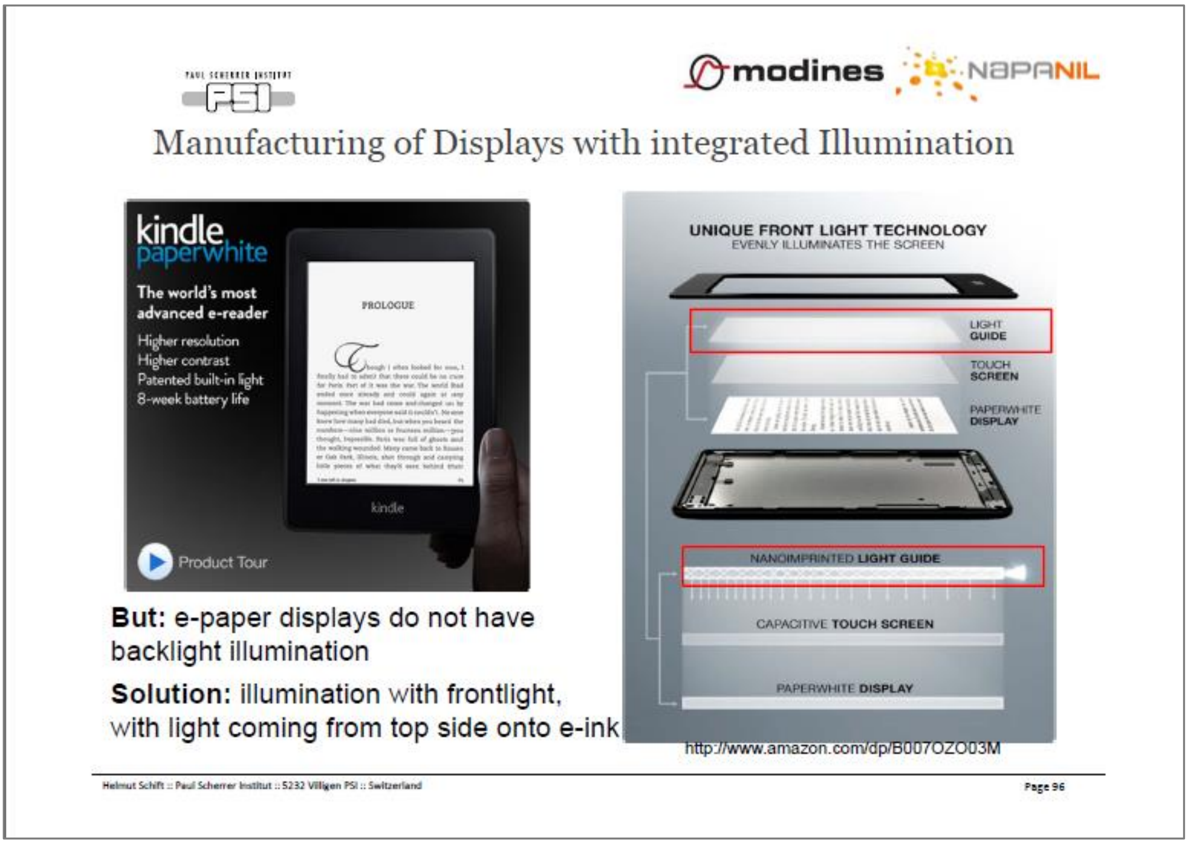


Figure 52. Manufacturing of Displays with Integrated Illumination

I just give you an example how this is done. You have light emitting diodes here on the side of the light guide. You shine light through it, and you have to have outcoupling gratings here and here. The outcoupling gratings shine light into your eyes. But the density of these outcoupling gratings has to change. In the beginning, you do not want to couple out all the light; at the end, you need to couple out all the light. Therefore, you can change density from here to here. And this has to become denser. And to make these kinds of structures, for instance, these kinds of structures with a prism light structure here, you have to be very clever with lithography which makes these kinds of very smooth surfaces. At the same time, you want to have these kinds of gratings here which are reducing the reflectance (Figure 53).

We were working on this kind of process. We were starting with 3D structures like this. You see here different kinds of steps. From the top, this means that this would be 3D structures with different steps. And we were applying a process with which we can selectively smooth out these surfaces. You see now, this would be a thermal reflow process, where only this is smoothed out, and these structures are kept. Then, we do what we call UV-NIL; we are replicating this in a structure with a negative tone, i.e. with the inverse topography. And then we are again replicating this, and this would be the final structure which you would want to use for screen (Figure 54).

And as for a test design, we have done it with a single light emitting diode that was placed here. This was a light guide here. And this was without any kind of electronic ink; this was simply a kind of an example where we were patterning this kind of area; the same kind of density here at the beginning of the grating and at the end of grating. And there were different grating densities on the top of the surface. And this is about the size. Therefore, you can make it larger, but with research instruments, you should not go to large areas because it costs you a lot of money (Figure 55).

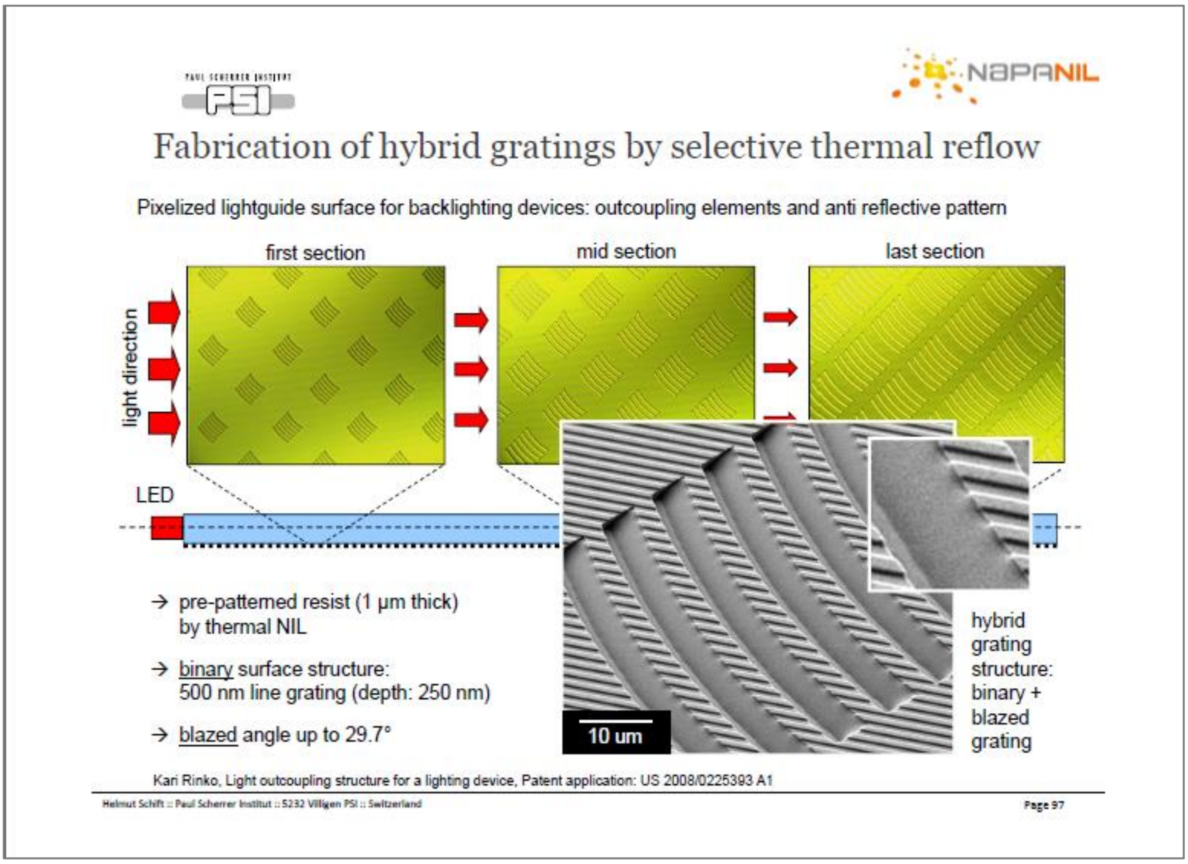


Figure 53. Fabrication of Hybrid Gratings by Selective Thermal Reflow (1)

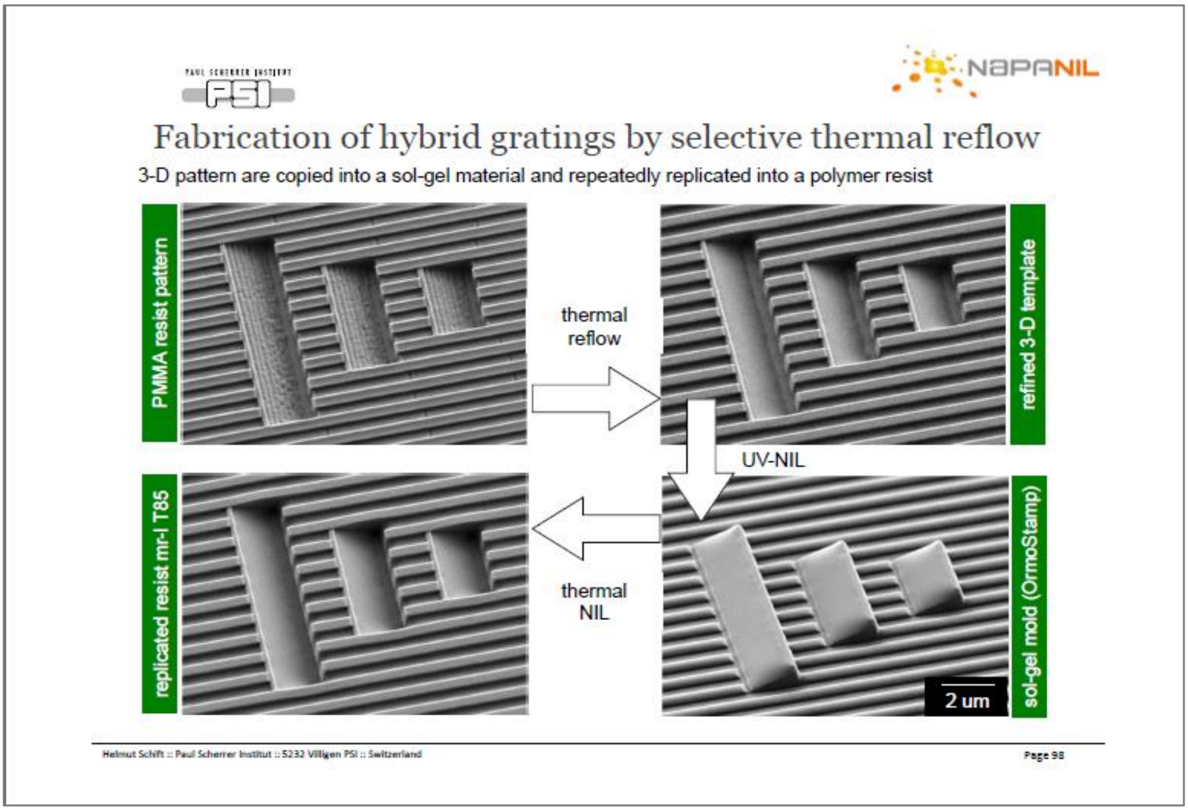


Figure 54. Fabrication of Hybrid Gratings by Selective Thermal Reflow (2)

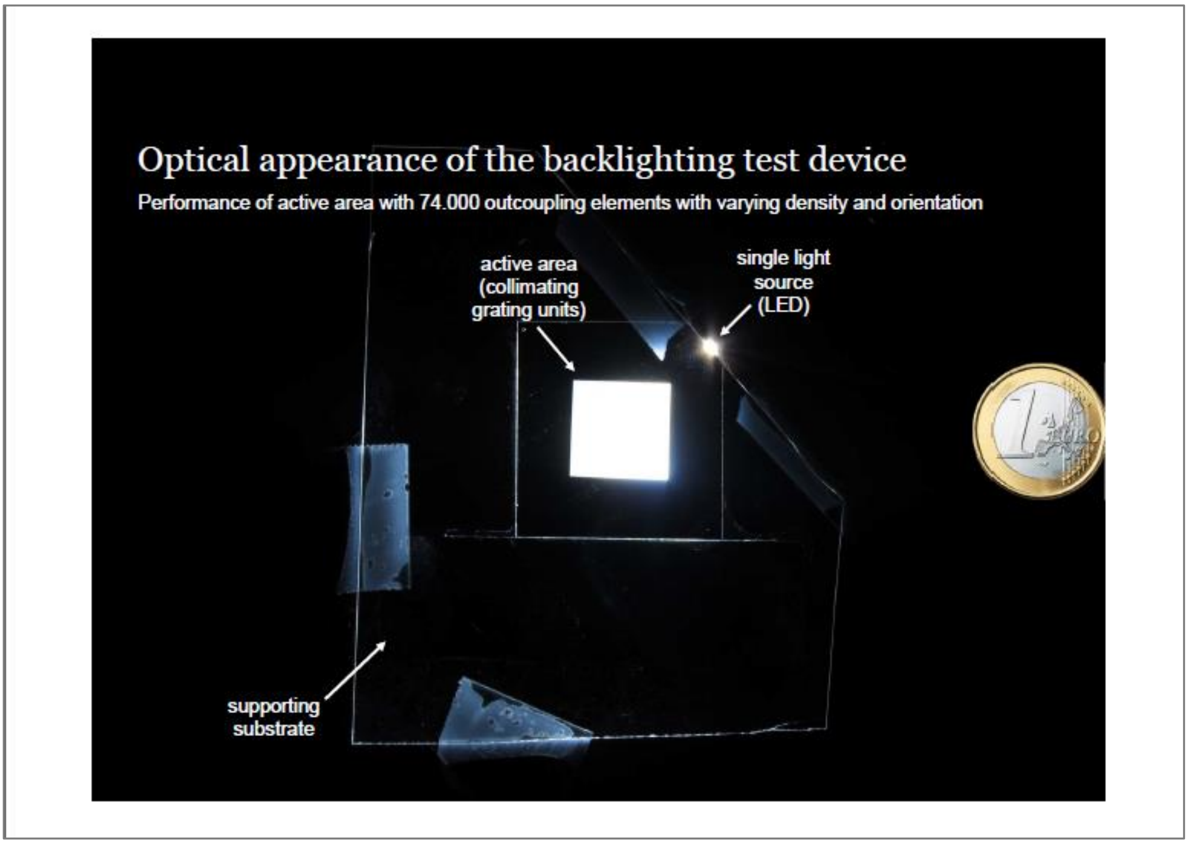


Figure 55. Optical Appearance of the Backlighting Test Device

- **Micro-optical Systems**

I will skip the nanofluidic devices. I just want to give you an example where Switzerland is very strong. There are companies working with these kinds of lenses which you might have in your smartphones. These lenses are in different kinds of areas. For instance, if you take a smartphone, you have different kinds of LEDs inside or different kinds of cameras inside and sensors, and so on. And inside this camera, it typically has lenses on top of it. And the enterprise, Heptagon, is a very small company in comparison with the companies building smartphones, but they do the design and the manufacturing of the molds of the stamps which are then used for the mass replication of these kinds of sensors (Figure 56).

And typically, they have to do a lot with this assembly, which is on the wafer level here. For instance, and they stack this kind of wafer level wafers here, or they put structures of both sides of a glass slide and then cut it. And for that, they also take replication processes. These lenses are mostly micro, but some of those processes are already ready to use nanopatterning (Figure 57).

And for instance, if you take a structure like this, this is also a wafer process. You have the individual lenses here which are later on cut out, and then they are stacked together in these kinds of devices (Figure 58).

Just to give you an idea about of what we are doing, we are testing new kinds of lenses which they can use here. And they are quite high. You see here it's 50 micrometers by 50 micrometers in an individual lens here. But the tricky thing is that these lenses are also 50 micrometers high as well. It means they have a very deep structure here which has to be replicated (Figure 59).

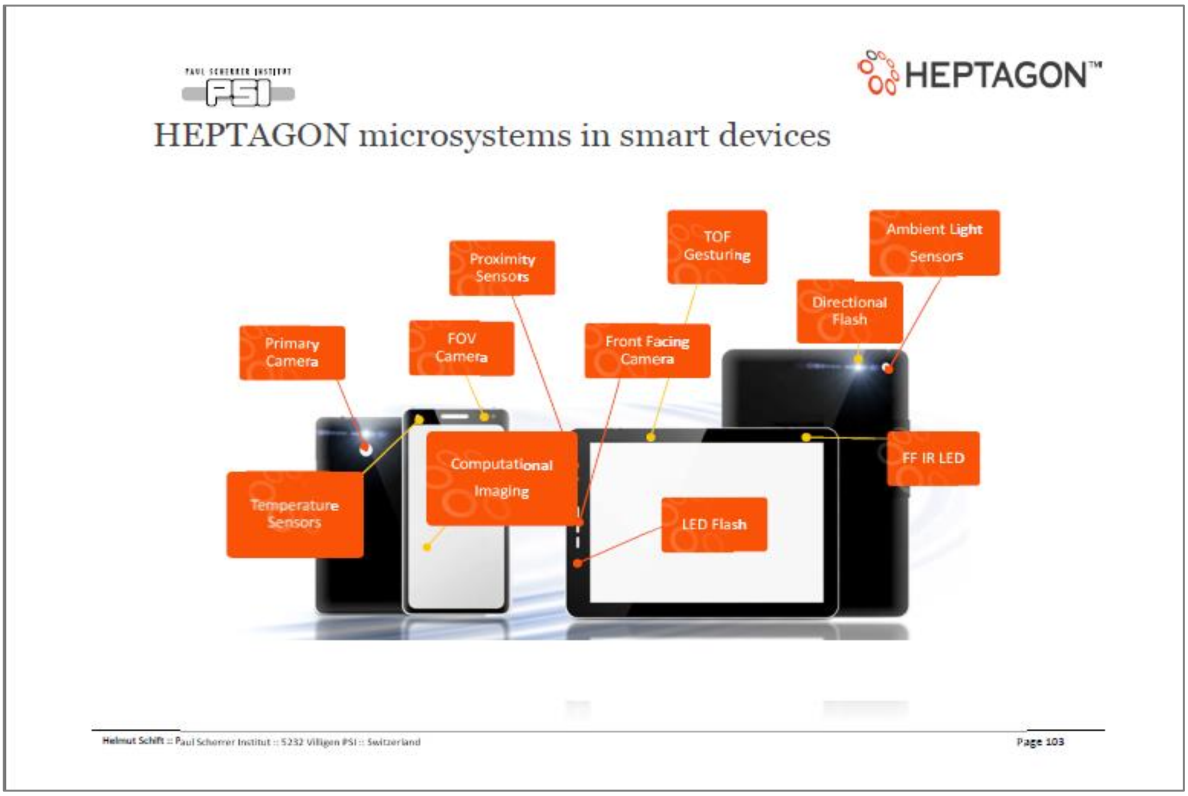


Figure 56. Heptagon Microsystems in Smart Devices

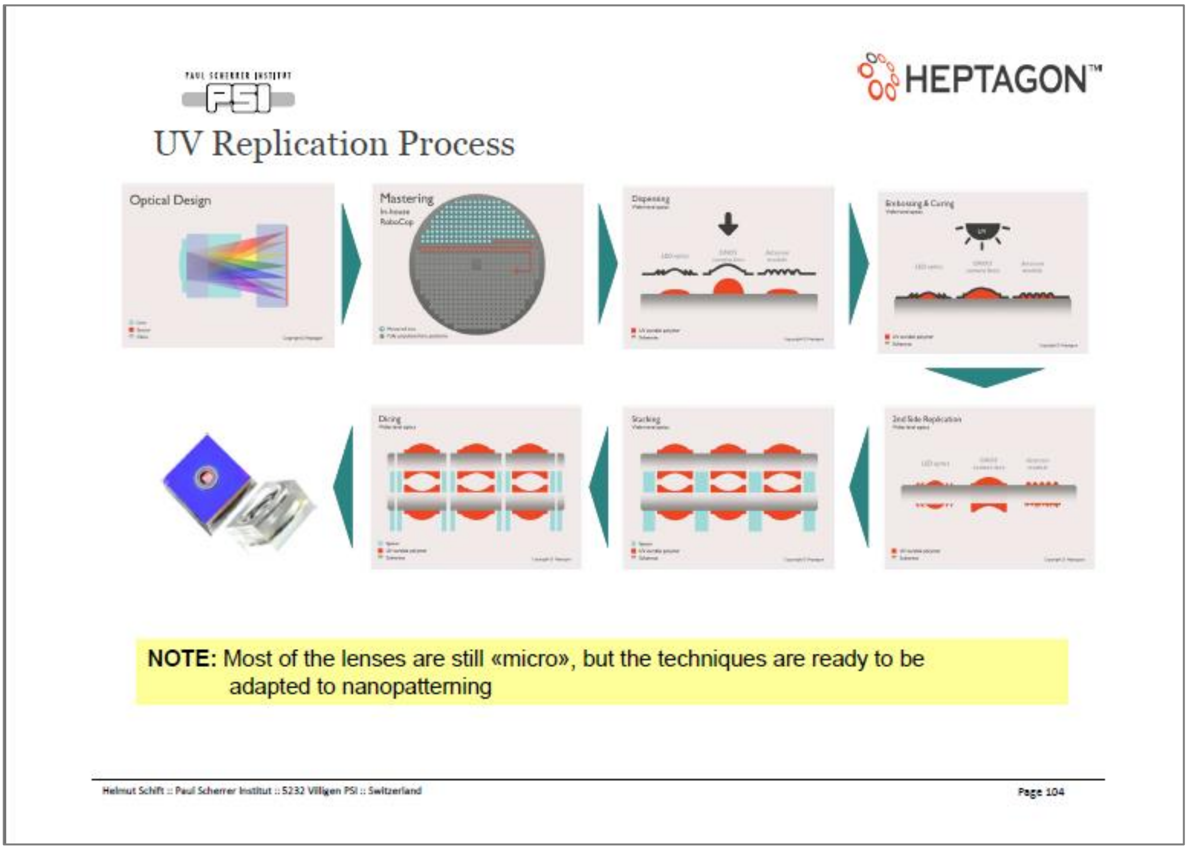


Figure 57. UV Replication Process

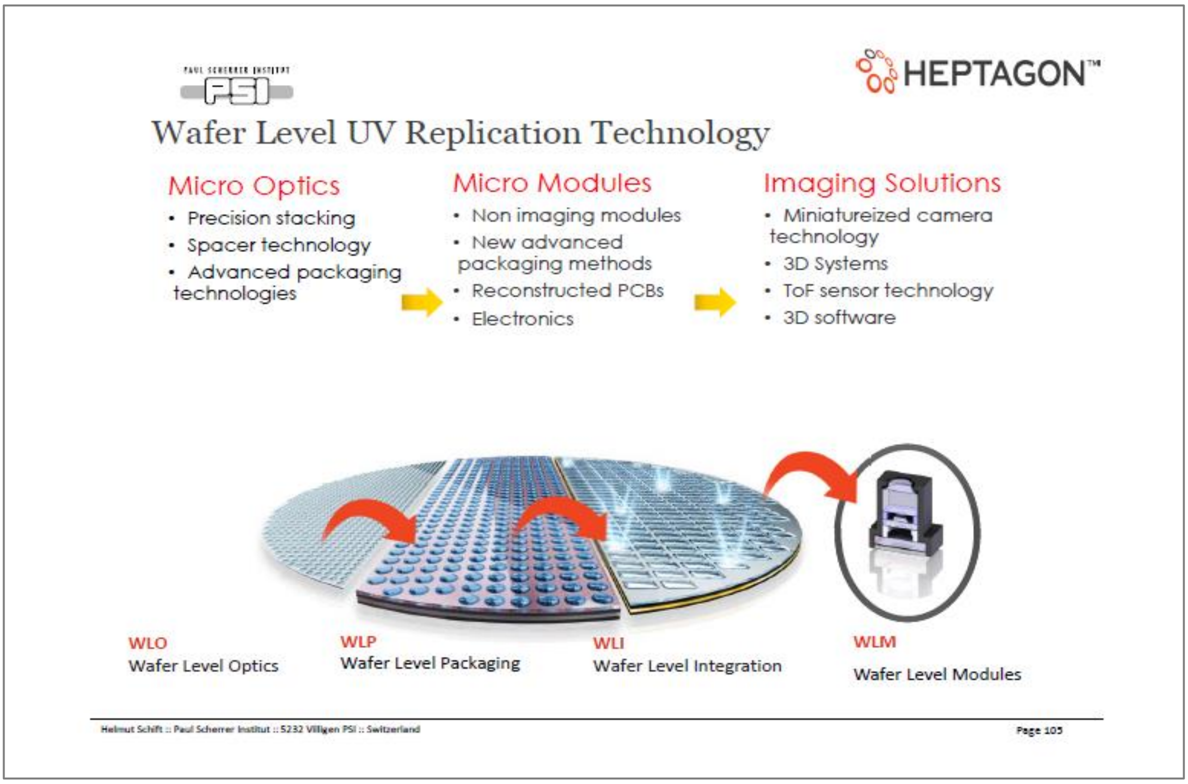


Figure 58. Wafer Level UV Replication Technology

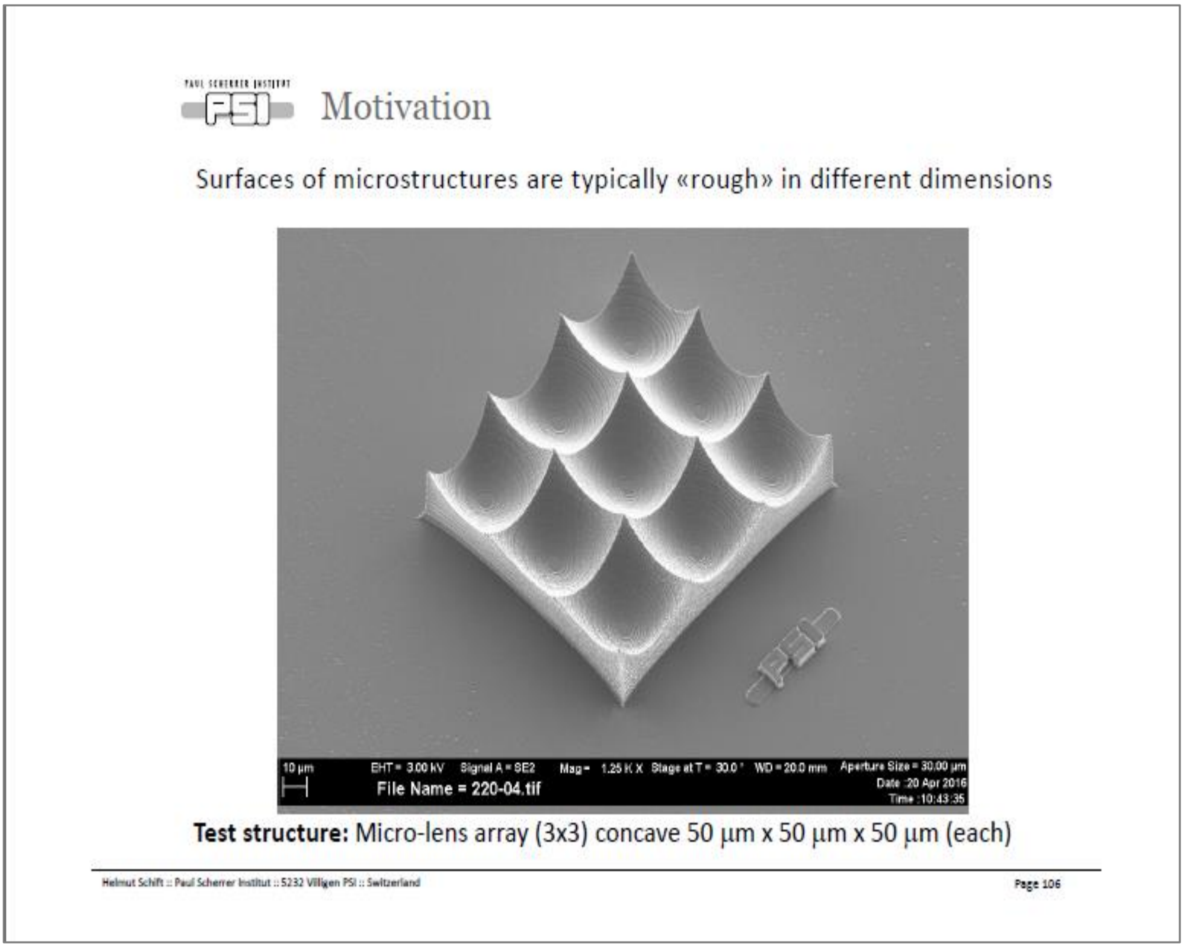


Figure 59. Motivation (1)

And if you look at it closer here, with our technology, the roughness of these structures are typically very high because 3D techniques typically used for that sometimes are not adapted for low roughness. And therefore, sometimes this roughness increases the scattering of the light.

Now, our aim was at the Paul Scherrer Institut to find chemical and mechanical processes in order to make this roughness vanish. This was possible by shining and damaging the surface of the polymer and then doing a kind of thermal reflow of the surface. It means we are smoothing out the roughness of the surface while the tips here between the different lenses were preserved. And you see here we were getting down to roughness below 5 nanometers, and these tips here look almost the same as before. Therefore, this is where sometimes nanotechnology and material technology come into place in order to make things like this happen (Figure 60).

And just to give you an idea about doing a large-area lens structure and micro lens structure here, they are possible with our machines. And we are taking these kinds of devices and looking at the CCD camera with how the density, how the illumination would be. Typically, if you just take the master, which is very rough, you would get a picture like this, which is a very inhomogeneous picture. And then, you go to that result here, meaning our Plexiglas® polymer, which we were smoothening out, and you see that these look totally different like this. That means that by smoothing out the surface roughness, you get relatively inhomogeneous patterning. Therefore, this is an example in which, I would say, mechanical techniques together with replication techniques can be used.

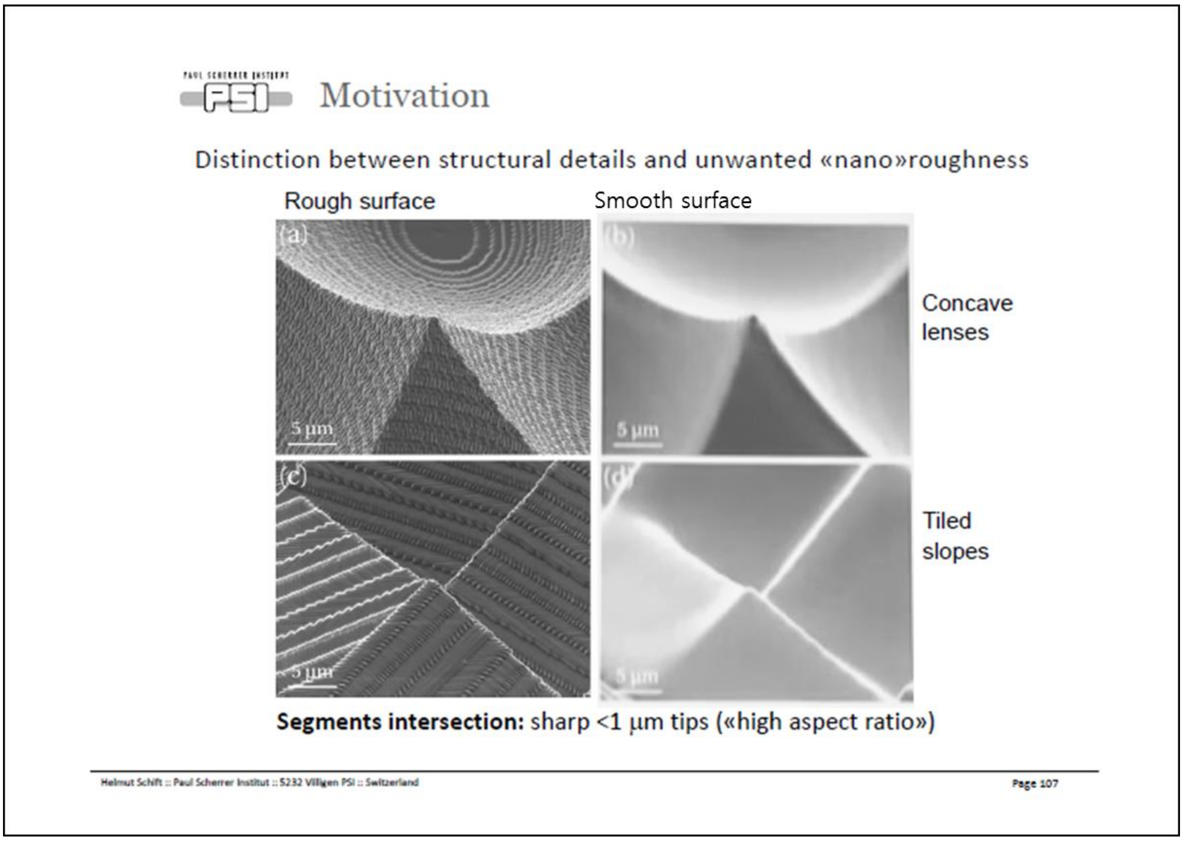


Figure 60. Motivation (2)

Conclusions

Now I have shown you different kinds of applications. I hope I gave a little bit of flavor about where replication techniques and mechanical techniques are used today.

Stephen Chou said that nanoimprint is now still at the beginning. That means we have seen 20 years of nanoimprint from the embryonic state to now. It has come, I would say, from infancy to some kind of mature state. But in the future, we will see more of these kinds of mechanical processes. And if this comes into play, for instance, if Canon is selling these kinds of tools to Toshiba, and other companies, maybe Samsung as well, then we will see chips coming out of these factories made by nanoimprint lithography. We all hope that nanoimprint is able to compete with other techniques. But I have already shown you that other applications as well will play a big role when you have these new techniques. Therefore, this was just beginning 20 years ago, and I have shown you the current status. Still a lot of research going on, and I am very proud that I can participate in this kind of development (Figure 61).

So I have come to the end of my talk. These are the people whom I want to thank. And this is the Laboratory of Micro- and Nanotechnology (LMN) at Paul Scherrer Institut which is participating in such kinds of process development, here at the Aare river in Northern Switzerland with me here, and many other people are participating in this, too (Figure 62, 63).

Thank you very much for your attention. I hope I gave you a flavor about mechanical manufacturing.

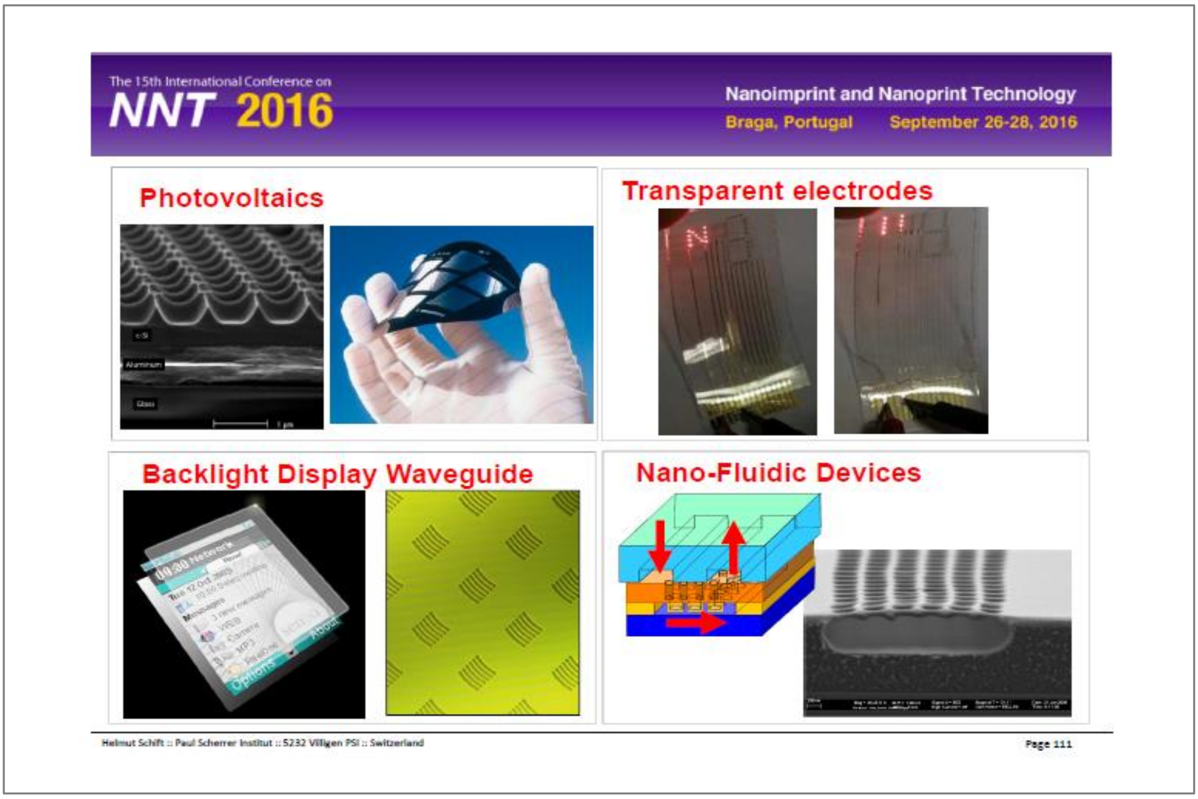


Figure 61. NNT 2016

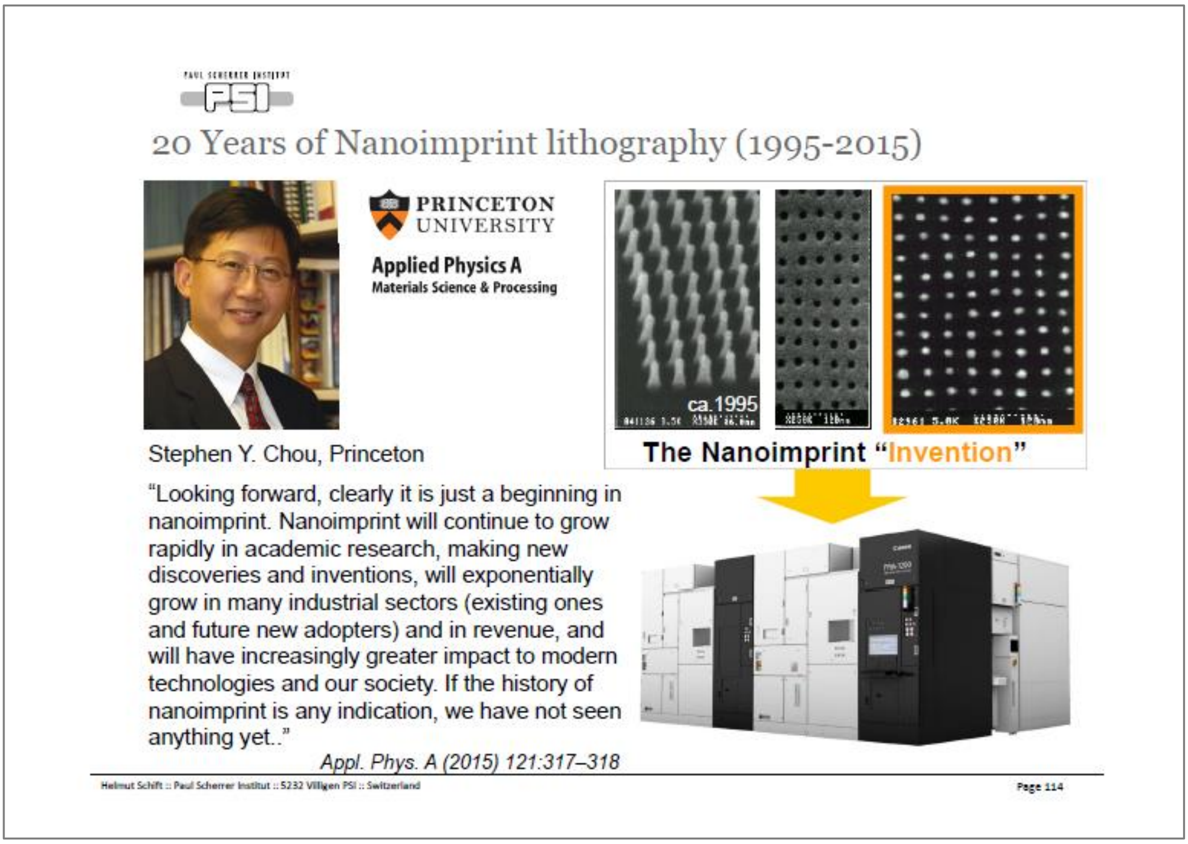


Figure 62. 20 Years of Nanoimprint Lithography (1995-2015)

Figure 63. Acknowledgement.

KIMM – BIRTH, GROWTH, and IMPACT

Dr. Hellmut Schmücker

Head (retired) Technical Division

Max Planck Institute for Physics

(Former Advisor to KIMM)

Dear Mr. President, honorable guests, ladies and gentlemen,

I would like to thank you, Mr. President, for the kind invitation to Daejeon upon the 40th anniversary of KIMM. It is an honor and delight for me to talk to you today about the history of KIMM and some new challenges. I am not going to present a scientific lecture in terms of new measurements and their interpretation. I simply present a story of a rather successful cooperation between Korea and Germany, two countries which bear a similar history.

Here are the topics I am going to talk about: the Political Scene when KIMM was founded, and then the Economic Situation will be highlighted. I shall sketch the Korean – German Deal. The Changes in the R&D Scene will be mentioned. New Challenges to Growth in the future will be identified, and some New Strategic Fields for enhanced activities will be suggested (Figure 1).

Figure 1. The Outline of the Presentation

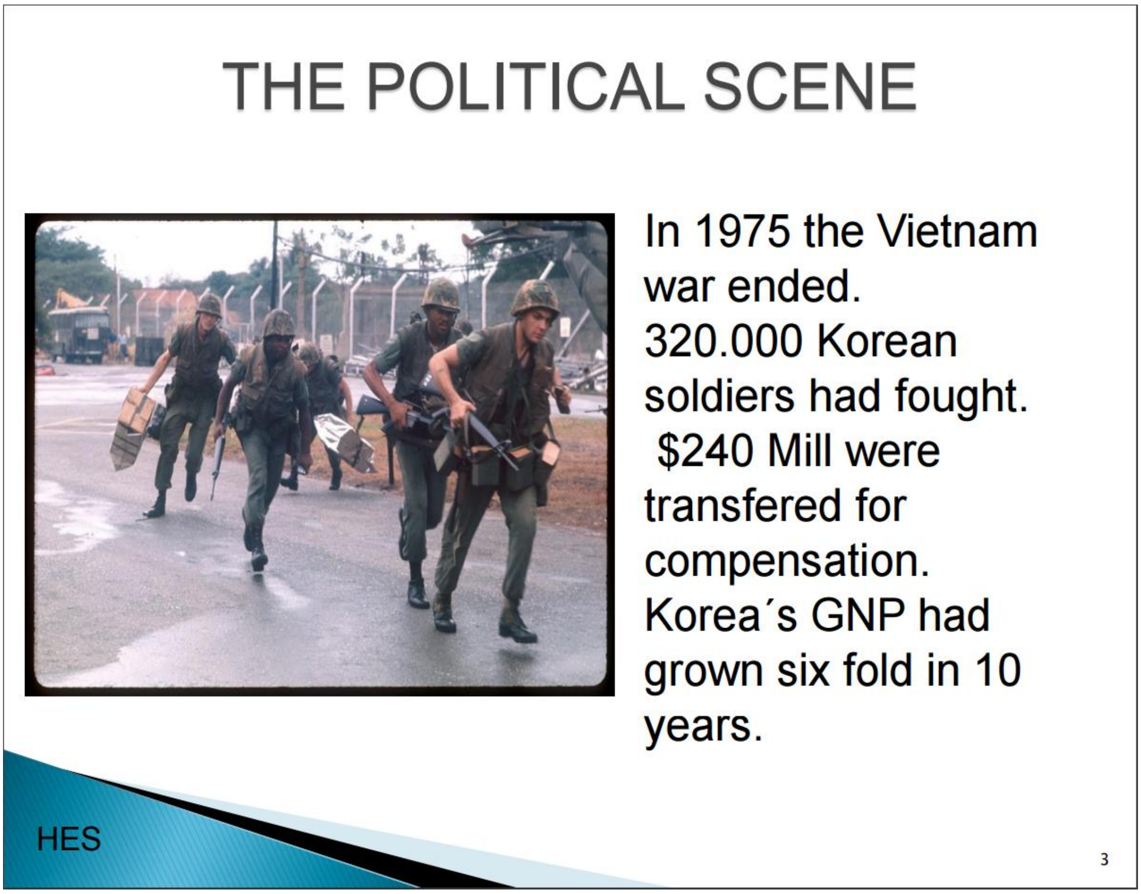


Figure 2. The Political Scene: Korean Economy After the Vietnam War

The Political Scene

The Vietnamese War had ended with the surrender of Saigon in April 1975. 320,000 Korean soldiers had fought there. The US had paid the Korean Government US $240 million for their service. In the meantime, the GNP had grown six fold in ten years (Figure 2).

Park Chung Hee ruled the country from 1961 until his assassination in 1979. His driving impetus behind his leadership was the fear from another invasion by North Korean/Chinese forces and from another domination by a foreign nation. Only an economically strong Korea is able to oppose the hegemonic attempts of neighboring nations or companies. He believed in self-reliance and national power (Figure 3).

Therefore, he started the industrialization of Korea. Under the foreign aid program of the US, Japan (by the pressure from the US), and the EU, roughly US $12 billion was poured into the country between 1945 and 1990. Park Chung Hee established the Economic Planning Board (EPB) and implemented several Five-Year Development Plans. The average growth rate of GDP per period went up to about 10%. Food self-sufficiency was attained. Accelerated development of chemical, machinery, and iron and steel industry (POSCO) was promoted in the Heavy Chemical Industry (HCI) program in 1973. Science and management skills were greatly improved. In 1974, a state of emergency was proclaimed. Night curfew ruled everyday life (Figure 4).

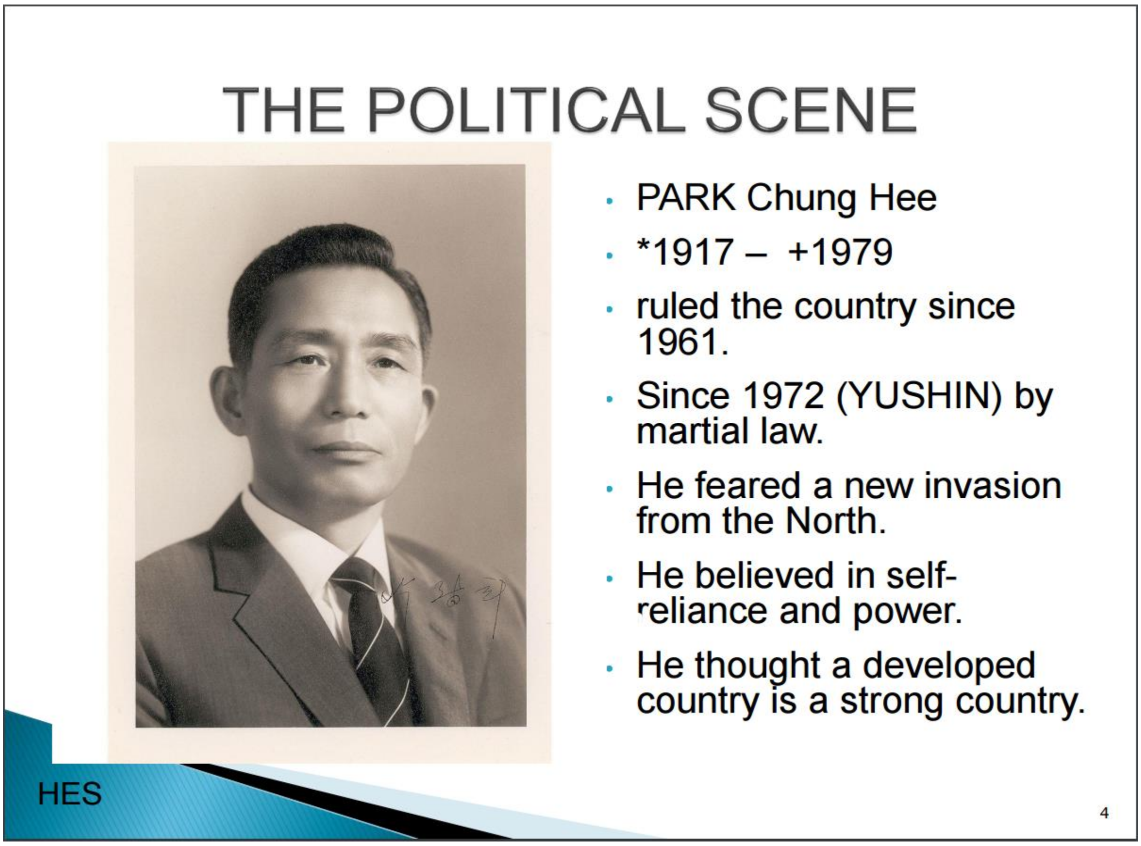


Figure 3. The Political Scene: President Park Chung Hee's Ideals

Figure 4. Political Situation

The Economic Situation

Around 1974, the GNP of the Republic of Korea surpassed that of the People's Republic of Korea, although nearly all natural resources were available to the North only (Figure 5).

Within a time period of 30 years (1965-1995), the GDP per capita was multiplied by a factor of 100 (Figure 6).

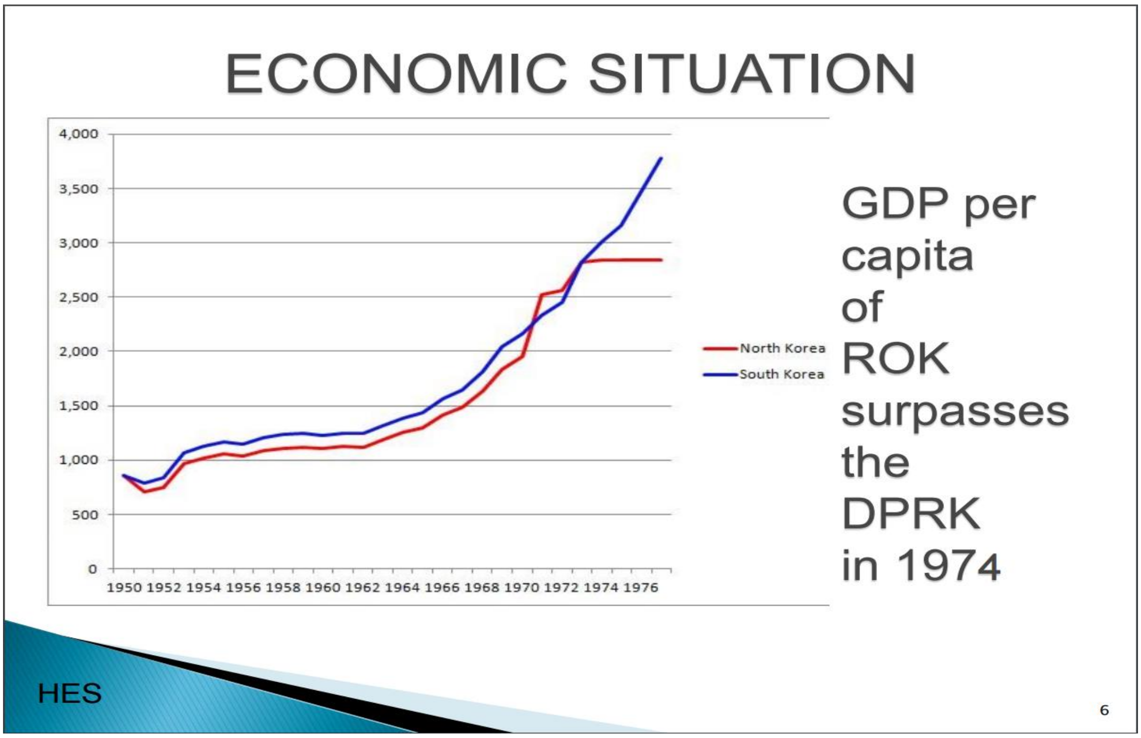


Figure 5. The Economic Situation: Rise in GDP of North and South Koreas

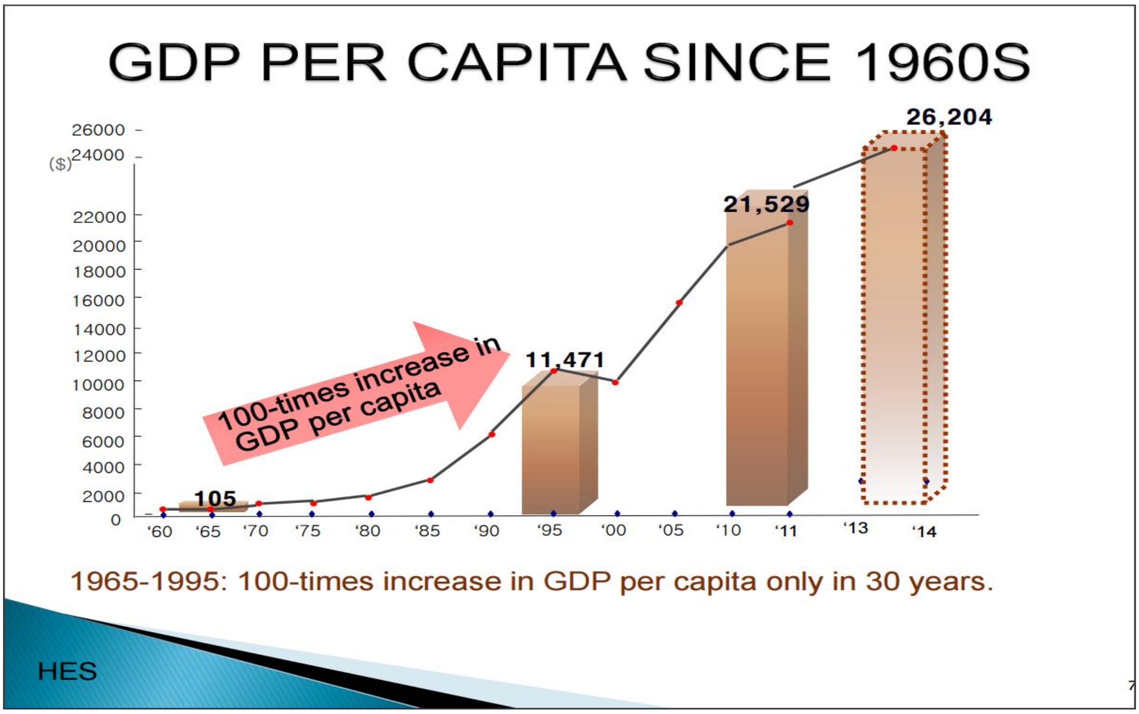


Figure 6. The Economic Situation: GDP Per Capita Since 1960

For historical reasons, the major part of the Korean industry was concentrated in the Seoul-Inchon area, only an hour away from the UN demarcation zone (DMZ) and the North Korean border. The threat from a North Korean invasion was and still is a decisive momentum of Korean politics. Therefore, it was a clear-cut strategic decision to settle modern industrial estates as far away from this endangered area as possible. Pohang, Ulsan, Gumi, Changwon, and Masan were seen as safe areas.

The gap in living standards between rural and urban areas was tremendous. Therefore, Park Chung Hee called for the Saemaul Undong (new village) movement in 1971. This program encouraged farmers to increase their income and achieve a higher amount of crops by using more modern methods and better organization (Figure 7).

The Korean Government and the EPB realized that a modern economy and industrialization were only possible by strengthening science and technology. Therefore, 27 research institutes were founded, most of them in Daedeok (Figure 8).

In 1976, KIMM was born under auspices of the Ministry of Commerce and Industry (MCI). A contract was signed in Fall 1976 between the German and Korean governments. The German contribution included scientific instrumentation, the instruction and training of Korean personnel in Korea and Germany, and the cooperation of a chief consultant to the president over a period of ten years (1976 – 1985). The total amount was 12 million Deutschmarks. The Korean side supplied the construction site, building, and qualified personnel (Figure 9).

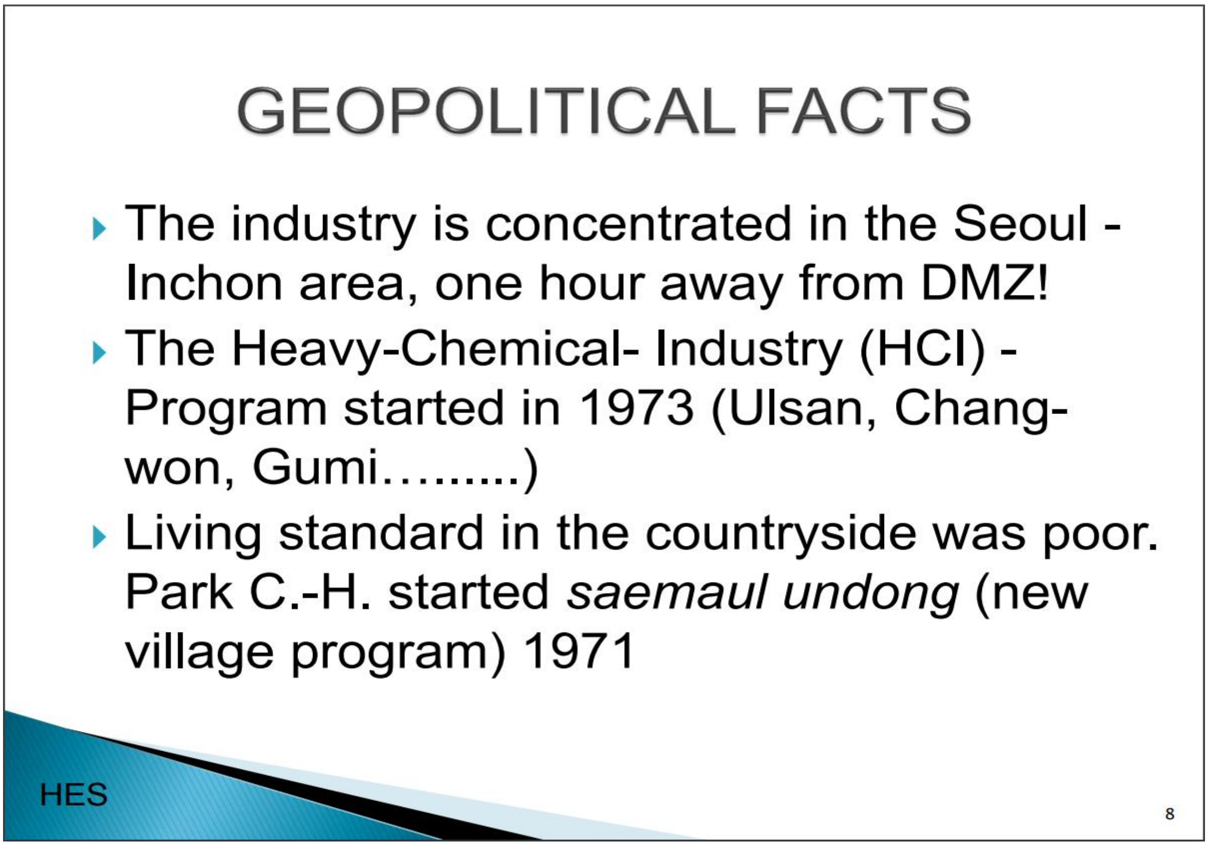


Figure 7. Geopolitical Facts

Figure 8. Revival of Research and Development

Figure 9. The Korean-German Deal

Only recently, I have found out that the Korean-German cooperation is over 100 years old. The Benedictine Congregation St. Ottilien opened a monastery in Seoul in 1913 and offered vocational training to young and underprivileged Koreans to become carpenters, blacksmiths, or farmer´s helpers (Figure 10 (a)). Instructions to Korean students were given in 1925 by the Benedict missionaries (Figure 10 (b)).

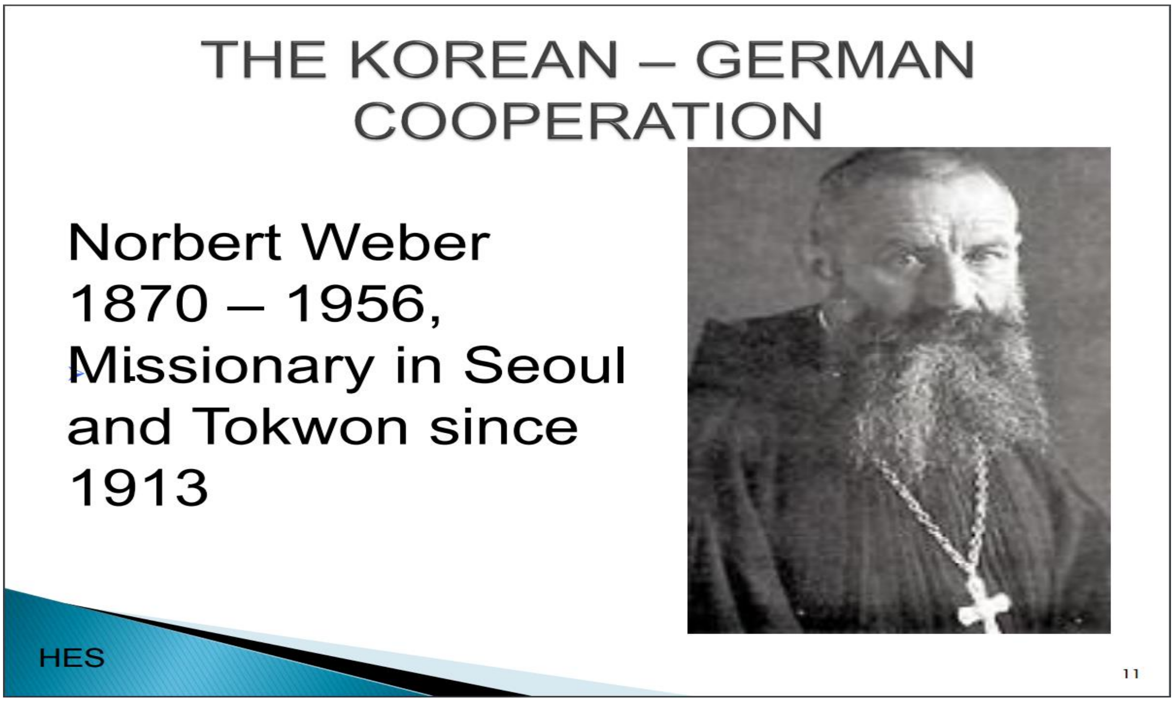


Figure 10 (a). The Korean – German Cooperation: Norbert Weber

Figure 10 (b). The Korean – German Cooperation: Vocational Training in 1925

Our mission in 1977 was to establish a machinery and metal testing institute. Its purpose was to enable the newly allocated industries around the Changwon and Masan area to cope with international standards and quality levels. Local industries should use KIMM´s services to establish and implement quality-enhancing processes in production. This should foster and increase their share in the international market (Figure 11).

Prof. Cho Sun Wi from SNU was the first vice president of KIMM. He was educated in Germany and, therefore, an ideal partner to implement the project (Figure 12).

Figure 11. Mission of KIMM

Figure 12. KIMM's First vice President Prof. Cho Sun Whi

KIMM opened its first offices in Yoido in 1977. Across the Han River, twenty-storied apartment houses were built. The “Miracle of the Han River” began. The GDP per capita passed the US $1,500 mark! The groundbreaking took place in Changwon in 1977, and rapid progress was achieved (Figures 13 - 14).

Gen. Lee Chun Hwa became the second president (Figure 15).

Figure 13. Initial Phase of KIMM

Figure 14 (a). Construction of KIMM: Advertising

Figure 14 (b). Construction of KIMM: Groundbreaking

Figure 14 (c). Construction of KIMM: People in Charge

Figure 14 (d). Construction of KIMM: Progress

Figure 14 (e). Construction of KIMM: Progress

Figure 14 (f). Construction of KIMM: Progress

Figure 15. Gen. Lee and Lee Han Hoon

Beside him, you see Lee Han Hoon, an engineer fluent in German and, therefore, another key figure in realizing our project. Soon the main buildings were visible (Figure 16 (a)). The main building was completed as early as 1979. A commemorating plaque was mounted in the entrance hall (Figure 16 (b)).

Figure 16 (a). Completion: the Main Building

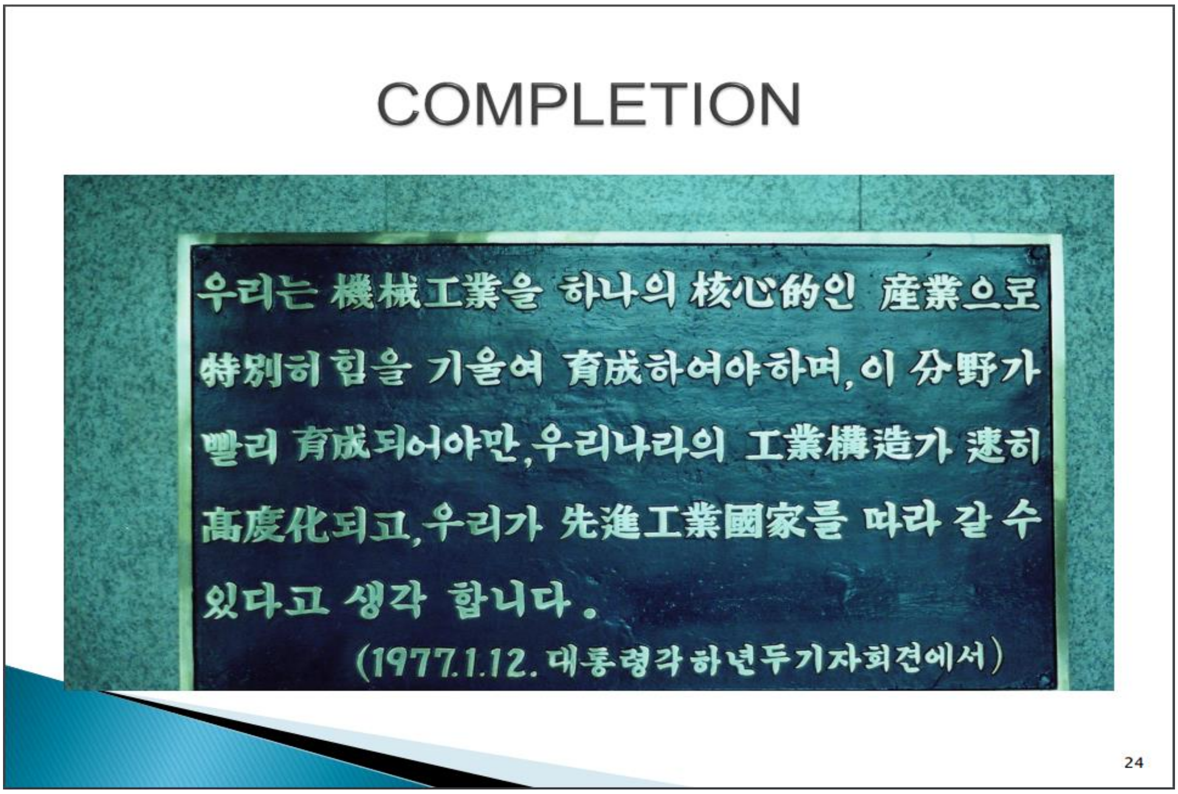


Figure 16 (b). Completion: Commemorating Plaque

The inauguration ceremony was held in the presence of Dr. Leuteritz, the German ambassador to Korea at that time (Figure 17).

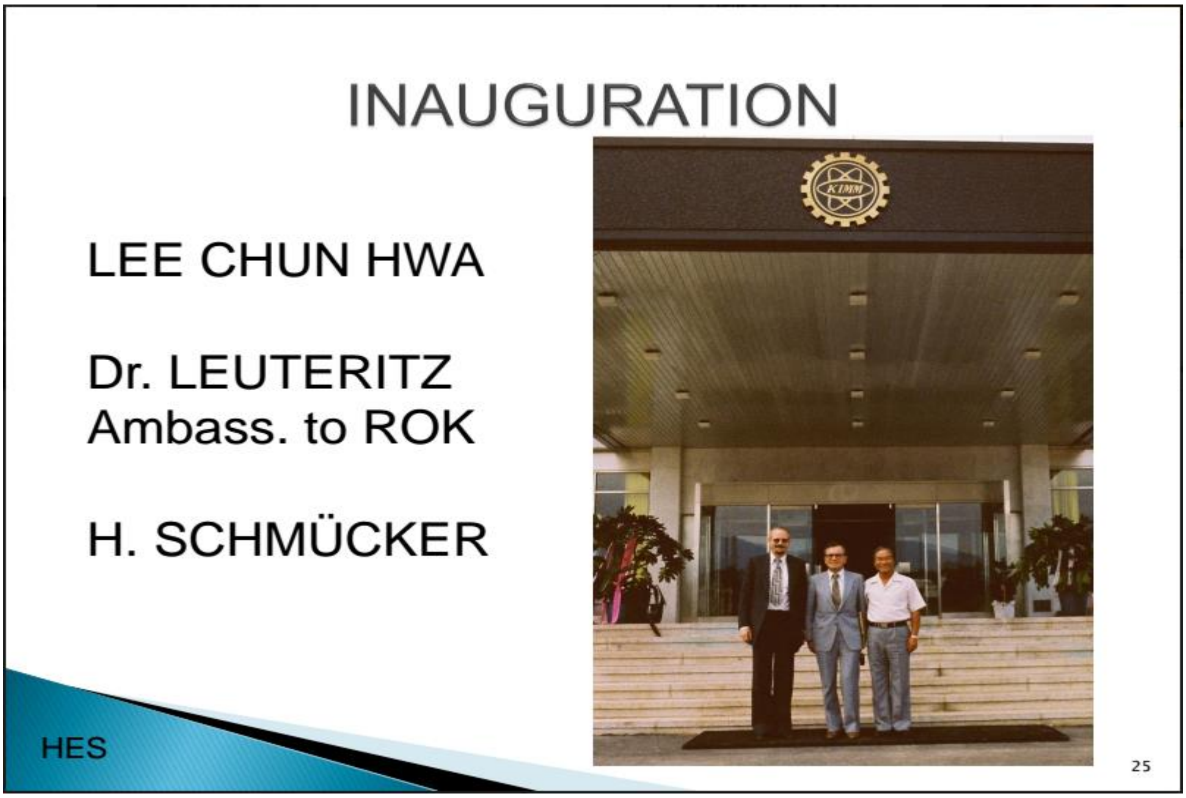


Figure 17 (a). Inauguration of KIMM

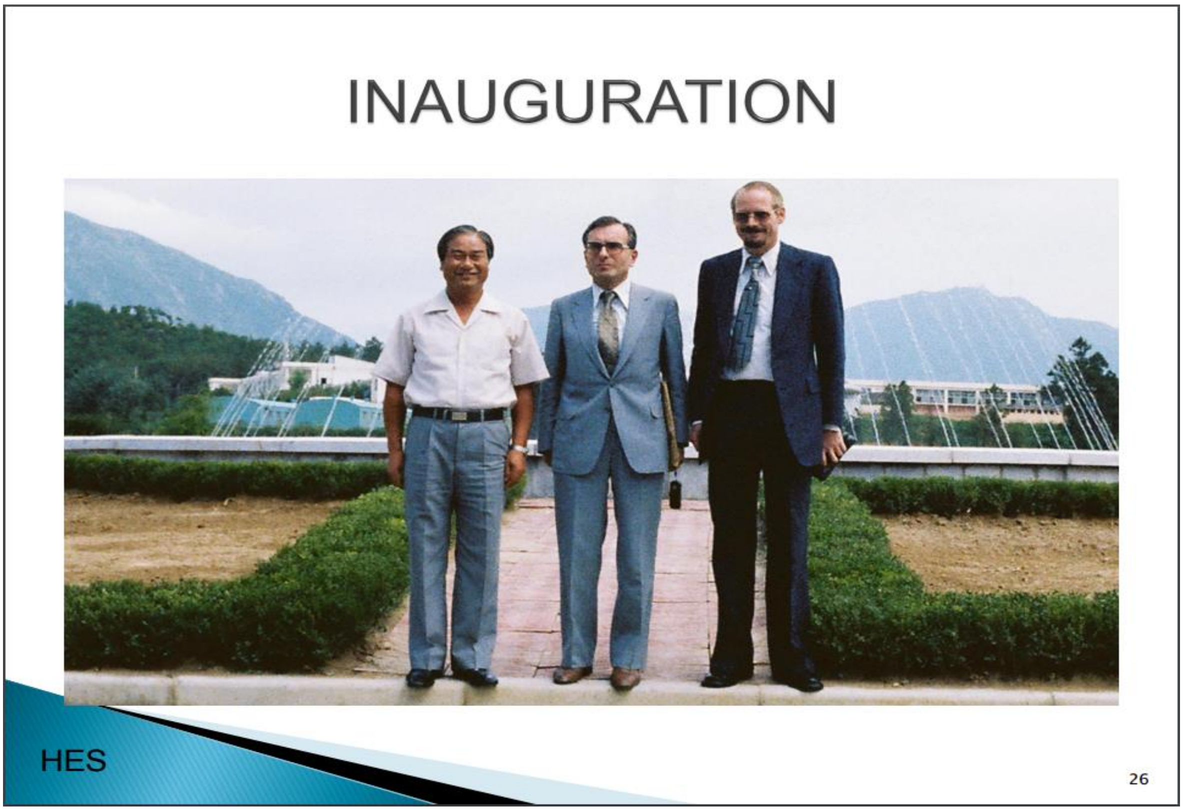


Figure 17 (b). Inauguration of KIMM

A replica of the Emile Bell (National Treasure of Korea No. 29) was placed in the entrance hall of the main building. This outstanding example of Korean craftsmanship in the 8th century encouraged our activities (Figure 18).

Figure 18 (a) KIMM's Emile Bell: Actual Bell

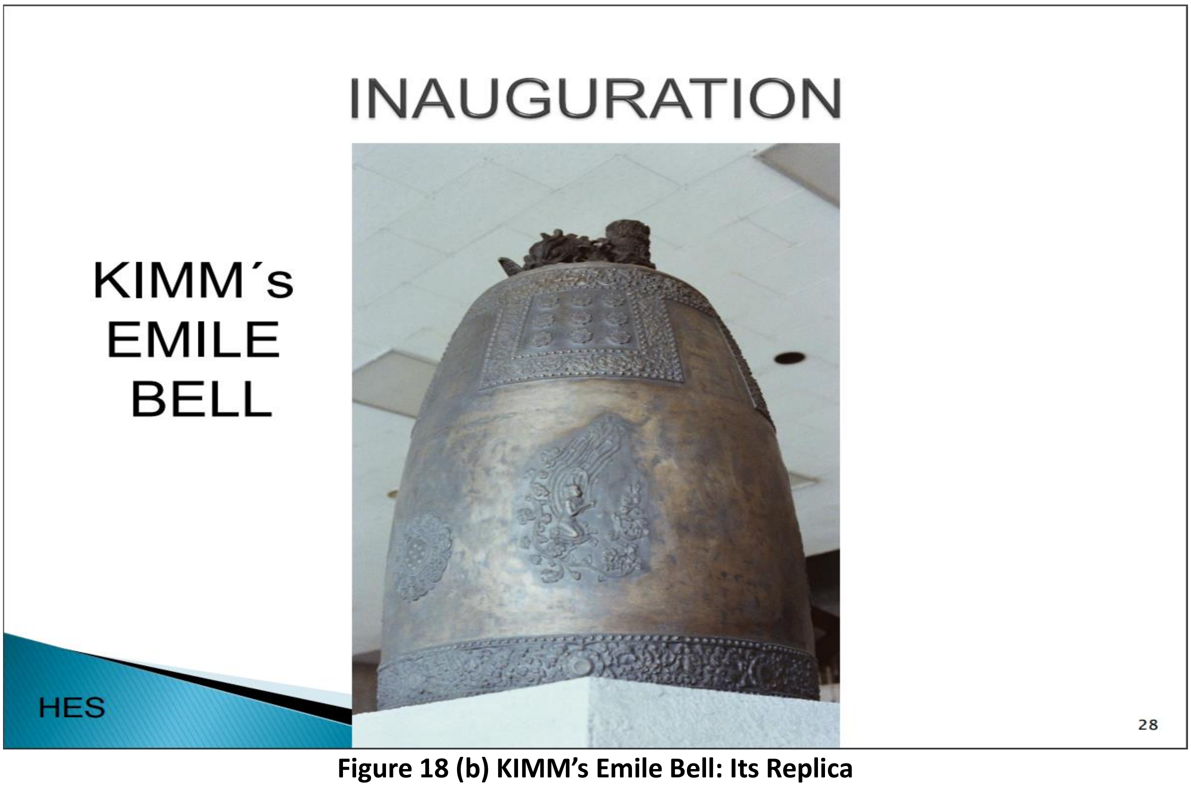


Figure 18 (b) KIMM's Emile Bell: Its Replica

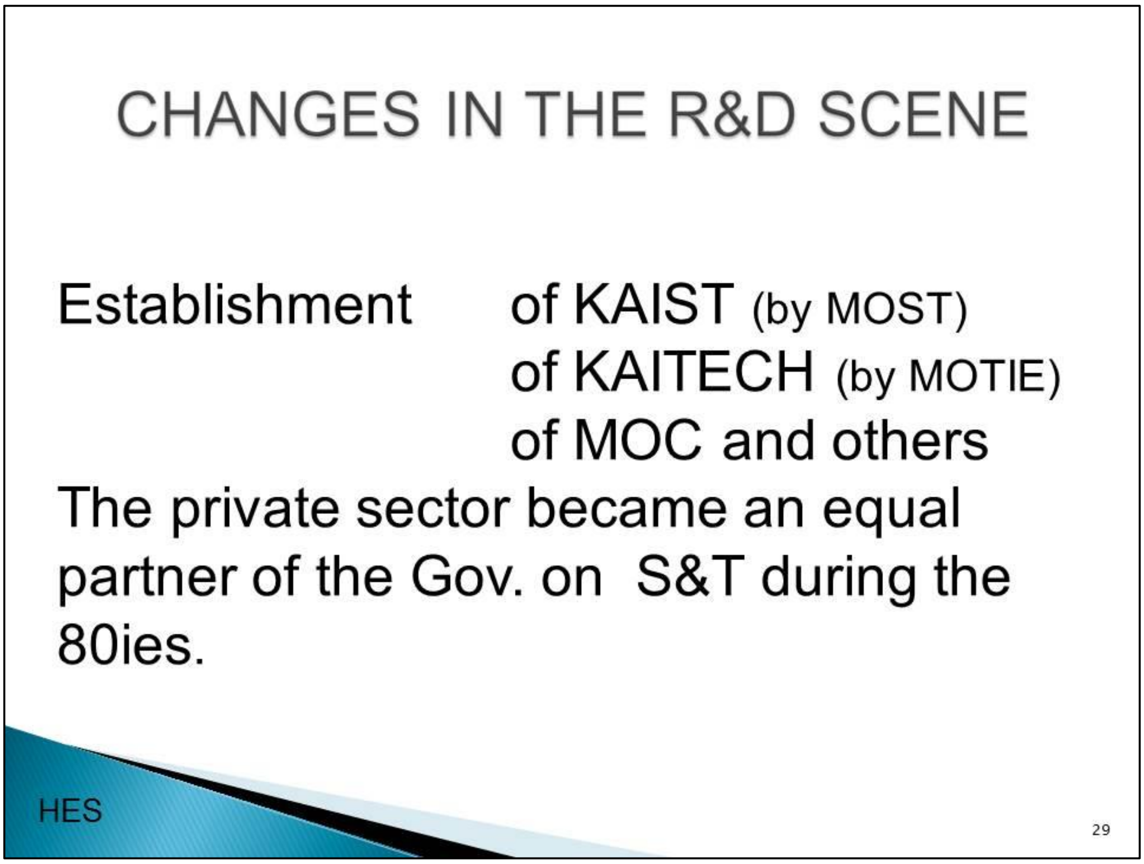


Figure 19. Changes in the R&D Scene: Establishments

Changes in the R&D Scene

To enhance and foster R&D further, the government established institutions like KAIST (by MOST), KITECH (by MOTIE), MOC, and others. Private companies also realized that they had to become independent of foreign technology. Therefore, they established their own R&D facilities and soon grew up to be mature partners for the government R&D funding during the 80's (Figure 19).

Enterprises understood very quickly that in the long run they had to invest in R&D to compete with the development of the world market and to successfully gain market shares. In 1980, only 321 companies had R&D capabilities. In 1988, 1,600 companies were proud of their R&D units or even had their own institutes (674). The companies became independent of foreign technology suppliers. The R&D government spending went up four times to US $1.66 billion, while the spending of the private sector went up nineteen times to US $28 billion (Figure 20).

The *chaebols* matured, and the private sector began to take the lead. The obvious competition between MOST and MOTIE unfortunately cut efficiency and resources. In the meantime, the companies had sufficient earnings to expand their R&D divisions. The government responded by establishing Korea Industrial Research Institute (KIRI) in 1979 (Figure 21).

The financial effort by the Government Expenditure on R&D (GERD) rose from 0.25% of GDP in 1963 to 3.5% of GDP in 2007. In 2008, it was US $90 billion (Figure 22).

In 2007, nearly 10 out of 1000 people in the labor force were engaged in R&D (Figure 23).

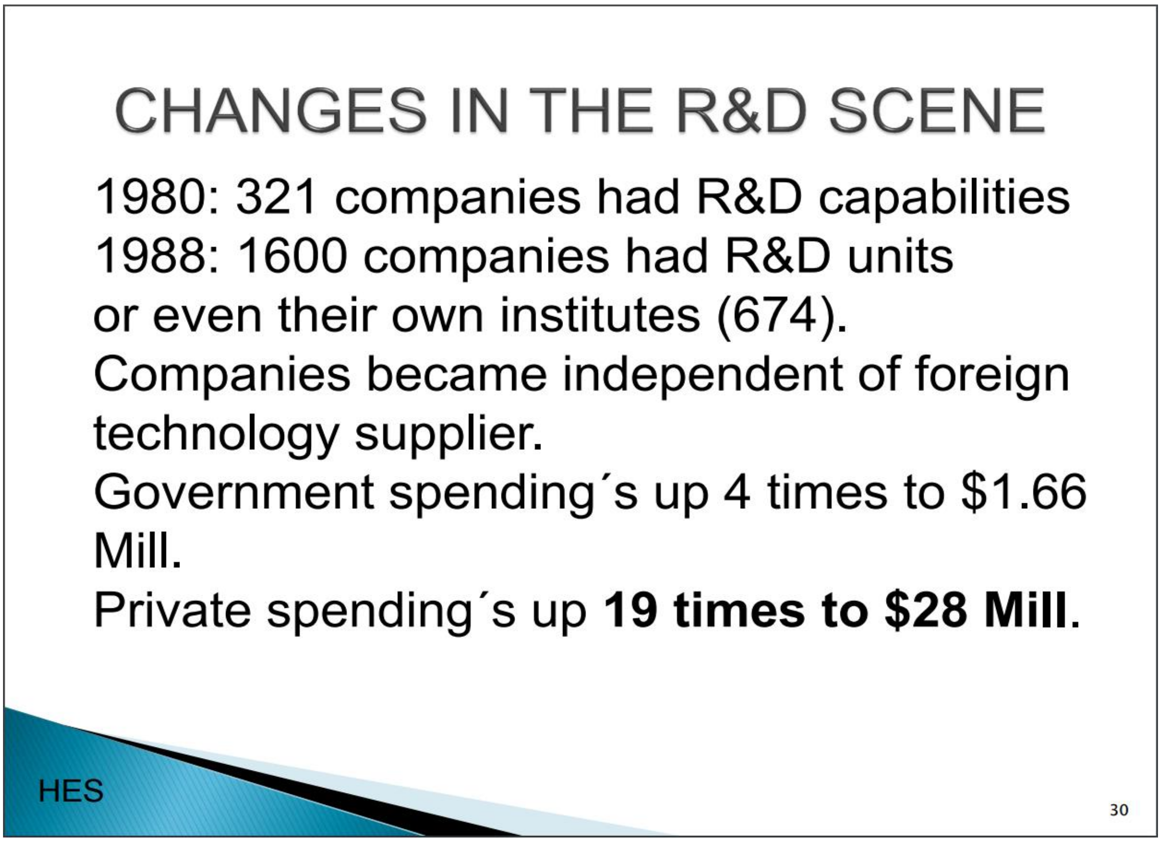


Figure 20. Changes in the R&D Scene: R&D Capabilities and Spending

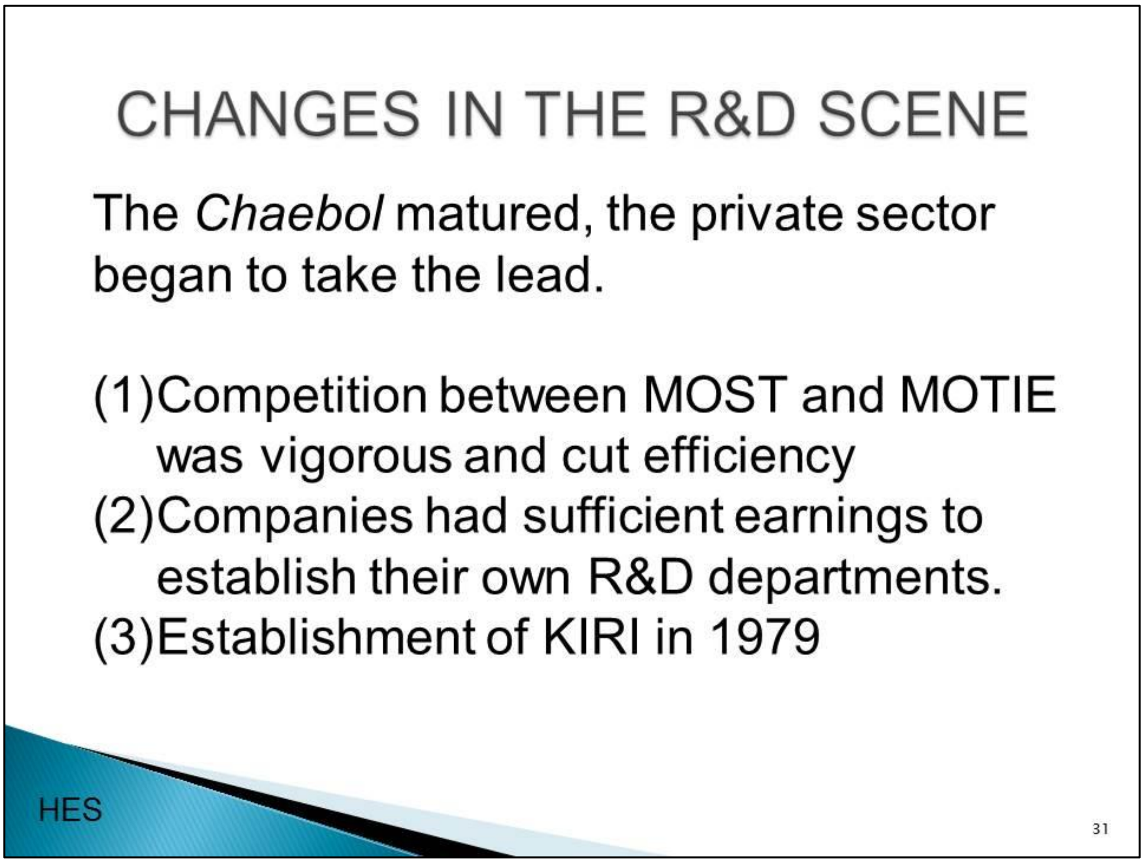


Figure 21. Changes in the R&D Scene: *Chaebol*

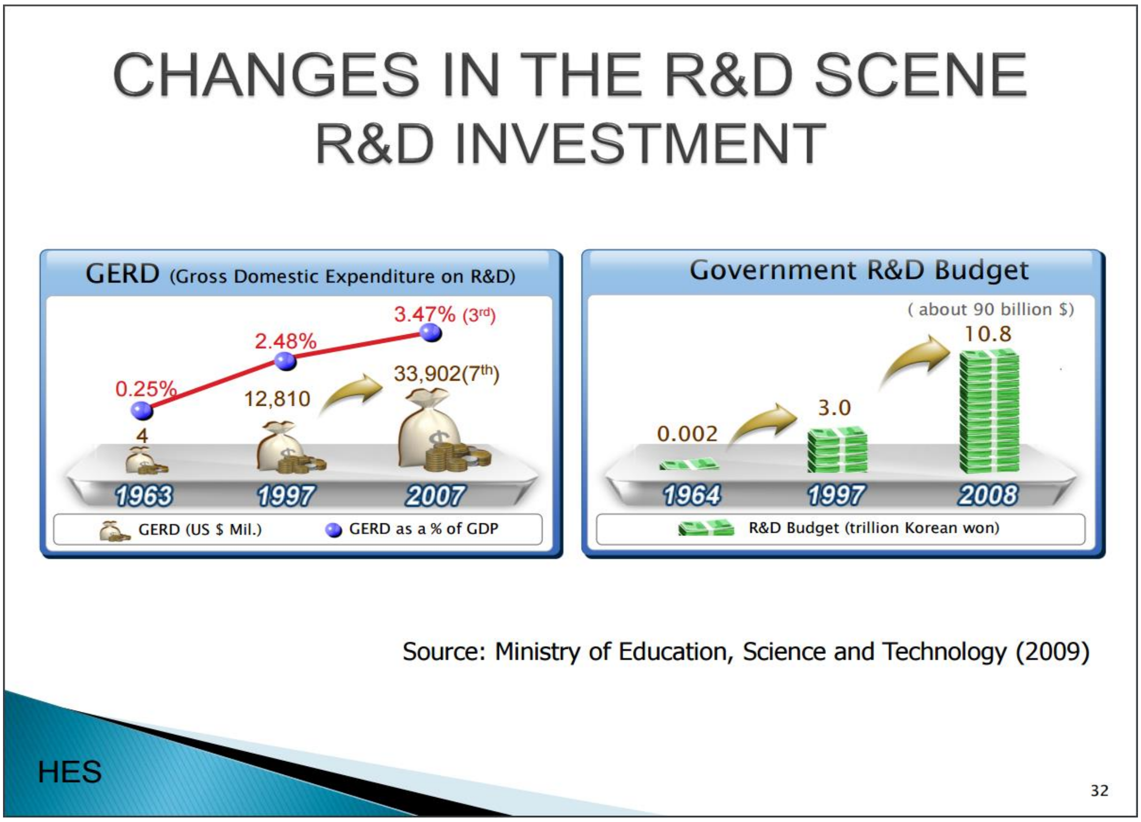


Figure 22. Changes in the R&D scene: R&D Investment

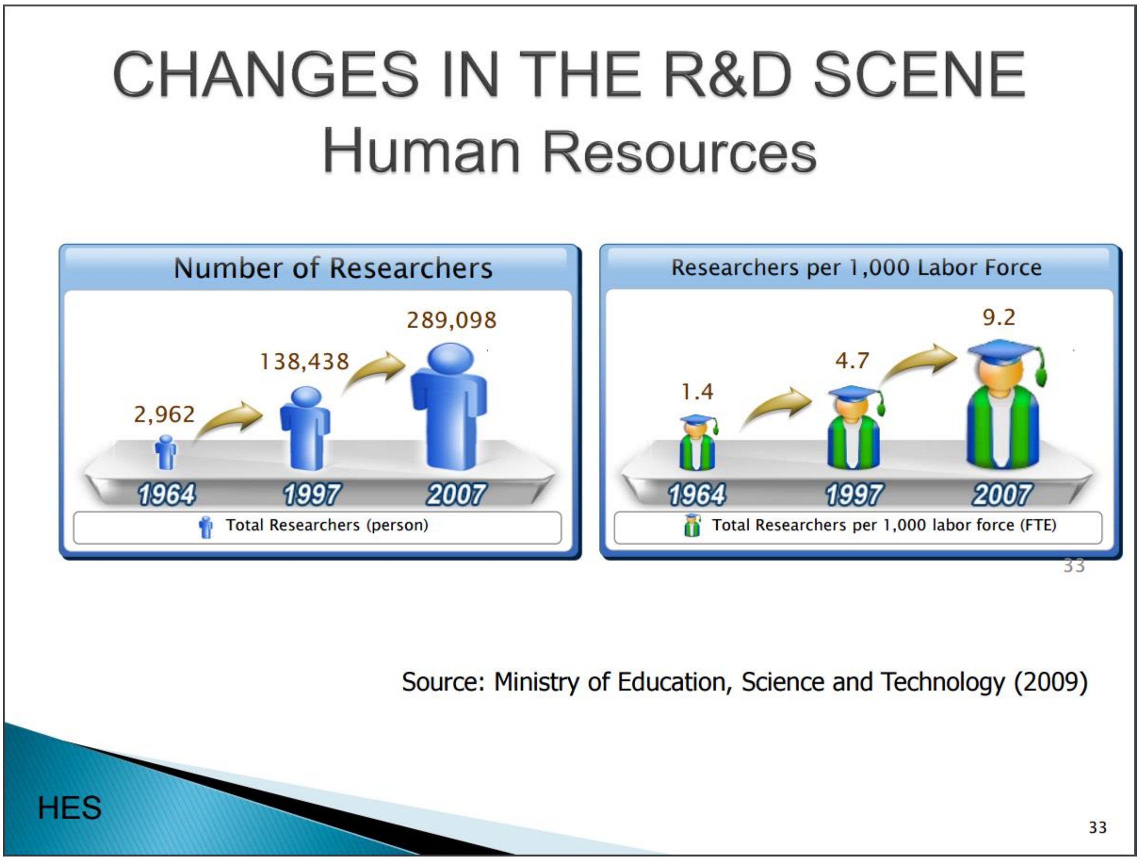


Figure 23. Changes in the R&D Scene: Human Resources

Let's look at three strategic fields that the government and the industry considered to be vital for Korea.

(1) The TDX digital switching telephone exchange development was a joint project of the Ministry of Communications. The partners were KTC, SEC, GSS Gold Star, and DTC Daewoo Telecom. This joint effort was extremely successful and provided the country with the most advanced telecommunication system in the world (Figure 24).

Figure 24 (a). TDX Project: Overview

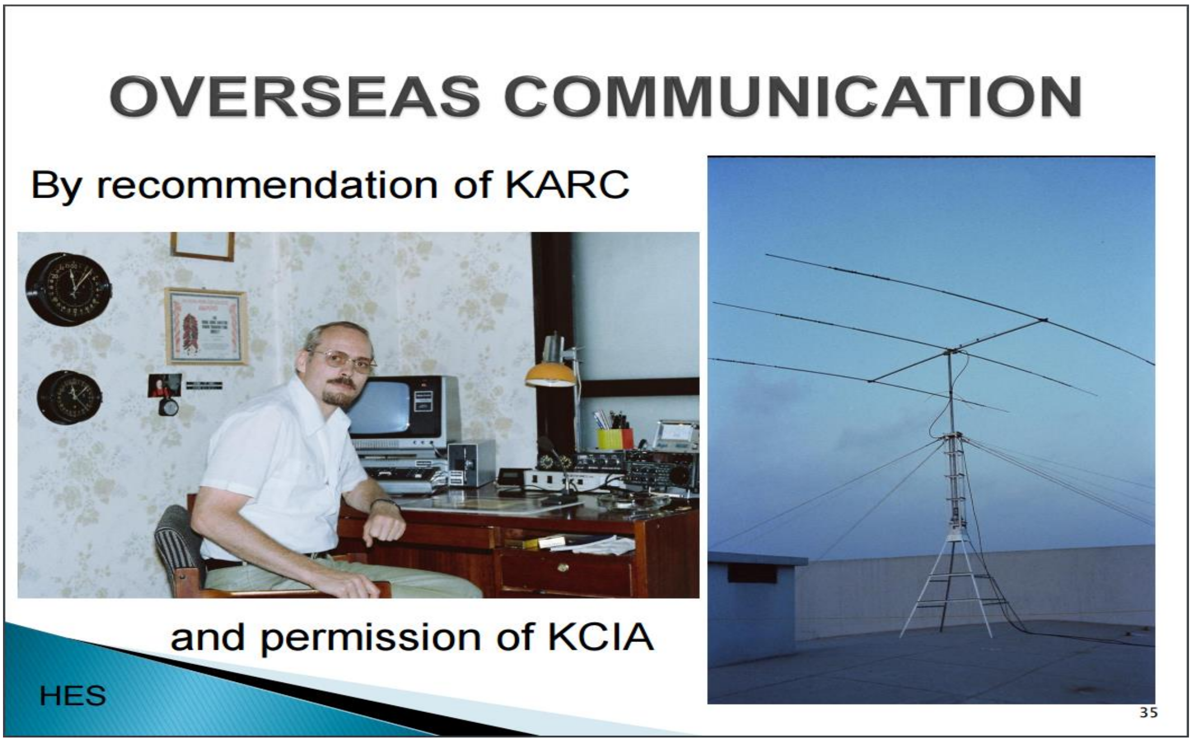


Figure 24 (b). TDX Project: Overseas Communication

(2) Another vital sector to be developed was computers.

MOC, MOST, and MOTIE with KITECH, KIET (Gumi), ETRI, EIAK, and KCRA on the public side were joined by GSS, SEC, OTC, Cheil, Taihan, TriGem, and HEI on the private side. The lack of locally produced IC´s made domestic sales very disappointing. By 1986, IBM lost the exclusive patent rights of the 32-bit model. Nevertheless, the TICOM-1 was only a limited success. Today, as we all know, nearly all computers worldwide are made in Taiwan and China (Figure 25).

(3) The third important field for the development of the country was semiconductors. From the government side, loans and guidance were extended by MOTIE, MOC, MOST, and ETRI to potential industries like SAMSUNG, LG, GSS, HEI, and DTC (Figure 26).

Figure 25. S&T Policy and Results: Computers

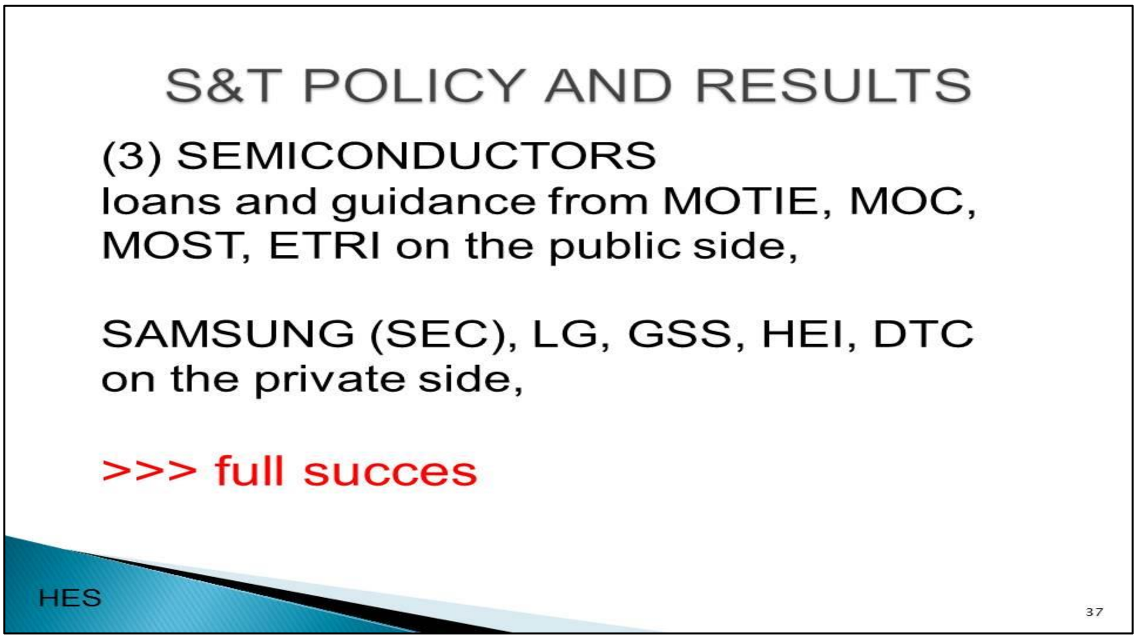
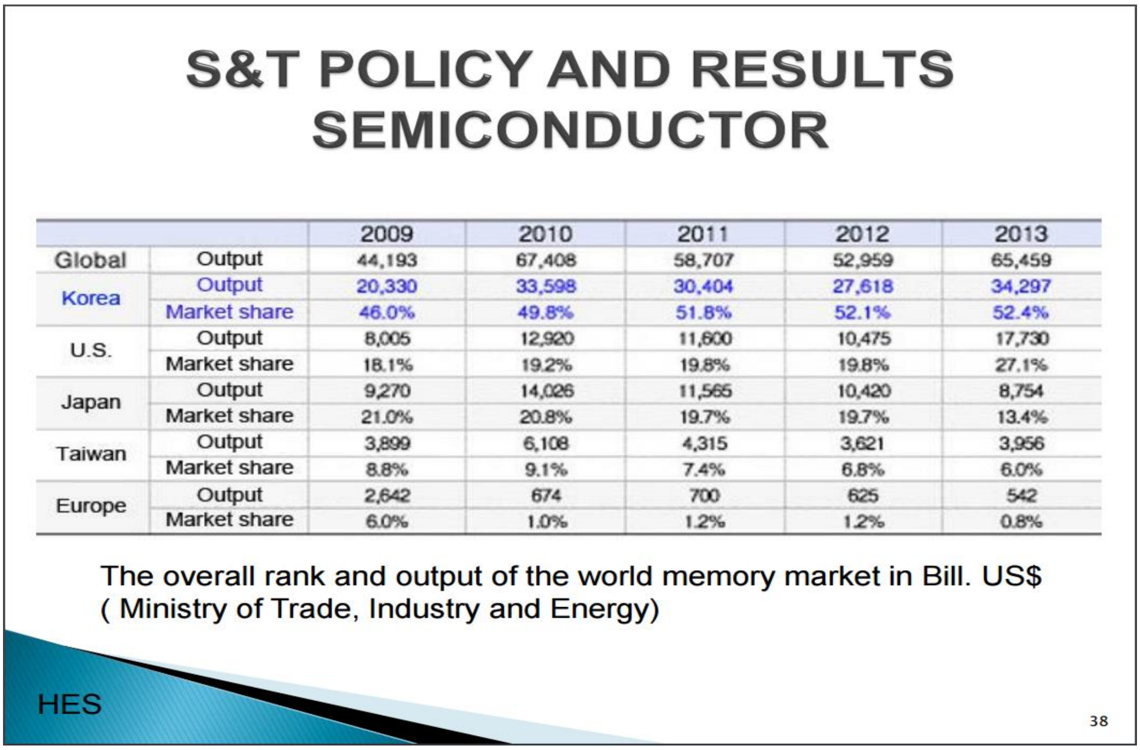


Figure 26. S&T Policy and Results

The success was overwhelming. In 2013, the worldwide market share of the Korean semiconductors was more than 53% (Figure 27).

Comparison of R&D performance with other advanced industrial countries showed gaining competitiveness in science as well as technology according to the International Institute for Management Development in Switzerland (Figure 28).



S&T POLICY AND RESULTS SEMICONDUCTOR

		2009	2010	2011	2012	2013
Global	Output	44,193	67,408	58,707	52,959	65,459
Korea	Output	20,330	33,598	30,404	27,618	34,297
	Market share	46.0%	49.8%	51.8%	52.1%	52.4%
U.S.	Output	8,005	12,920	11,600	10,475	17,730
	Market share	18.1%	19.2%	19.8%	19.8%	27.1%
Japan	Output	9,270	14,026	11,565	10,420	8,754
	Market share	21.0%	20.8%	19.7%	19.7%	13.4%
Taiwan	Output	3,899	6,108	4,315	3,621	3,956
	Market share	8.8%	9.1%	7.4%	6.8%	6.0%
Europe	Output	2,642	674	700	625	542
	Market share	6.0%	1.0%	1.2%	1.2%	0.8%

The overall rank and output of the world memory market in Bill. US$ (Ministry of Trade, Industry and Energy)

HES

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Figure 27. S&T Policy and Results – Semiconductor

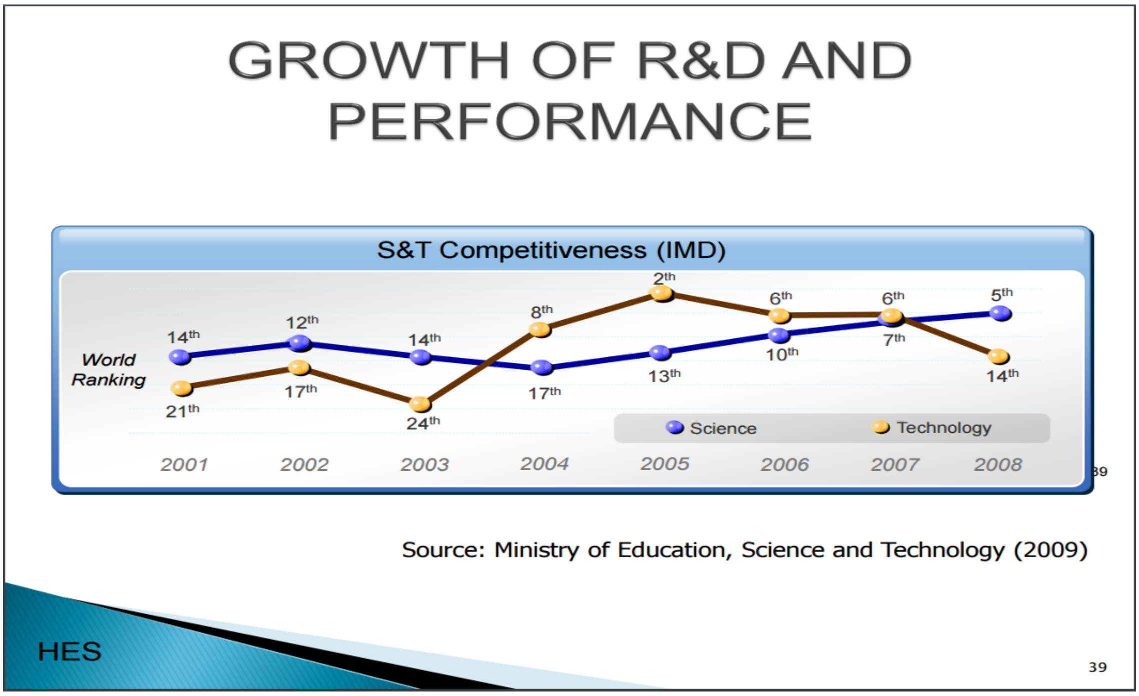

Figure 28. Growth of R&D and Performance

Threats to Growth

The extraordinary growth of the economy in terms of GDP (US $30,000 in 2016) and the export volume of industrial goods caused Korea to be the fifth largest exporter in the world in 2014. The annual growth rate reached 9.5%. Integrated circuits, refined petroleum, and cars accounted for 10%, 8%, and 8%, respectively. This is the past. We have to look to the future (Figure 29).

The growth rate of GNP per capita, as in many industrial countries, is levelling off (Figure 30).

Figure 29. Threats to Growth: Overview

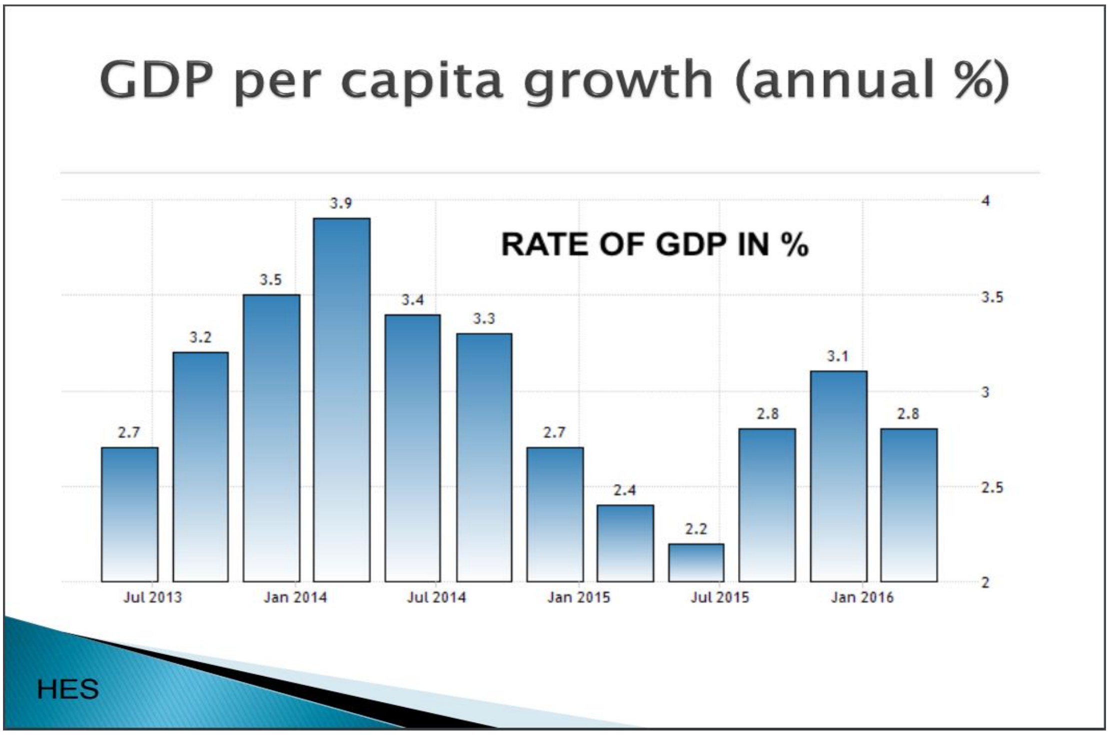

Figure 30. GDP Per Capita Growth (Annual %)

The following factors might limit further growth: (1) available manpower/labor force, (2) structure and competition, (3) energy / resources, and (4) political issues.

(1) *Manpower*

The growth rate of the Korean population decreased to less than 0.4%, which is not an unusual figure for a highly industrialized country. The fertility rate (births per woman) came down to 1.2 in 2016. The outlook on the work force compared to the total population will only yield 49% in 2050, while the total population will diminish to about 45 million (Figures 31 - 33).

A compensation of this decreasing labor force is hardly feasible. The immigration inflow accounts for 67,000 persons per year, and this figure is negligible! Korea cannot increase its labor force by just opening its boundaries. Germany did so in the 60's (Italy, Greece, Spain, and Yugoslavia) and in the 80's (Turkey). This inflow kept wages down. Non-profitable enterprises survived, and the productivity remained on the same level or even decreased. It is not advisable to follow this path.

Korea has a very homogeneous population, so the integration of foreign ethnic groups is difficult or even impossible (Figure 34).

A severe threat is youth unemployment. Although Korea's rate is still moderate and below the OECD average. The rate is more than 11%. This indicates a dangerous development. In Europe, we find youth unemployment rates up to 45% in Mediterranean countries. The reasons are simple and well known, but no appropriate actions are taken. The current education does not meet industrial and administrative requirements (Figures 35 and 36).

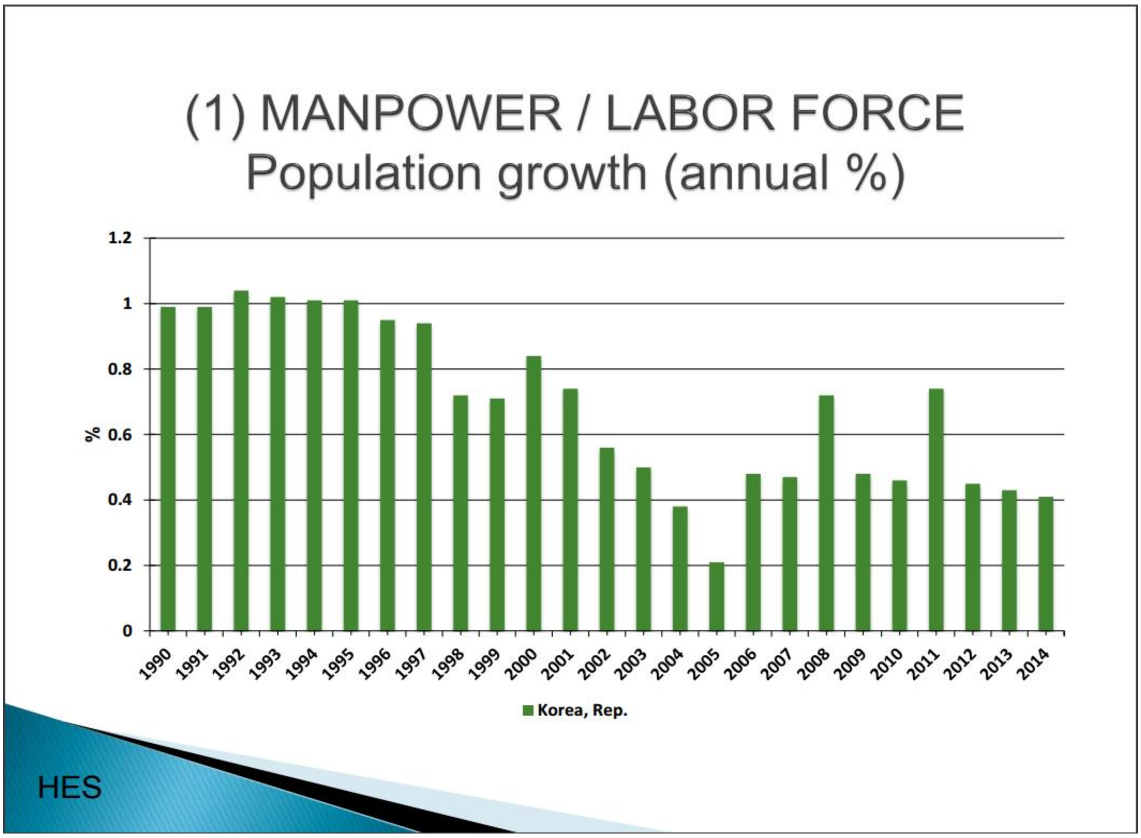

Figure 31. Manpower/Labor Force: Population Growth

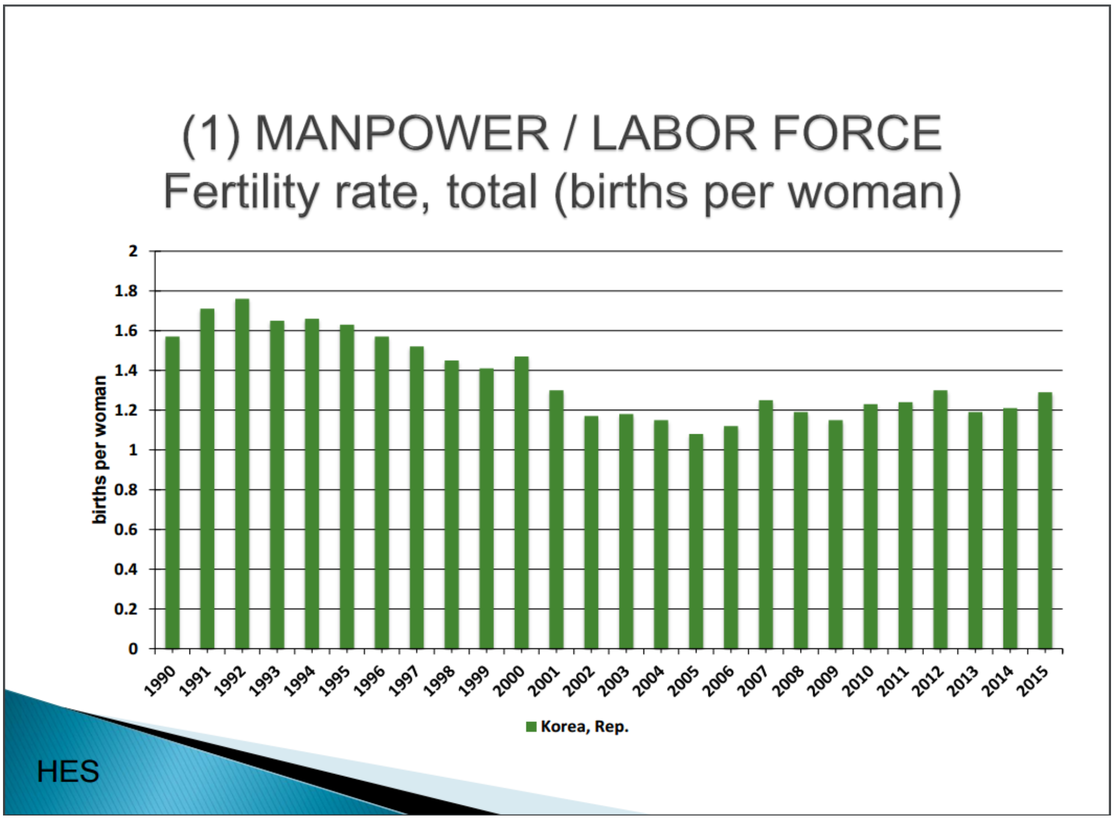

Figure 32. Manpower/Labor Force: Fertility Rate

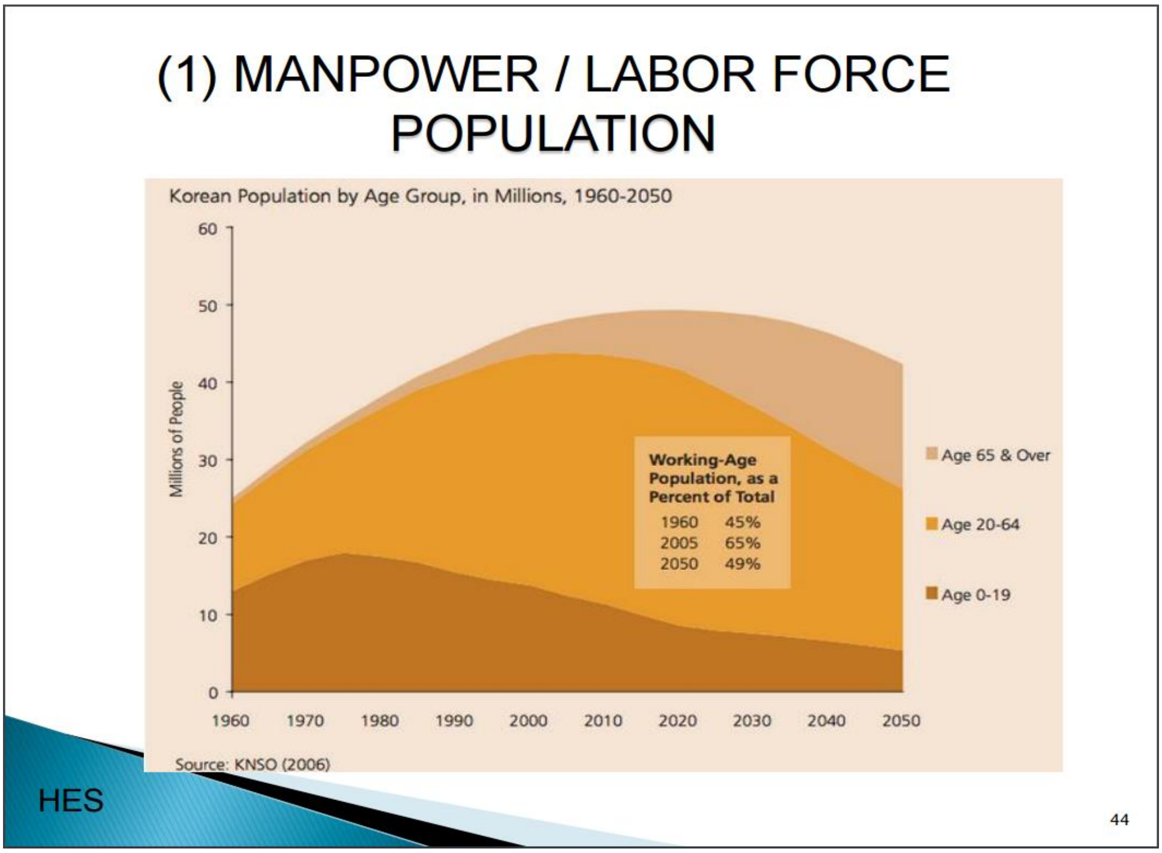

Figure 33. Manpower/Labor Force: Population

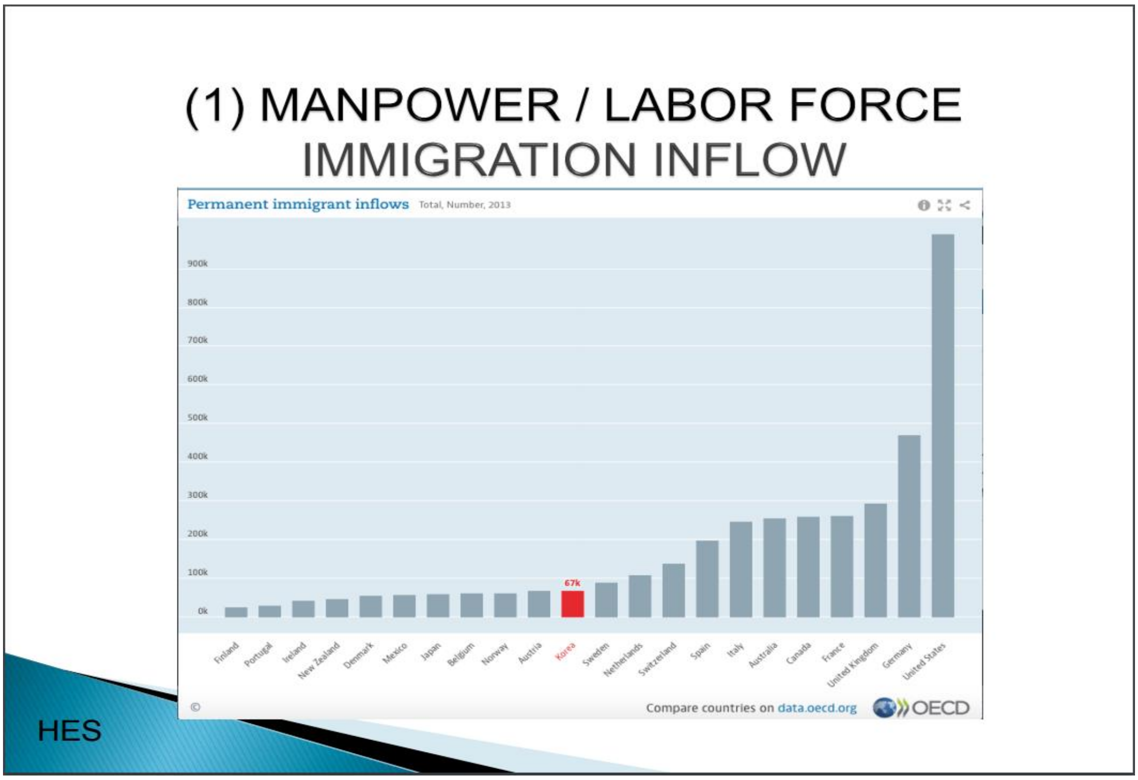

Figure 34. Manpower/Labor Force: Immigration Flow (Korea in red)

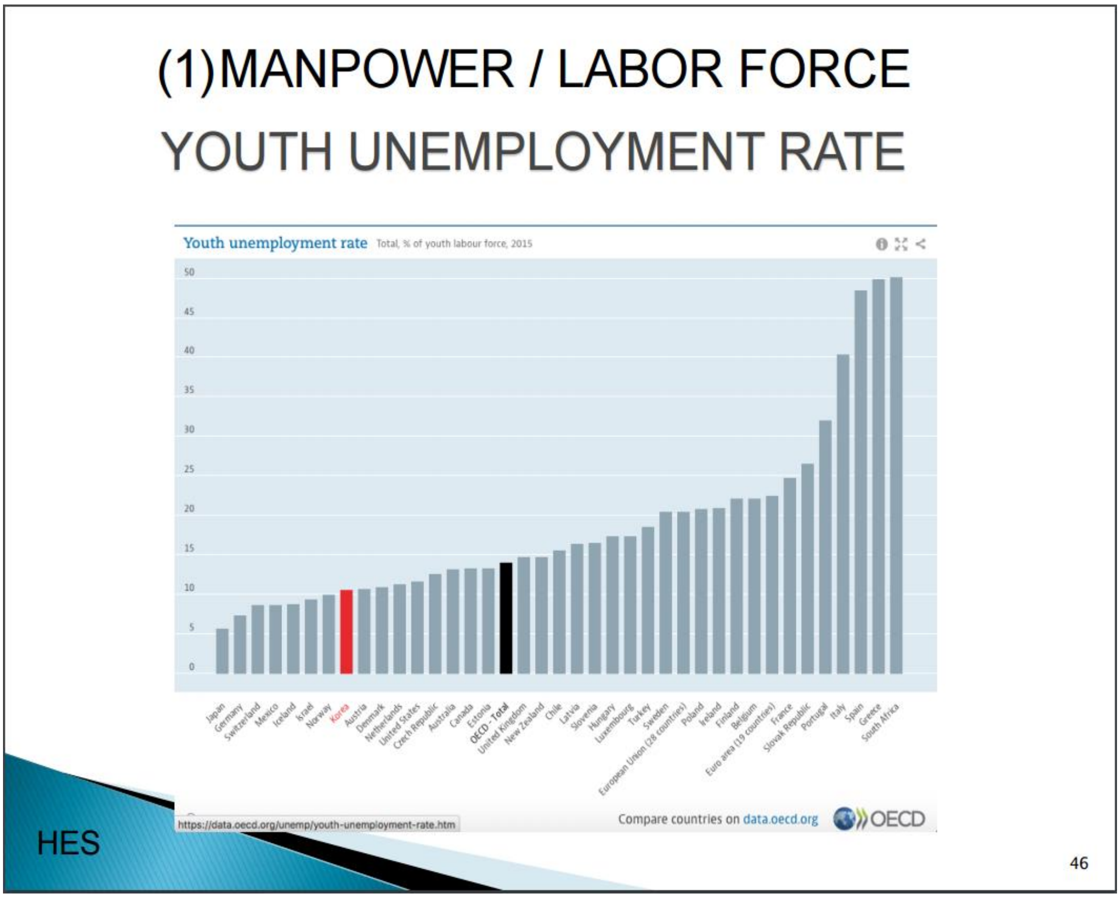

Figure 35. Manpower/Labor Force: Youth Unemployment Rate (Korea in red)

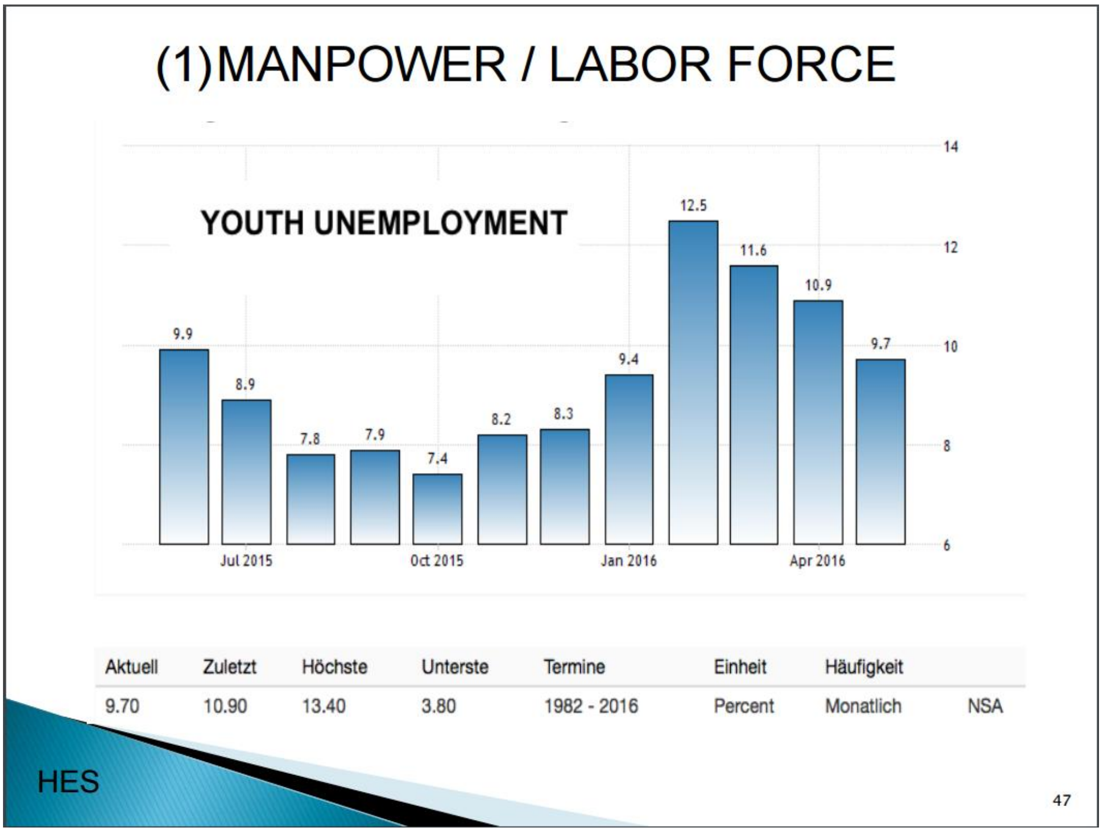

Figure 36. Manpower/Labor Force: Youth Unemployment Rates in 2015 and 2016

A rather unique problem is the expenditure on education. There are not many countries where education is sought after by all social classes as much as Korea, even though education is very expensive on all levels. The spending on higher education requires 164% of net disposable income, well above the OECD average of 133% (Figure 37).
Therefore, the OECD proposes two measures: restructuring their depth by market-based credits and having prudential measures for financial institutions to improve mortgage lending (Figures 38 and 39).

On top of the decreasing labor force, the interest of young people in studying science and engineering has decreased. We all know that value-adding progresses are realized only by strong, diligent technicians and engineering manpower (Figure 40).

Let’s summarize:

1) Two thirds of young Koreans have a university degree

2) Many are overqualified and therefore underpaid

3) 12% of young people are jobless

4) Skilled labor force is diminishing because of its low social status (Figure 41)

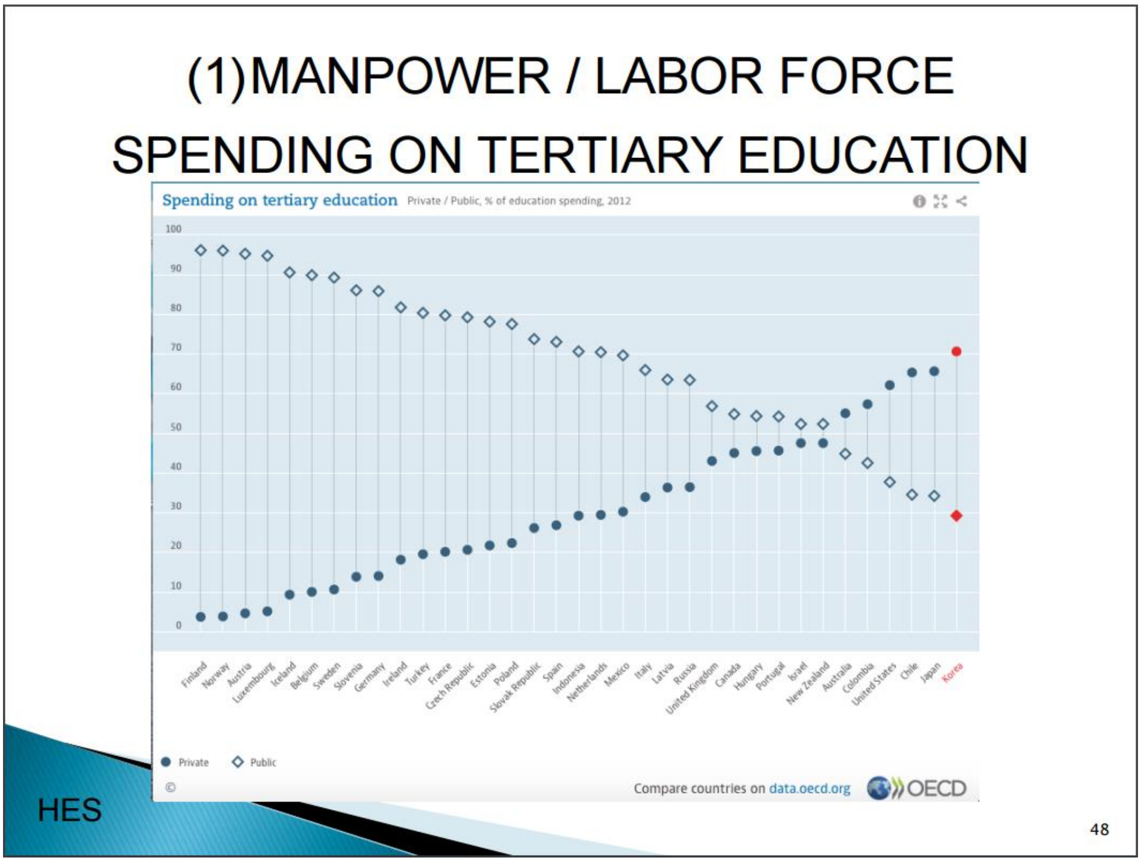

Figure 37. Manpower/Labor Force: Spending on Tertiary Education (Korea in red)

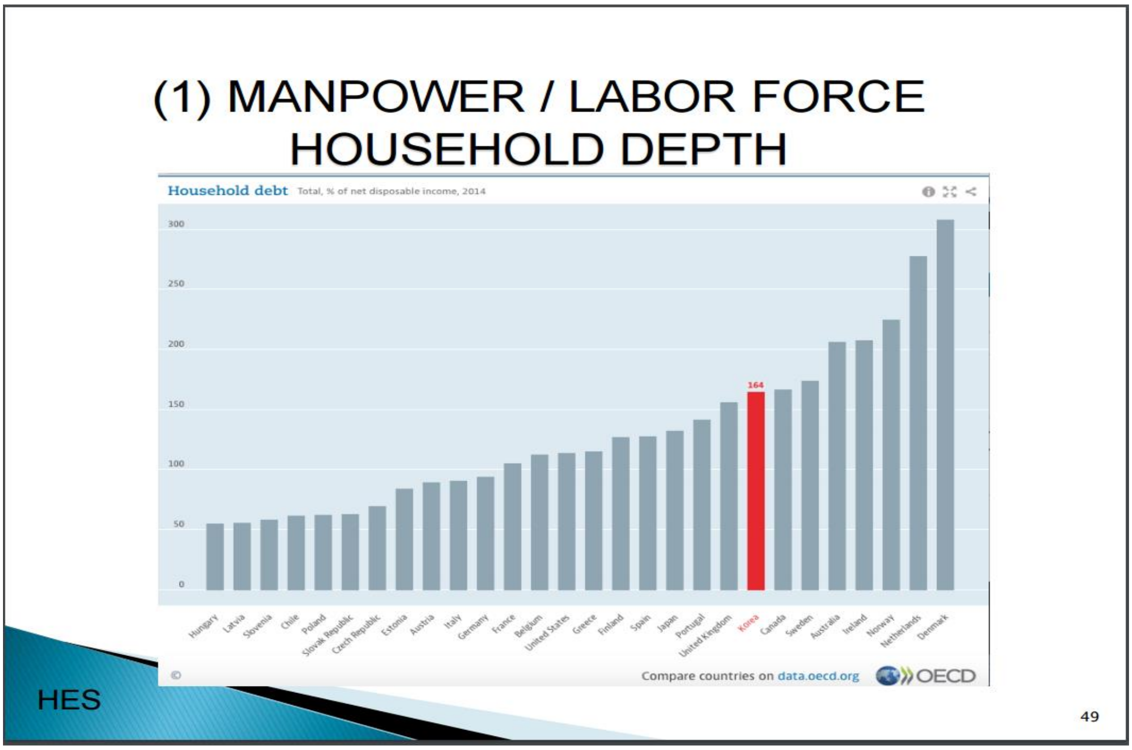

Figure 38. Manpower/Labor Force: Household Debt of Various Countries

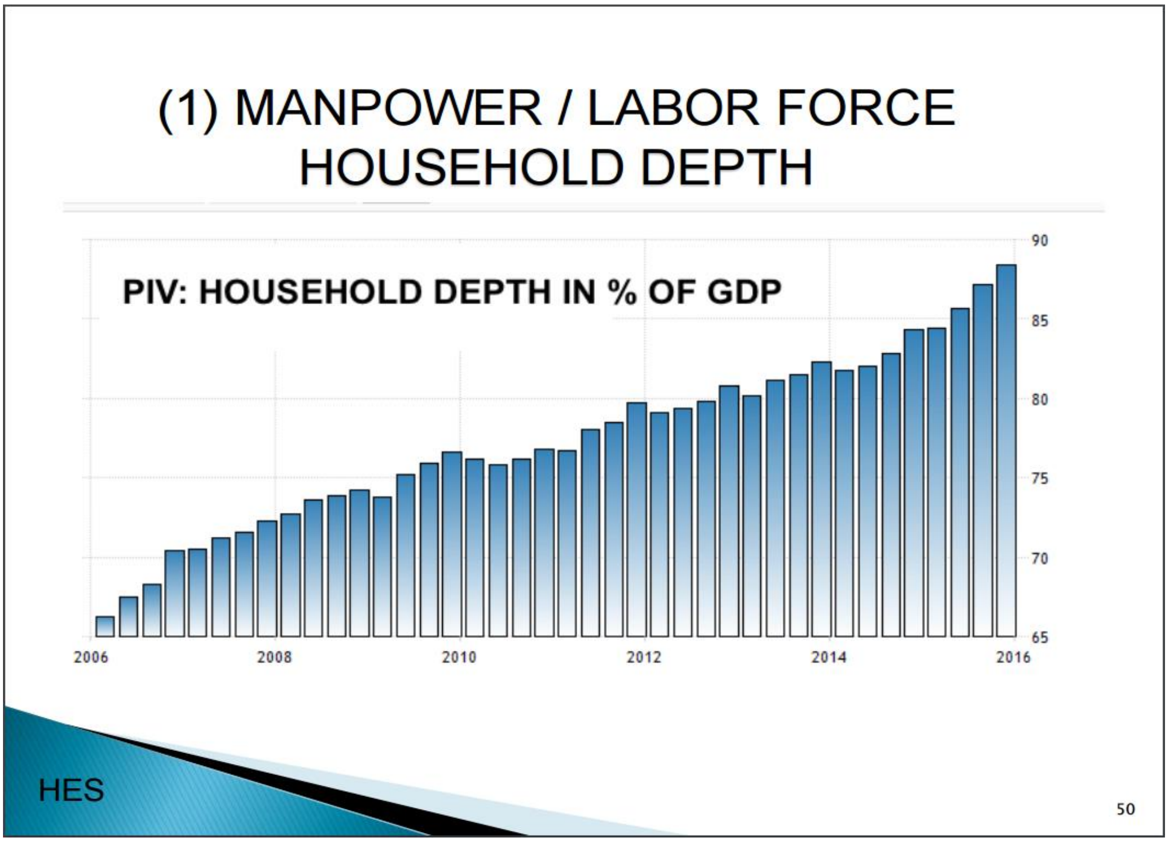

Figure 39. Manpower/Labor Force: Household Debt from 2006 to 2016

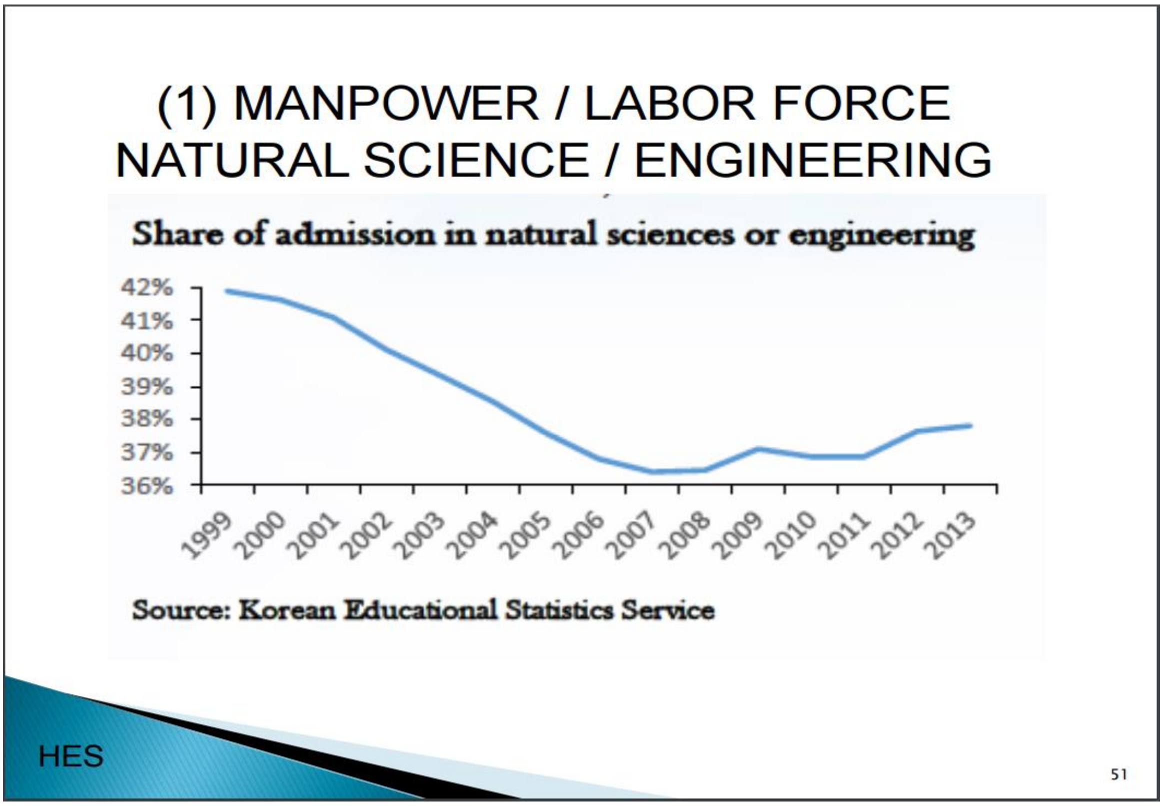

Figure 40. Manpower/Labor Force: Natural Science/Engineering

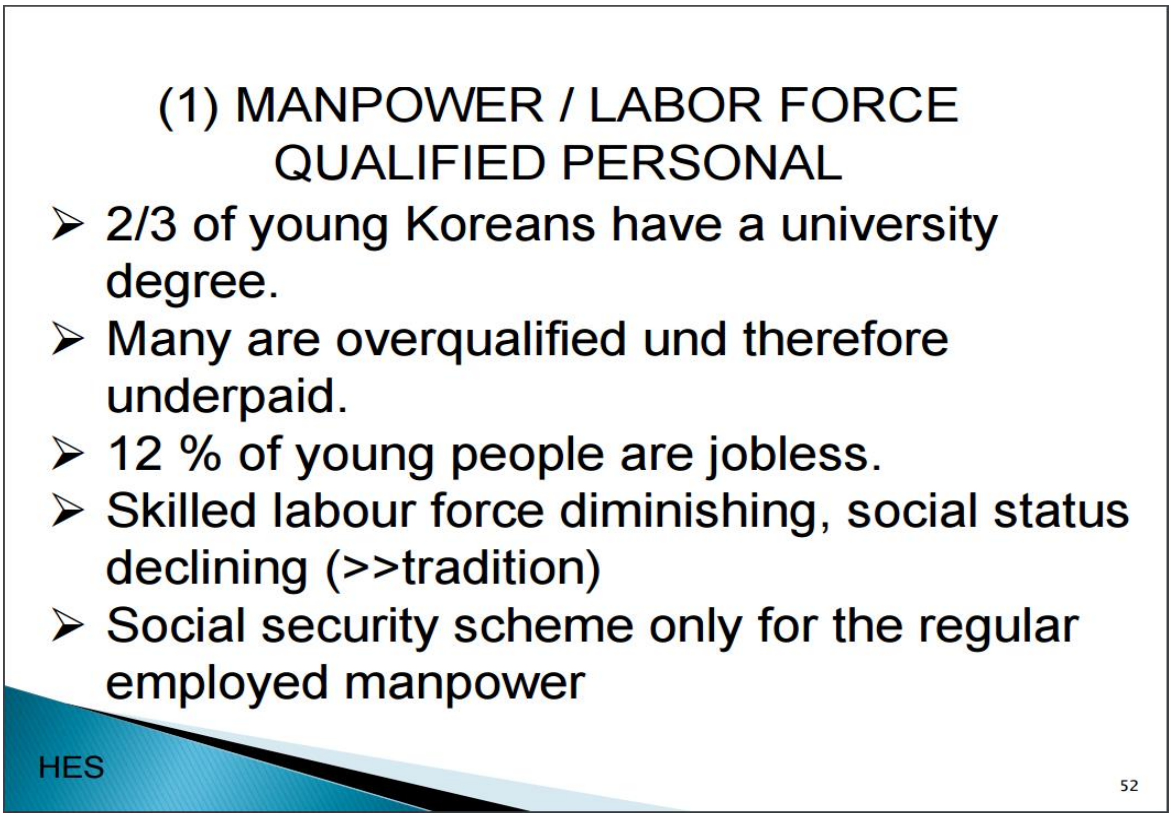

Figure 41. Manpower/Labor Force: Qualified Personnel

Possible measures are the following:

1) Increase productivity

2) Encourage automatic manufacturing

3) Attract foreign engineers

4) Foster vocational training on all levels with industrial participation

5) Encourage students to choose science and engineering by providing industrial grants

6) Increase the efficiency of R&D investment

7) Improve R&D management systems

(Universities have 72.7% PhDs but account for about 10% of GERD!)

8) Create fundamental/generic technology

9) Strengthen the very weak SME sector (Figure 42)

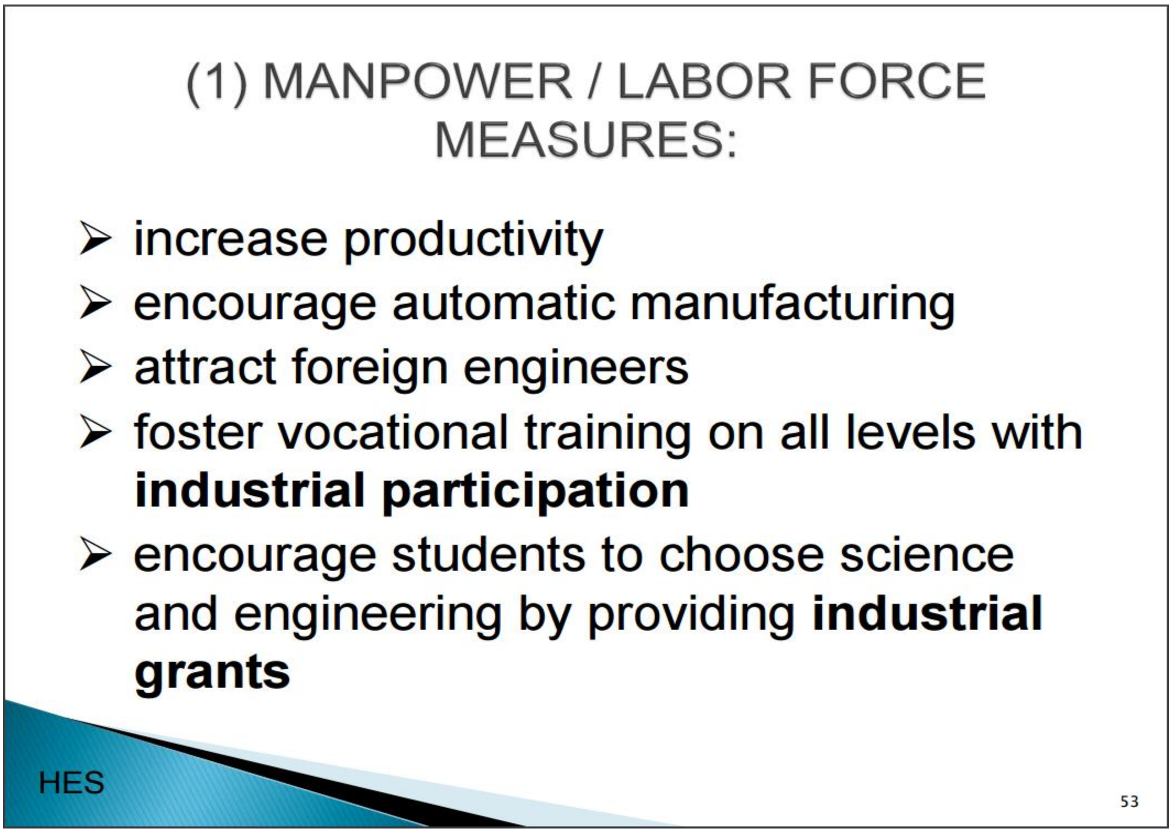

Figure 42 (a). Manpower/Labor Force Measures

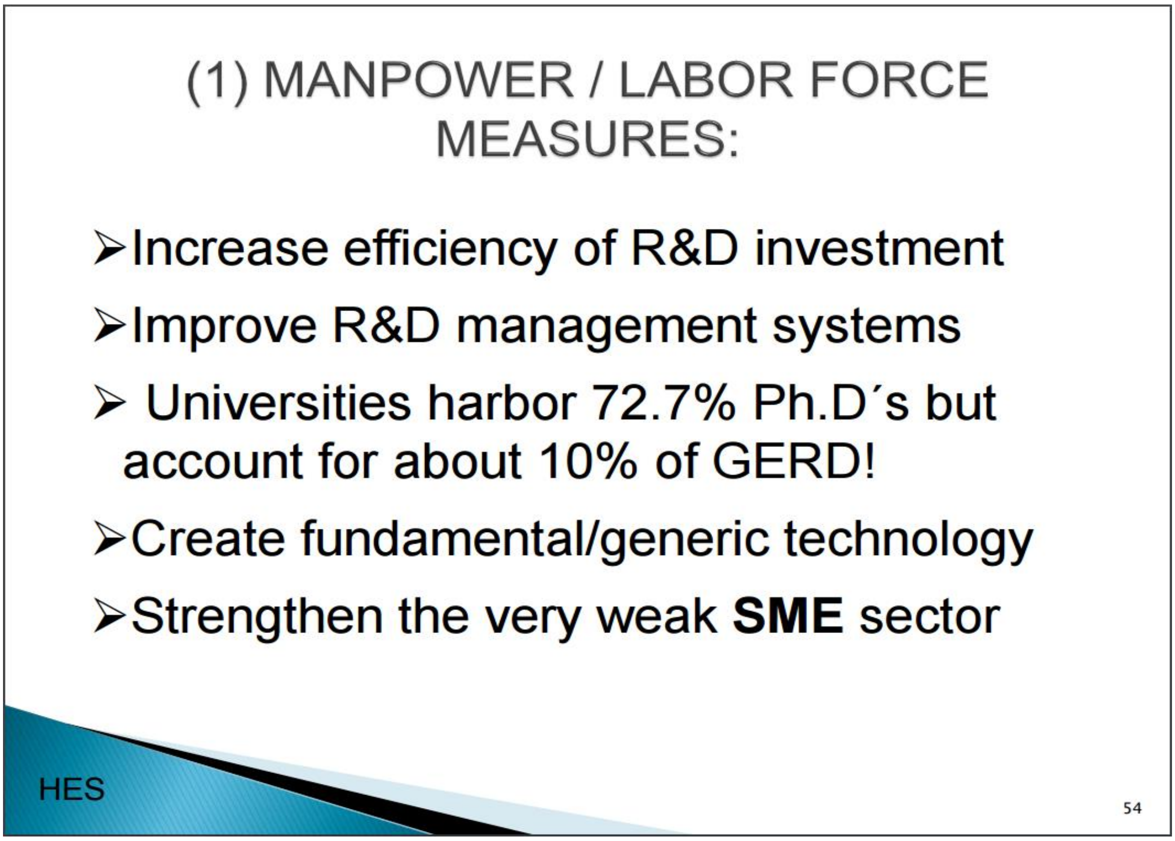

Figure 42 (b). Manpower/Labor Force Measures

(2) *Structure*

The structure of the economy is in favor of big conglomerates, so called *chaebols*. Again, there are historic reasons. Today, Samsung stands for 20% of the GDP, and Hyundai Motor stands for 13%. The five big *chaebols* account for 90% of all revenues. Hyundai and Samsung together count for 76%. Before assuming that size prevents failure, one should think of names like Nokia, Kodak, Compaq, Xerox, and Volkswagen (not yet). “Too big to fail” is a dangerous belief (Figure 43).

(3) *Competition*

Everybody is aware of the fact that competition is the driving force to new design and development. An edge ahead of the competitors gives you a safe margin in the market share (see semiconductors). Just this summer at the International Supercomputer Conference in Frankfurt in 2016, the Chinese scientists reported the super speed computer in Wuxi. It operates at 93 Penta FLOPS with a power economy of 6 gigaflops/Watt. This is a rate five to ten times higher than that of Oak Ridge in the US. The super computer is fully equipped with Chinese RISC processors (Figure 44).

(4) *Energy*

The energy consumption in Korea is still high at 10,000 kWh per capita. The European Union stands at 6,000 kWh per capita. Looking at the trend, it is still growing, and measures of saving energy do not show a significant effect (Figures 45 and 46).

Only about 1% is covered by renewable sources. Possible scenarios to reduce the energy consumption were proposed by the Korea Energy Management Cooperation in 2014, with little effects until now (Figures 47 and 48).

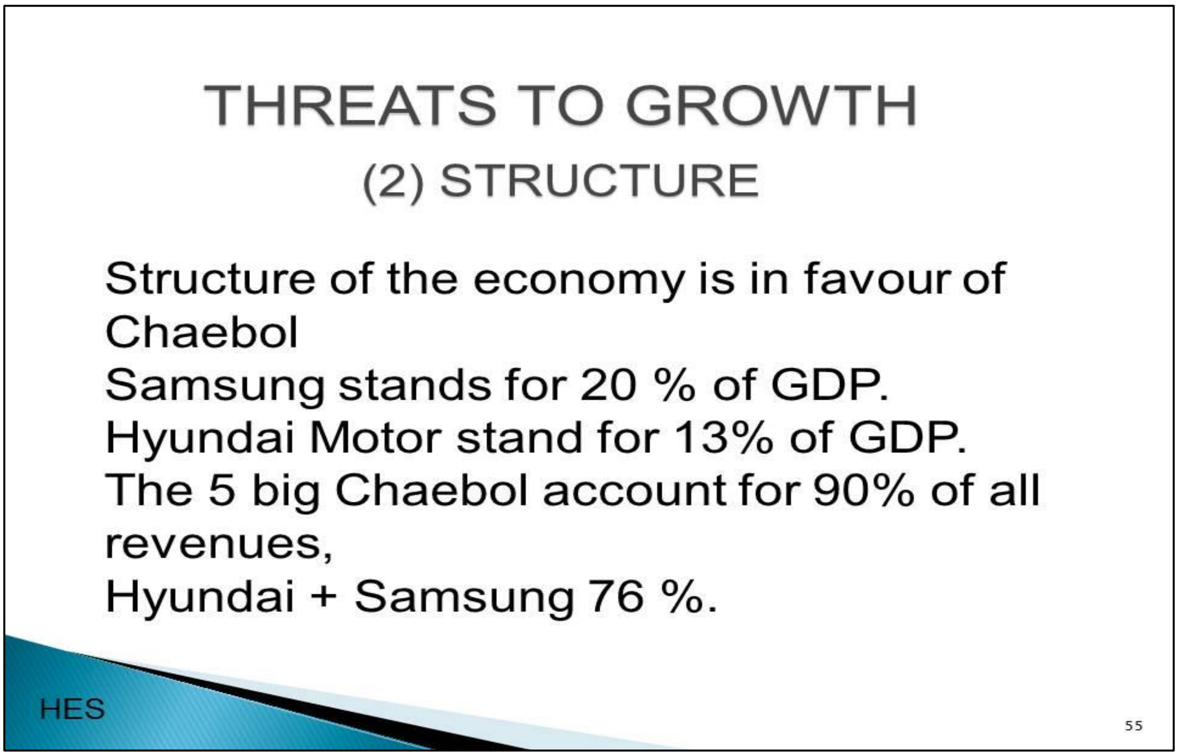

Figure 43 (a). Threats to Growth - Structure

Figure 43 (b). Threats to Growth - Structure

Figure 44 (a). Threats to Growth - Competition

Figure 44 (b). Threats to Growth – Competition

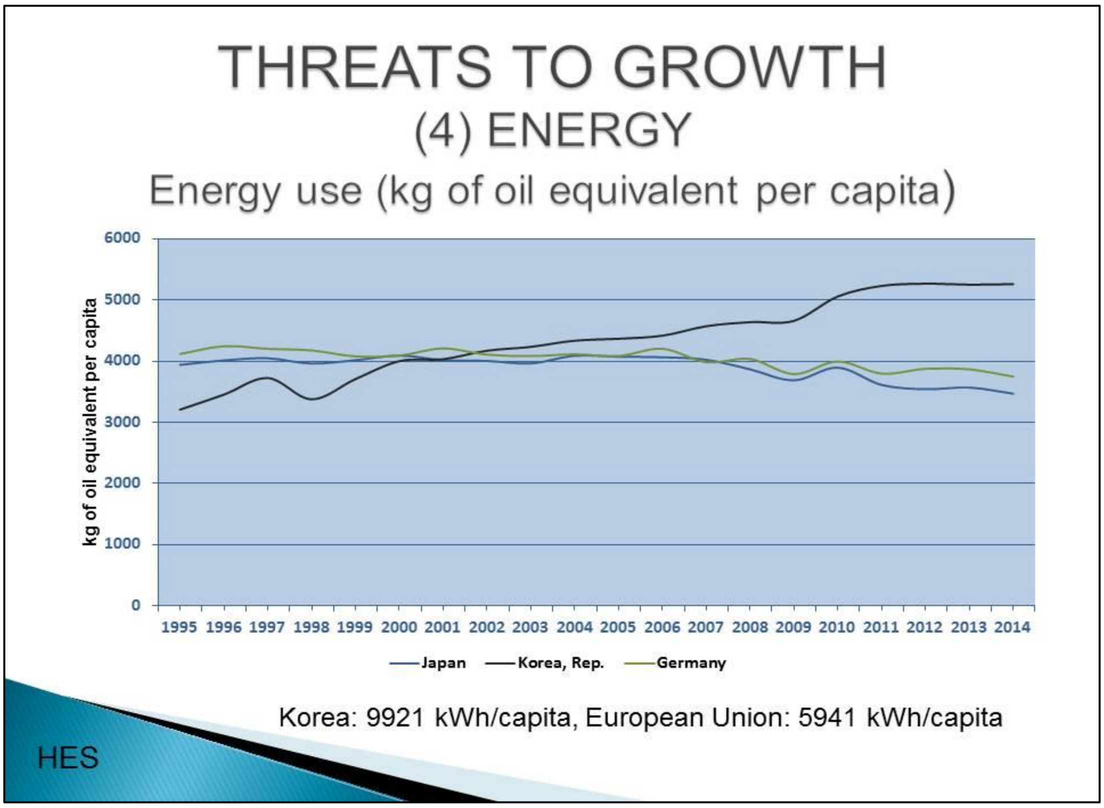

Figure 45. Energy Use of Japan, Rep. of Korea, and Germany

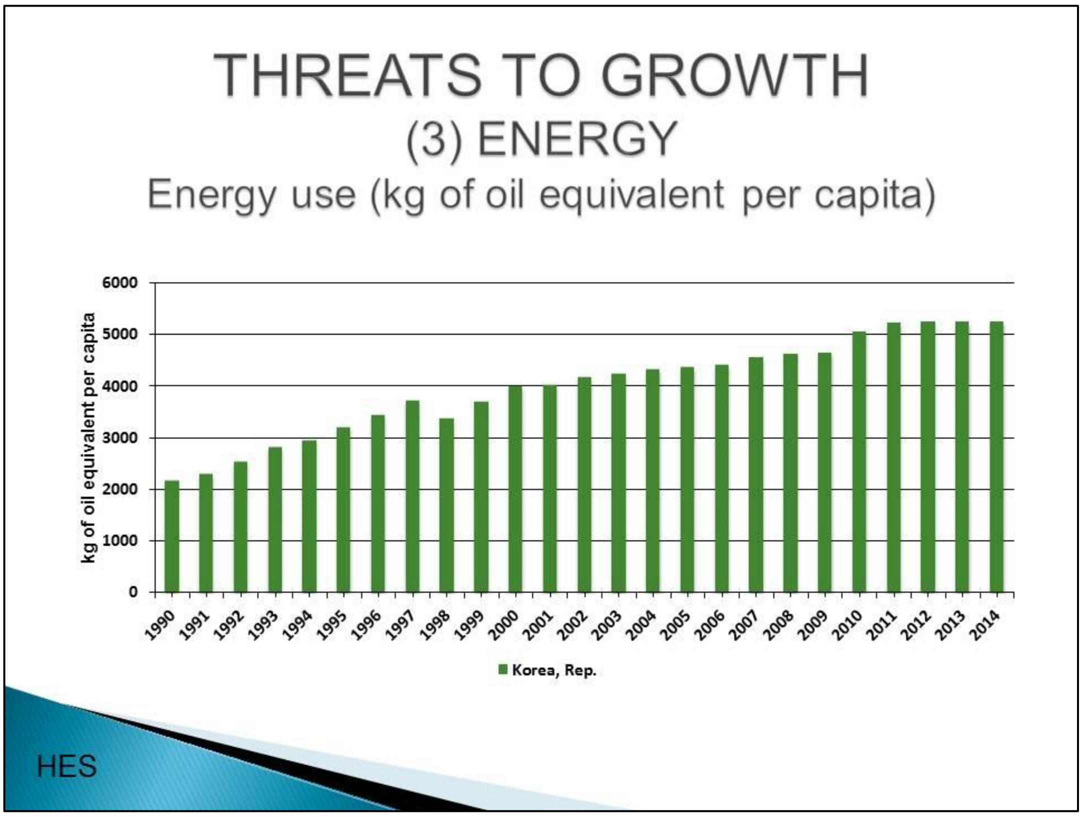

Figure 46. Energy Use from 1990 to 2014

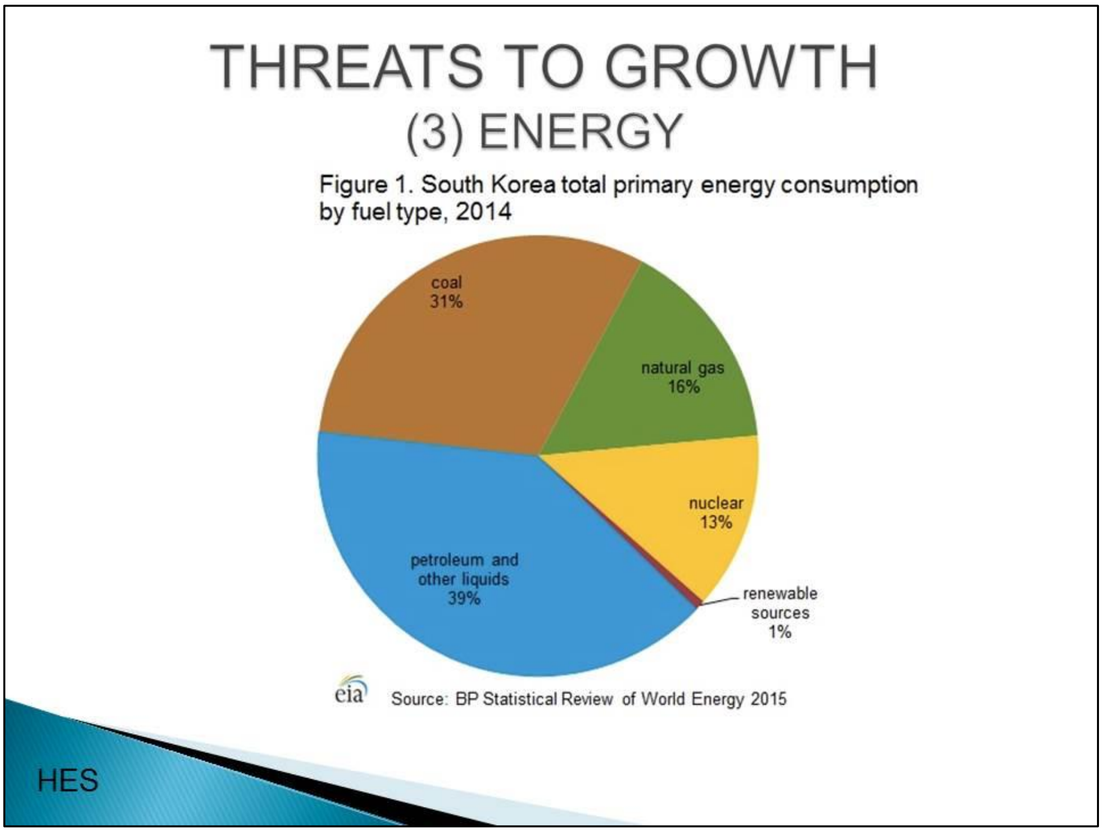

Figure 47. Total Primary Energy Consumption by Fuel Type in S. Korea in 2014

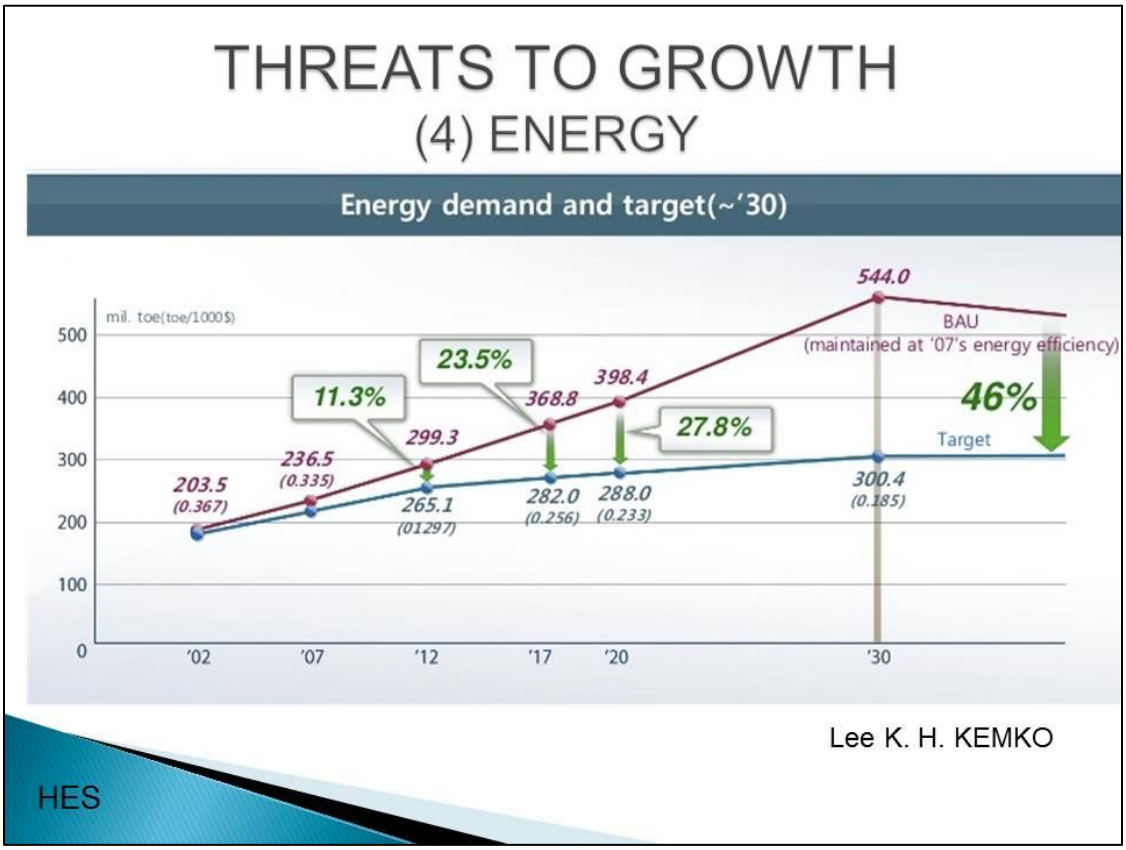

Figure 48. Energy Demand and Target

New Strategic Fields

When Korea's industrial development was focused on strategic fields, joined by the government and the private sector, the result in general was excellent for the benefit of the country.

The location and identification of such strategic technologies today still are a rewarding adventure. I shall propose four fields where Korea can become a world leader. They are (1) highly efficient solar energy converters, (2) energy storage, (3) new car industries, and (4) additive molding (3-D printing).

(1) *Highly Efficient Solar Energy Converter*

Although quite a large number of solar power plants exist worldwide, conventional converters have a limited efficiency. The yields realized in laboratory experiments show that the efficiency can be doubled.

Here are some numbers: Multi junction concentrator (ISE) 45%, Crystalline Si cells 22%, thin film 13 - 22%, and Perovskite 10 - 12% (Figure 49).

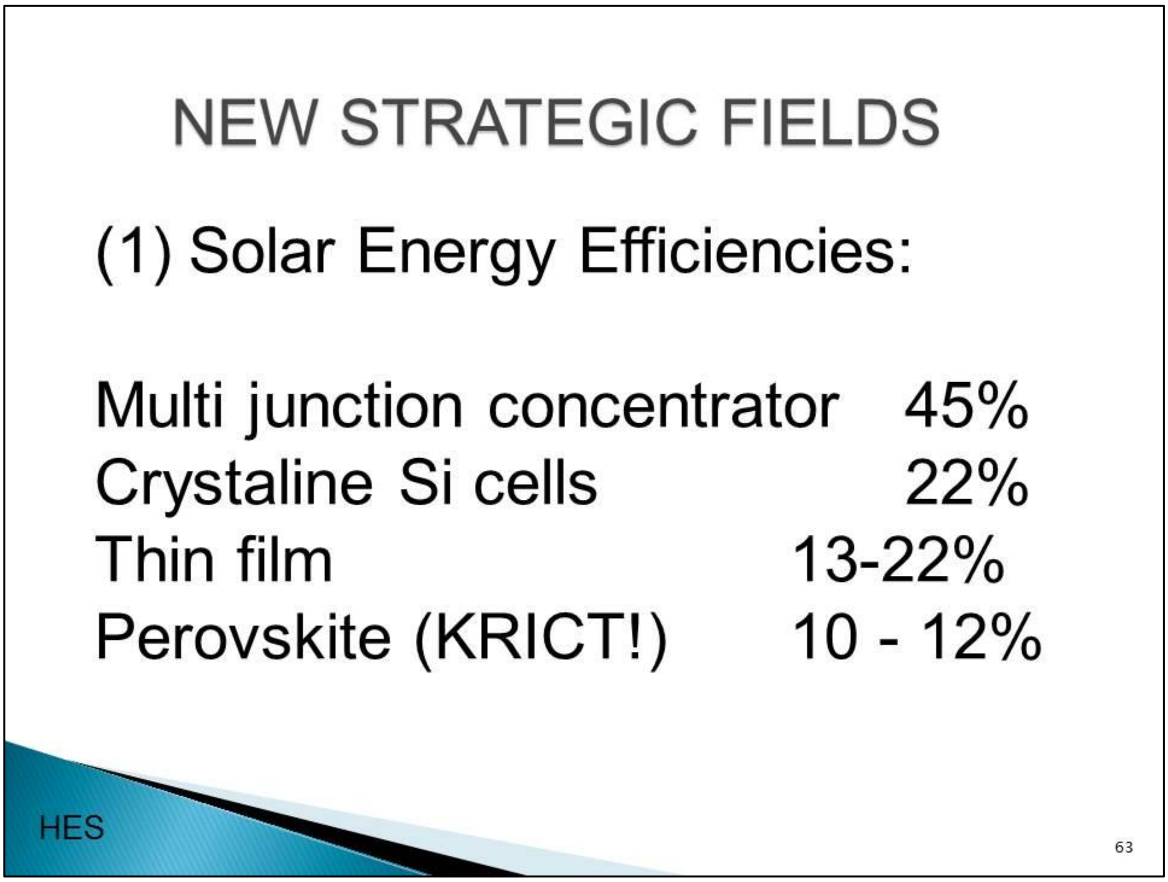

Figure 49. New Strategic Fields: Solar Energy Efficiency

Korea Research Institute for Chemical Technology (KRICT) is successfully engaged in the very cost efficient technology Perovskite. This engagement plus other technologies might be strengthened.

Just recently, a solar driven airplane flew around the world, not in 80 days but in one year! It shows, however, the status and potential of solar power converters.

Efficiency over time clearly shows a significant increase in recent years, and the outlook is promising, as suggested by the National Renewable Energy Laboratory (NREL). A comparison of energy production costs using conventional fuel (lignite, coal, gas, and oil) and regenerative sources show a competitive level. No nuclear power generation is quoted because it is no longer an option in Germany. Expected generation costs are forecasted to be between 0.05 and 0.10 €/kWh in 2030 (Figures 50 – 52).

(2) *Energy Storage*

Regenerative energy production requires storage technology. This fact has been hardly recognized by system engineering. Possible technologies are storage in batteries, power to gas converters, and thermal storage (Figure 53).

Development of battery storage is well underway, and it is driven by the automotive industries. Power to gas converters and thermal storage are still large fields requiring new ideas and engagement. Hydrogen technology and methane technology are promising onsets for new developments. System engineers should consider ready-to-use units of different power levels, combining conventional and regenerative power conversion together with storage capabilities (Figures 54 - 57).

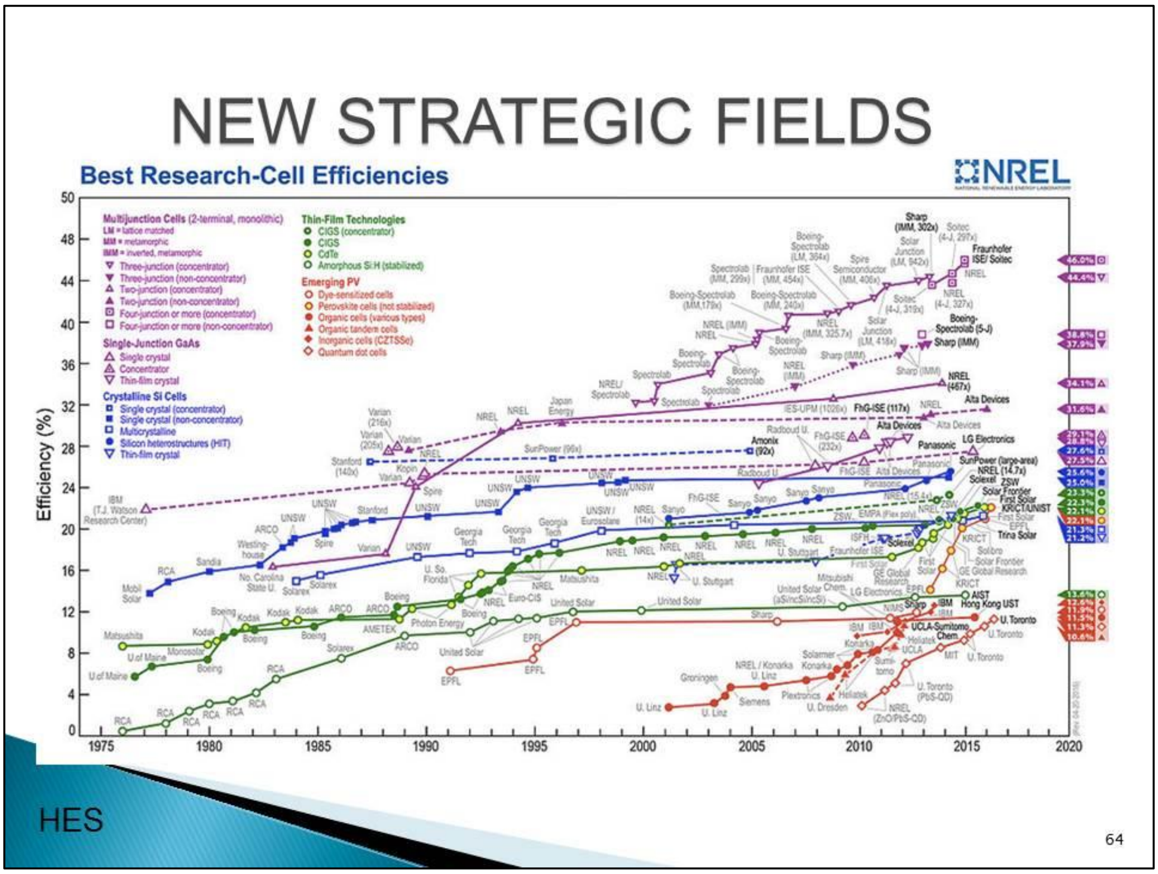

Figure 50. New Strategic Fields: Best Research Cell Efficiencies

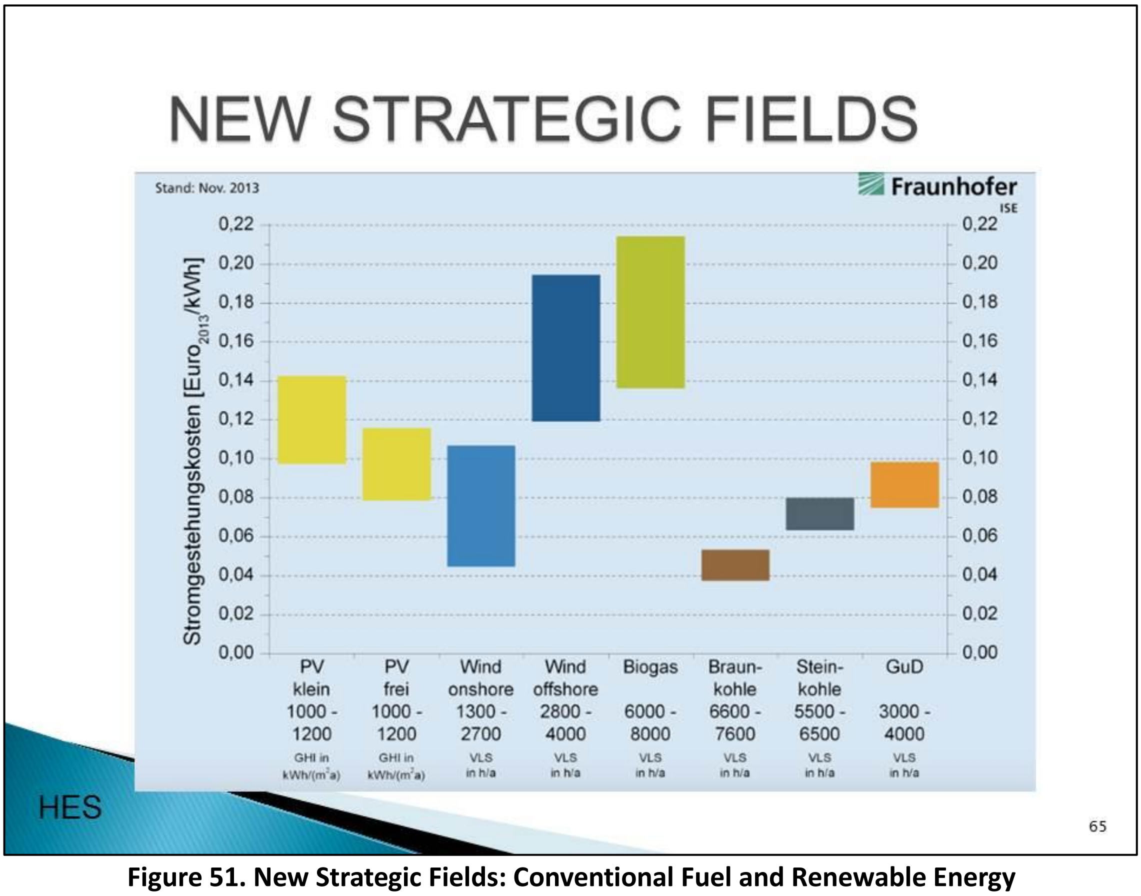

Figure 51. New Strategic Fields: Conventional Fuel and Renewable Energy

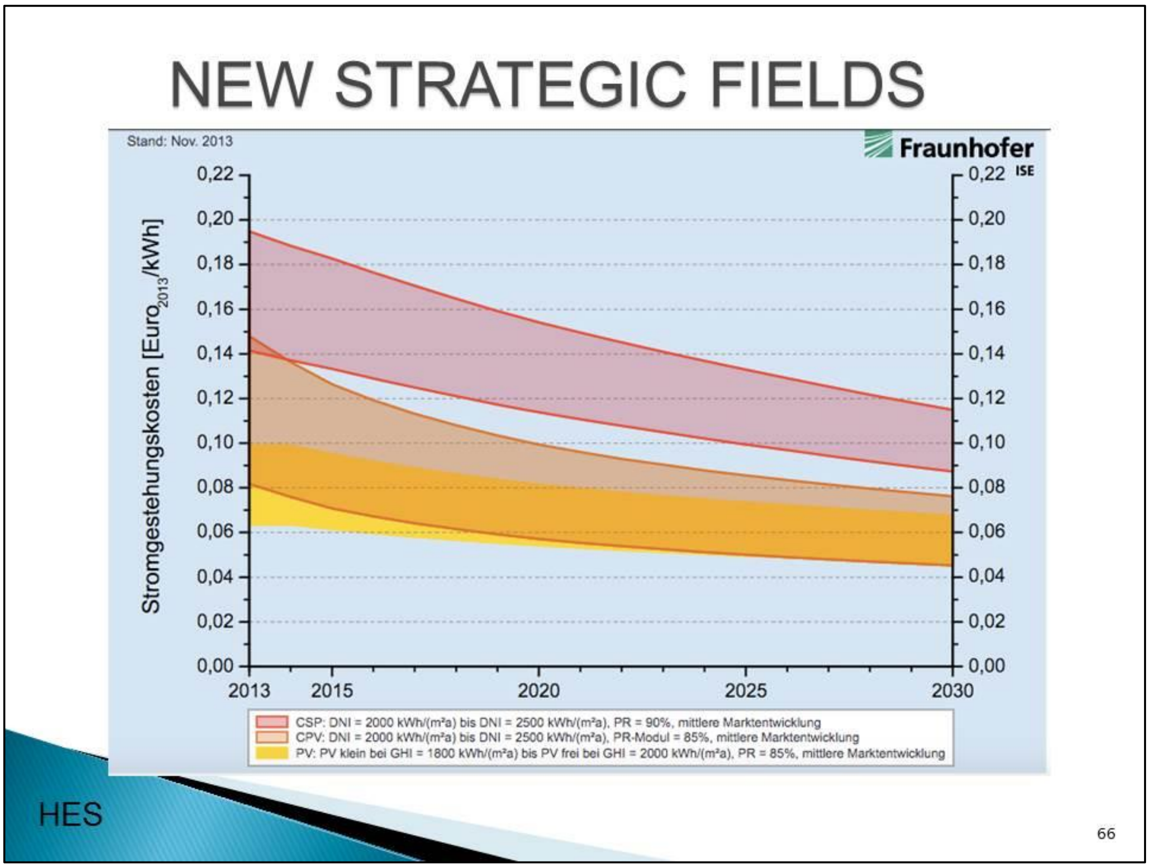

Figure 52. New Strategic Fields: Generation Costs over Time

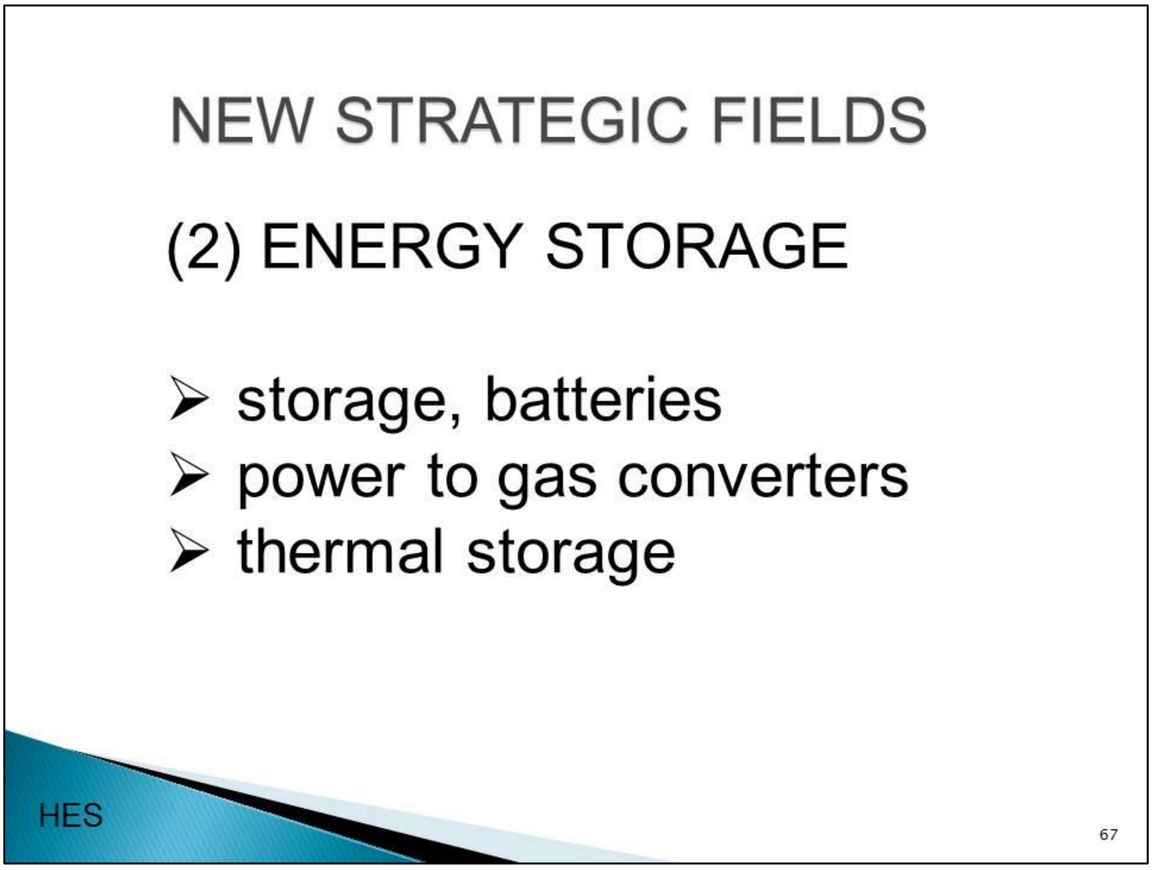

Figure 53. New Strategic Fields: Energy Storage

Figure 54. New Strategic Fields: Green Energy

Figure 55. Threats to Growth: Quote from Seung Il Cheong

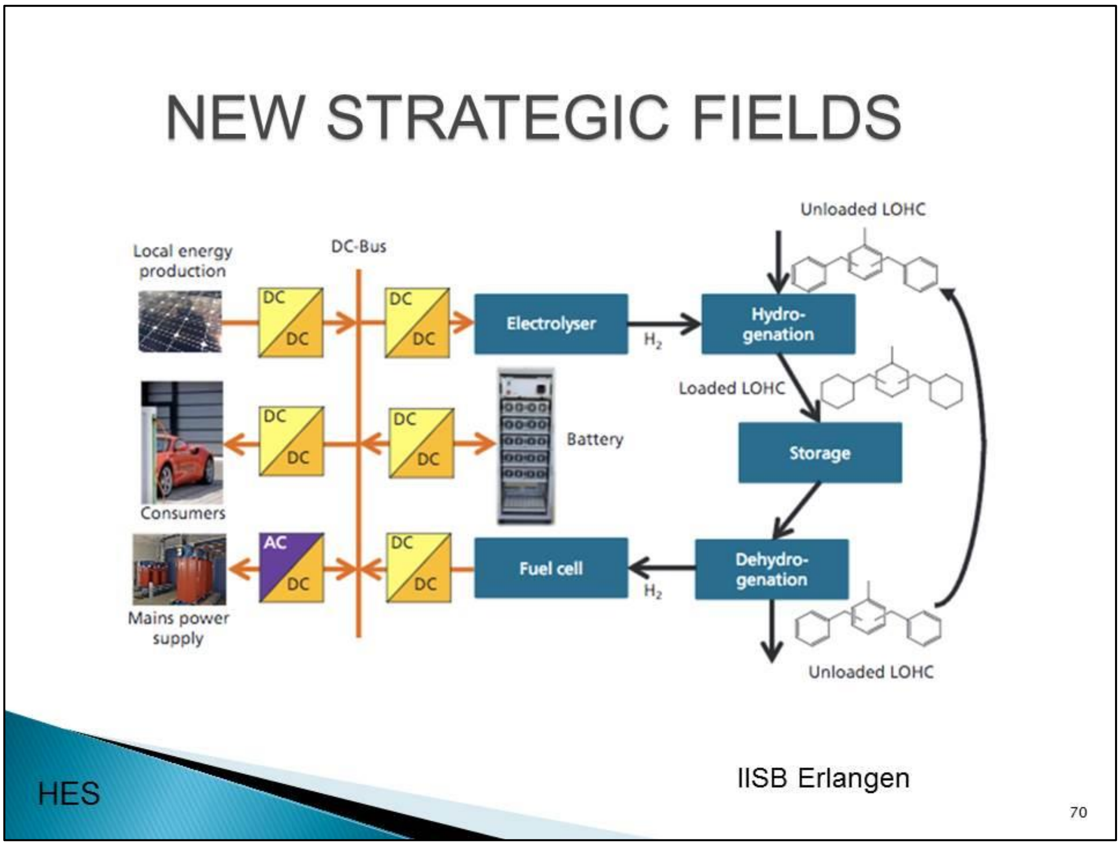

Figure 56. New Strategic Fields: Regenerative Energy and Storage

Figure 57. New Strategic Fields: Car Industries

(3) *New Car Industries*

Today, the car industry faces a revolution:

1) Sheet metal is replaced by carbon fiber and araldite

2) Pistons are replaced by magnetic fields and rotors

3) Gear boxes are replaced by power electronics

4) Drivers are replaced by sensors and actuators (Figure 58)

IONIC by Hyundai is quite a good answer to this challenge. It is offered as a hybrid electric vehicle (HEV), a plug in hybrid electric vehicle (PHEV), or a purely electric vehicle (EV), leaving options for technology development in every direction (Figure 59).

Automotive suppliers have already developed complete drive trains, hub motors, and control electronics, but car manufacturers hesitate to integrate these solutions. Their way of thinking is fixed in the past! Their mentality is welded to sheet metal! In their minds, the car still is a sum of boxes (trunk box, passenger box, motor box) and not an integrated transportation system (Figure 60).

Figure 58. New Strategic Fields: Car Industries

Figure 59. New Strategic Fields – HEV, PHEV, and EV

Figure 60 (a). New Strategic Fields: Hub-Motor

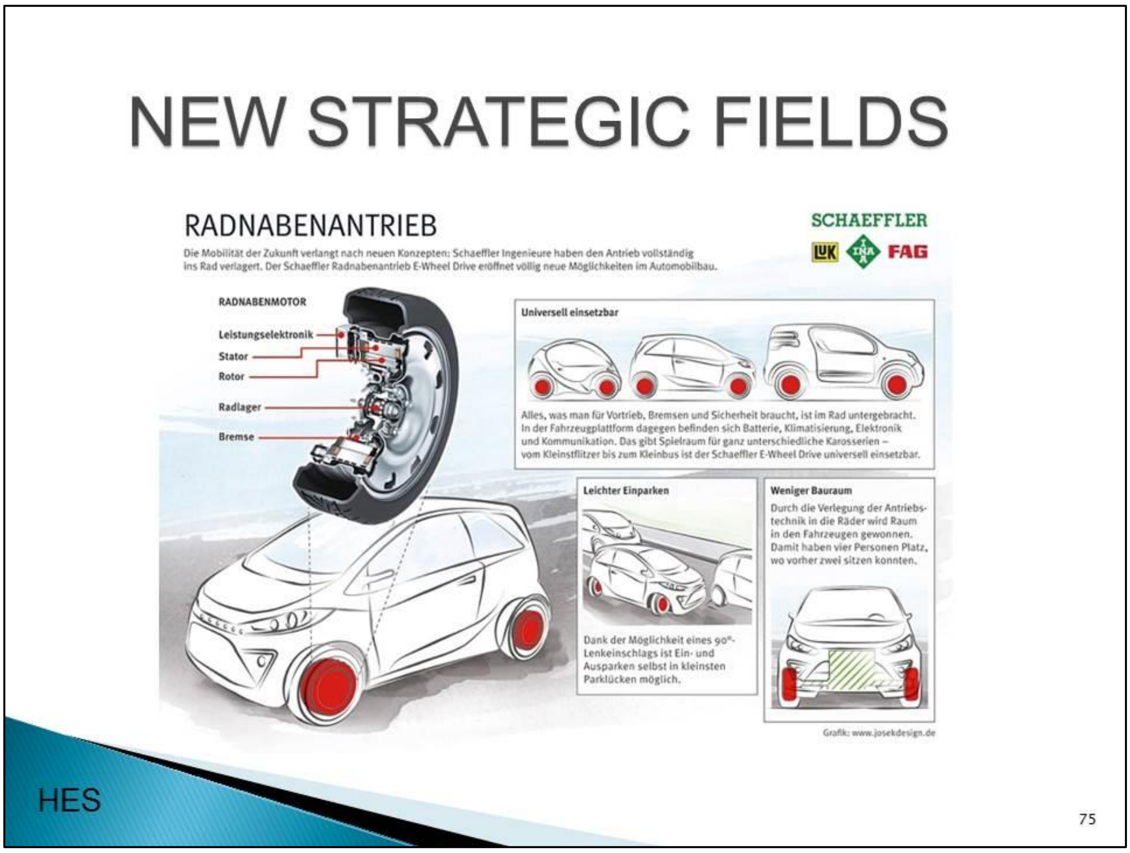

Figure 60 (b). New Strategic Fields: wheel drive

Figure 60 (c). New Strategic Fields: battery

Figure 60 (d). New Strategic Fields: wheel system

(4) *Additive Molding*

This new production technology has a growth rate of 30% per year. These names are in use: 3-D printing, fused deposition modelling (FDM), and free form fabrication (FFF). It involves machine tool design, material science, powder technology, and heat transfer (Figure 61).

The advantages are high precision, unlimited shape and size, and a variety of materials from plastics to metals. Today, a number of technologies have been developed, and they are in the experimental phase. They are (1) stereo-lithography, (2) digital light processing, (3) laser sintering / laser melting, (4) extrusion / FDM / FFF, (5) selective deposition lamination (SDL), and (6) electron beam melting (EBM) (Figure 62).

The variety shows the dynamics of this technology and the vast field of applications in all industries. Here, it is worthwhile to become a global player!

My message: “Seek for system solutions, not for single solutions!” My vision: “Not to be bigger, but to be better!” and “Think different (Steve Jobs)! (Figure 63)”

Ladies and gentlemen, this was my personal review of the last 40 years of KIMM. I also outlined the limits of growth, and I suggested a few strategic fields for the future. I thank you for your attention. Upon the inauguration of KIMM, I received a bronze plaque showing the Emile Bell on one side. After 40 years, I would like to return this plague to the current president of KIMM Prof. Yong-Taek Im. Thank you (Figure 64).

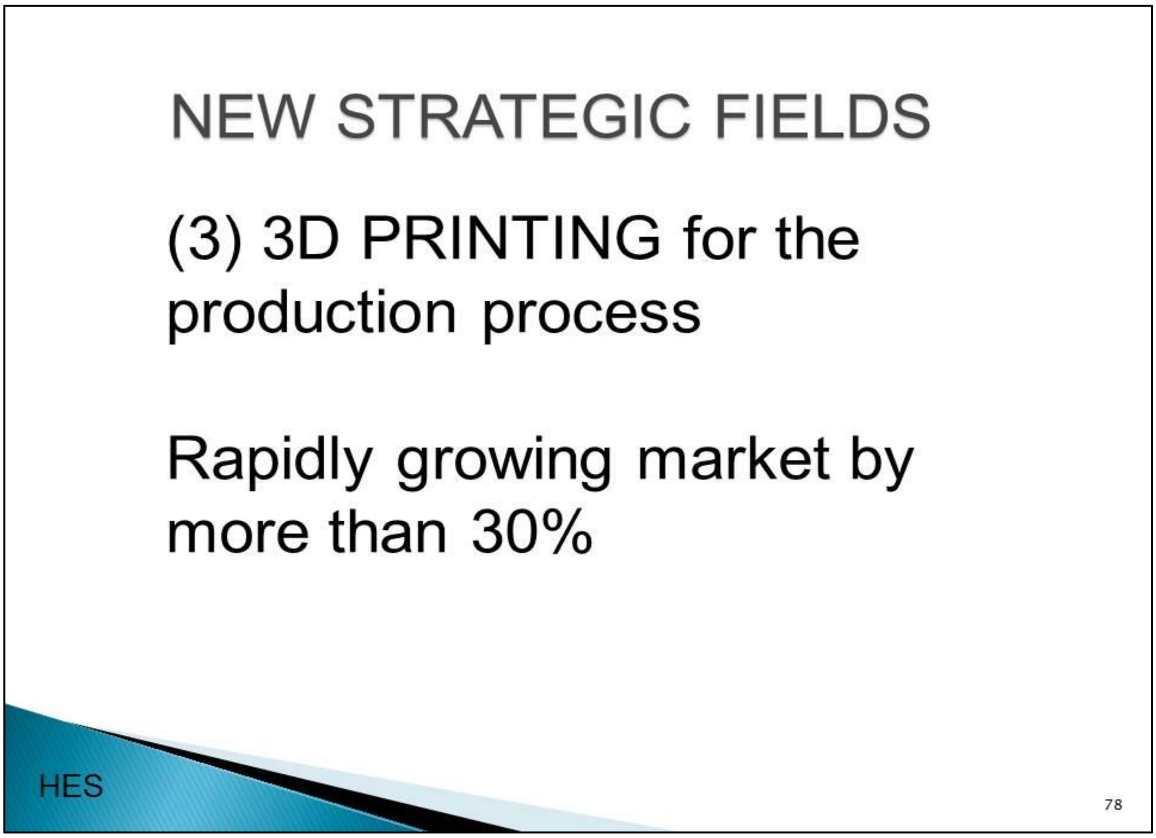

Figure 61. New Strategic Fields – Additive Molding

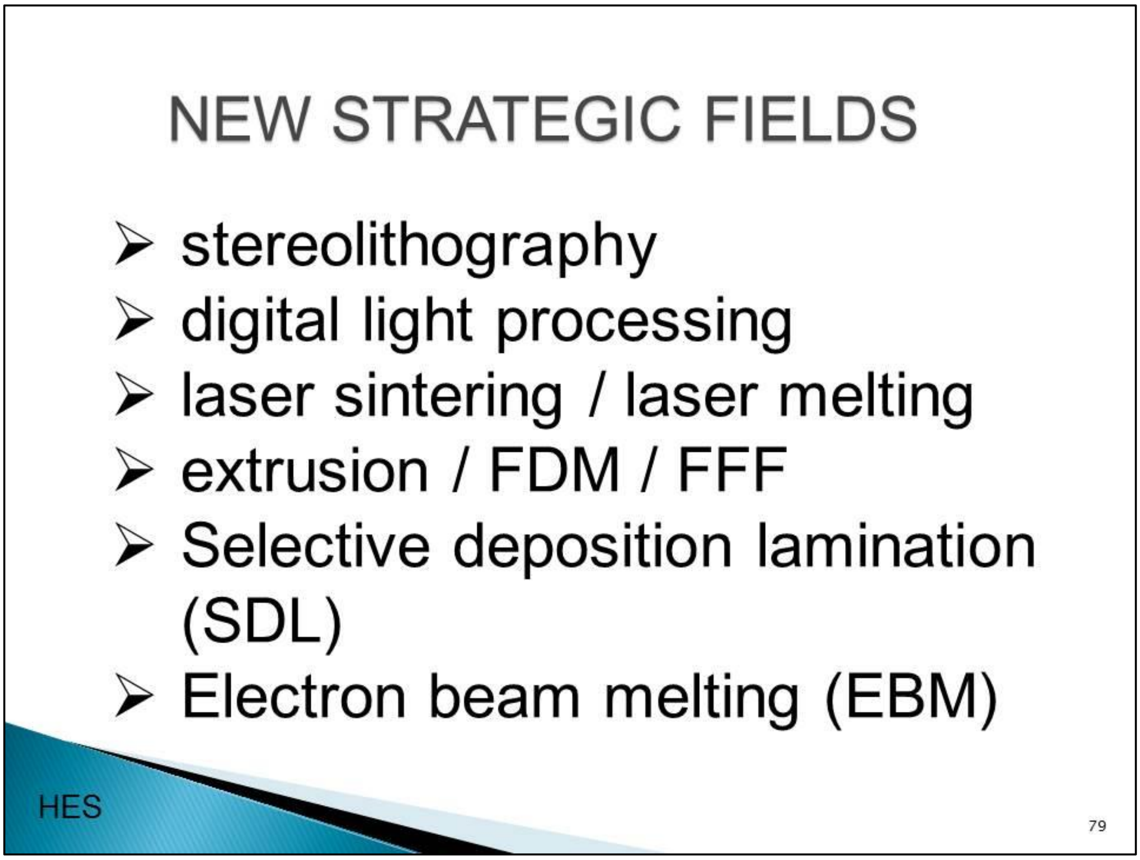

Figure 62. Technologies in the Experimental Phase

Figure 63 (a). New Strategic Fields: Message

Figure 63 (b). New Strategic Fields: Vision

Figure 64. Thank You

Innovative MEMS, Opto, and Nano Technologies in LG Electronics

Dr. Jeong-Soo Lee
Vice President Materials & Devices Advanced Research Institute
LG Electronics

Introduction

Good afternoon. I am JS Lee from LG Electronics. I'm in charge of the Materials & Devices Advanced Research Institute. The title of my talk is "Innovative MEMS, Opto, and Nano Technologies in LG Electronics." Today, I would like to explain why such kind of materials and device technologies are becoming more and more important, even in electronics companies.

This is the content of my talk. Firstly, I will shortly introduce about the recent trends in the IT industry. Next, I will mention about the new business strategy of LG Electronics. And finally, I would like to show you some recent achievements in the development of MEMS, opto, and nano technologies in LG Electronics (Figure 1).

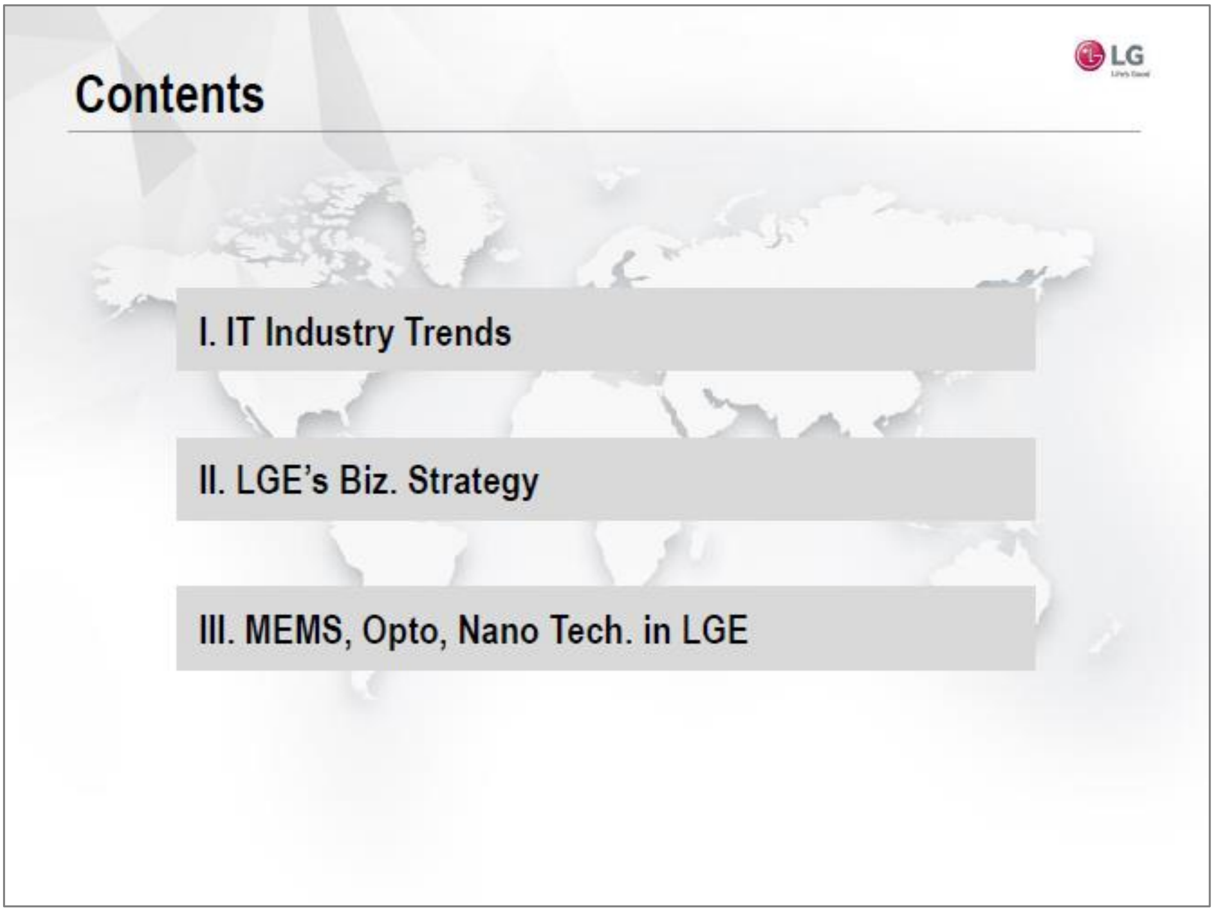

Figure 1. Contents

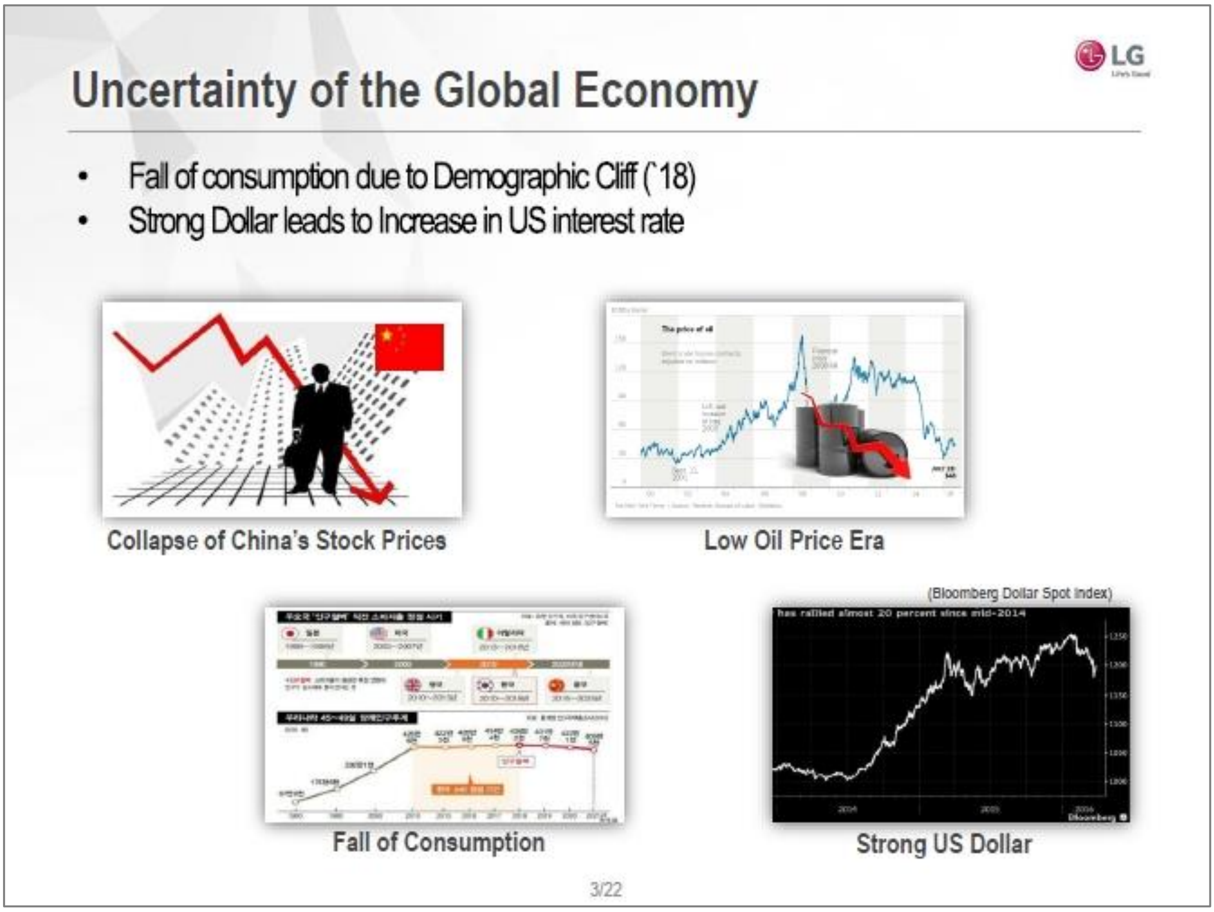

Figure 2. Uncertainty of the Global Economy

I. IT Industry Trends

As you well know, the recent global economy shows many uncertainties. Especially due to the demographic cliff, the consumption falls very fast leading to market saturation. Also, uncertainties such as raw material prices and exchange rates make the market unclear. As the competition is becoming more and more severe, many companies are concerned about the new growth and sustainability (Figure 2).

There have been some dynamic changes even among the world leading top companies. Formerly, the most leading IT companies were the so-called "TGIF"—Twitter, Google, Apple (iPhone), and Facebook. But recently, there have been some changes even in these world leading companies. I think that, for example, Apple, are still very good but not so strong as before. Their product seems not so innovative as before. Twitter, also. Instead, other companies like Amazon or Netflix look very good recently, and now the leading IT companies are the so-called "FANG." This means that, even the big companies have to go thorough endless innovation to secure future growth (Figure 3).

Another important factor is the rise of Chinese companies. In the past, the only competitiveness of Chinese companies was low cost. But now, they have not only cost competitiveness but also technologies and even brand power. For example, Samsung and Apple are doing still very well in the smartphone market. However, the Chinese companies including Huawei, Vivo, and Oppo are very aggressive, and their growth is very noticeable. In the case of LCD or semiconductors, the investment of Chinese companies is very huge. They invest heavily for the next-generation production lines to take market initiatives. Also, they are actively pursuing strategic M&A deals. For example, earlier this year, Huawei merged with GE Appliances to take a market or brand leadership (Figure 4).

Figure 3. The Rise and Fall of IT Companies

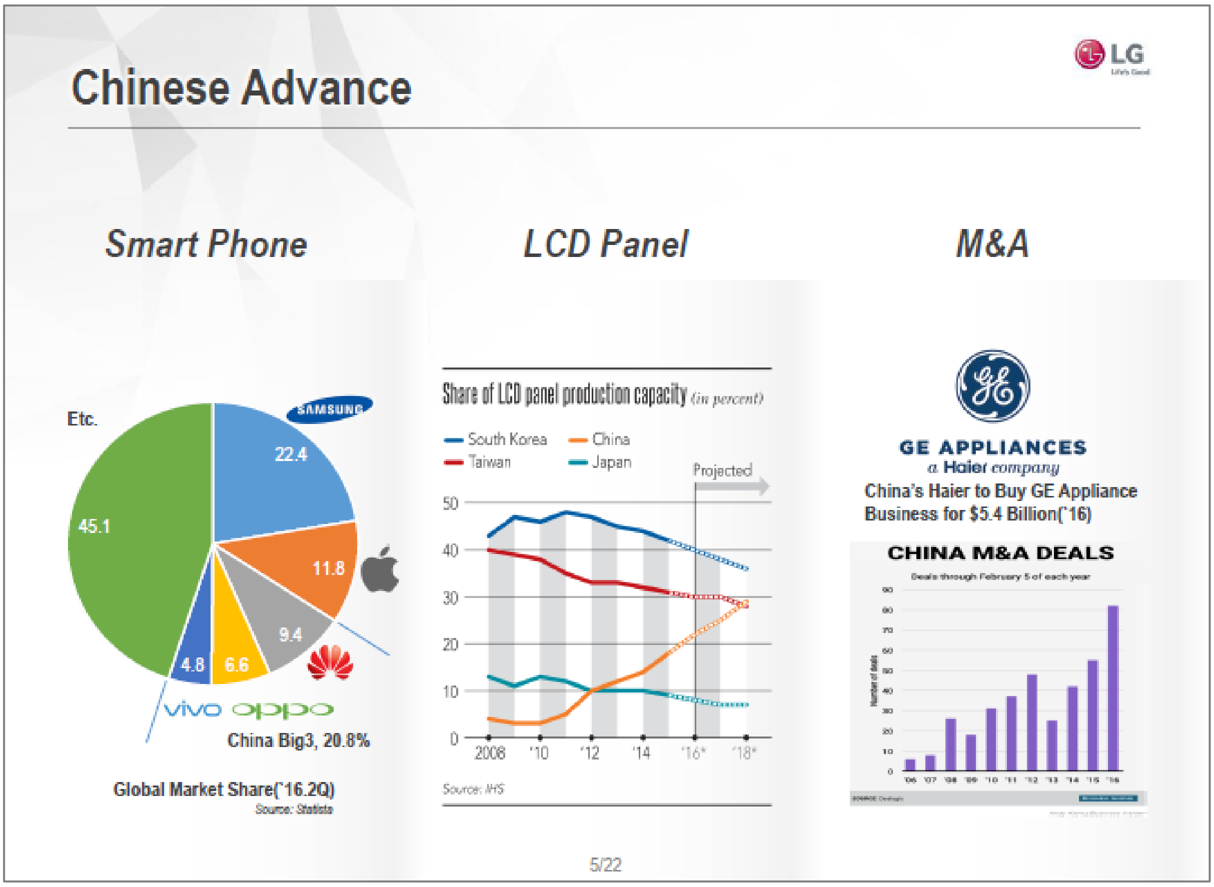

Figure 4. Chinese Advance

Recently, every company is concerned about future growth. Their top priority is to find a new growth engine. In the past, the general way of starting a new business was to analyze the market and then to analyze which technologies were feasible or not. Then, after considering all the factors they would start a new business. But now, rules of the game have changed. In order to secure market leadership, we need to take a risk. No pain, no gain. For example, when we first saw and heard about new technologies like drones, autonomous navigation vehicles, 3D printing, reusable rockets or Hyperloop, many considered them as a farfetched dream and would not be realized within our lifetime. However, they are beginning to become realized. For example, the reference test for Hyperloop has already started in California. So for the electronics or IT companies, there are many challenges but we should take a risk and we should make an effort to innovate and to find new opportunities. To achieve these goals, new technologies relevant to materials and devices will play a critical role (Figure 5).

II. LG Electronics' Business Strategy

Now, I will explain about the current situation of LG Electronics. Currently, there are four business units: Home Entertainment, Mobile Communications, Home Appliance, and, finally, Vehicle Components. The first three business domains are our traditional business domains. I think we are still doing very well, but, as I have said before, the competition is becoming severe. The market is saturated and thus the profit margin is becoming increasingly narrow. So we are focusing on premium products, launching OLED TV and ultra-premium brand called LG Signature for home appliances. Several years ago, LG launched a new business unit called Vehicle Components as the growth engine for the future. Experience in TV or home appliance business would help to gain competitiveness in the automotive display infotainment (Figure 6).

Figure 5. New Challenges

This is the recent global sales of LG Electronics. It is stagnated at around 50 US billion dollars. Growth could not be achieved by focusing only the traditional business domains and thus we decided to make some changes in our strategy (Figure 7).

Figure 6. Business Units

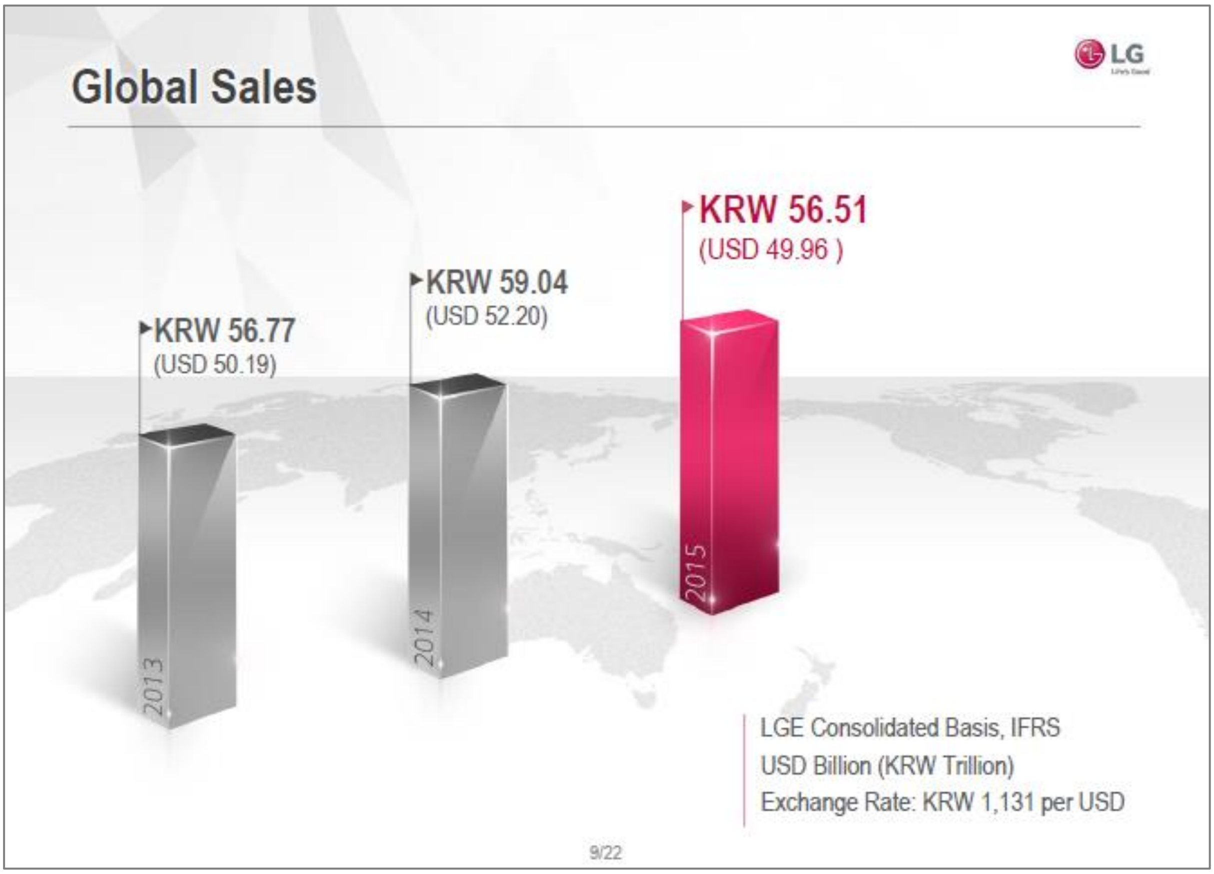

Figure 7. Global Sales

Traditionally, LG Electronics focused on B2C business, but now we are looking for opportunities in the in the B2B area. For example, we only made consumer TVs for the display sector but now we are expanding to new business areas such as signage, based on similar technologies (Figure 8).

Also, energy is one of our new business domains, including solar energy and energy storage systems. Several years ago, the competition in the solar industry was very severe as the Chinese companies, backed by the Chinese government, reduced cost aggressively. At that time, we decided to focus on next-generation technology with much higher efficiency. Finally, we succeeded and now we are producing very high efficiency silicon wafer solar cells based on the n-type and back-contact technology. Currently, this business division gains very high profit over 10% in the market and we are investing more to expand our capabilities (Figure 9).

Another very important new business domain is vehicle components. As I have mentioned previously, we have a lot of experiences in developing motor, battery, display, HVAC, and car infotainment. So for the past several years, we have made some strategic partnerships with global car companies including GM, Volkswagen, Fiat, and Mercedes Benz. Now we believe that we can make competitive products in this area. For example, we can make a solar rooftop on the electric vehicles based on the solar cell technologies (Figure 10).

Figure 8. Business Strategy

Figure 9. Solar Energy

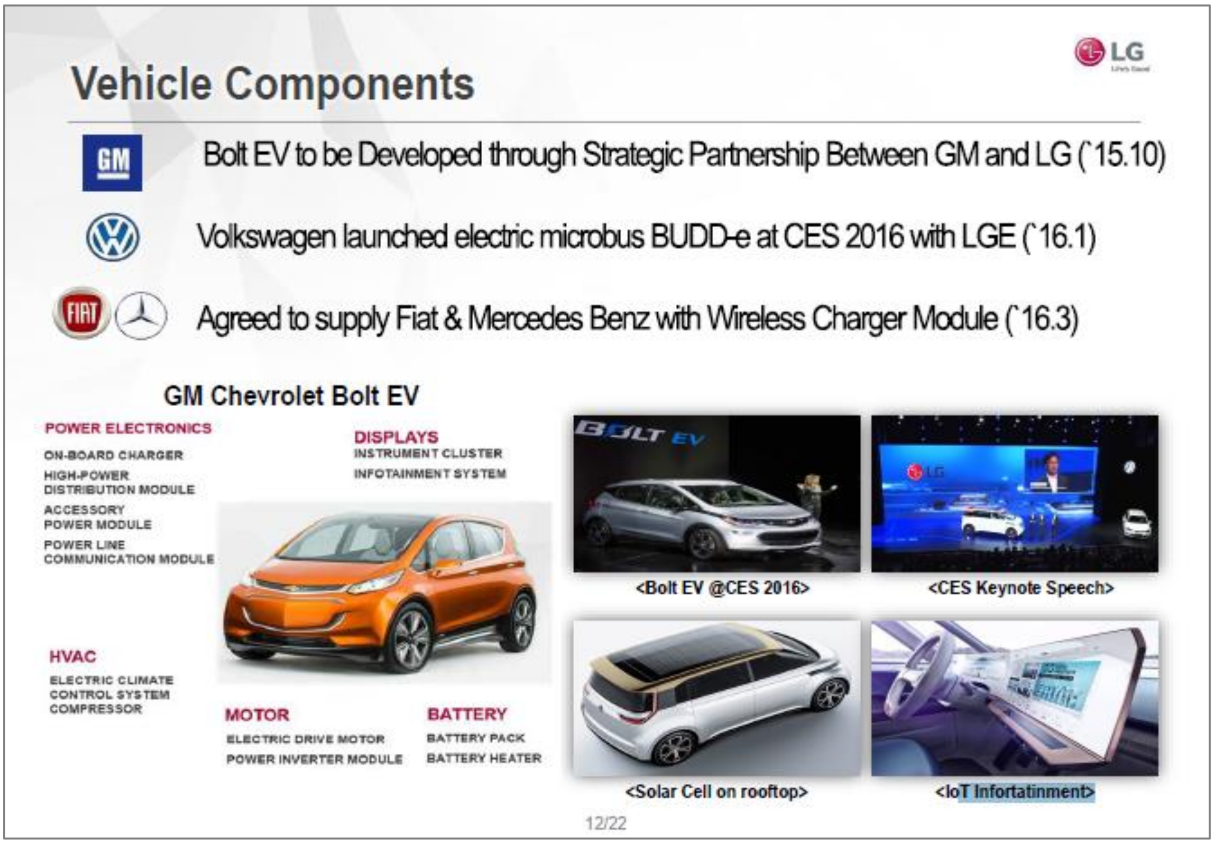

Figure 10. Vehicle Components

III. MEMS, Opto, Nano Tech. in LG Electronics

Finally, I would like to share some of our recent developments relevant to MEMS, opto-, and nanotechnologies. Firstly, I would like to introduce our institute. Our institute is one of the oldest research institutes in LG Electronics, established in 1987. We also have big facilities for semiconductor design and process technology, together with optics and nanomaterial technology. We have developed a series of Korea's first technologies. For example, we have developed Korea's first TFT-LCD, and we transferred this technology to LG Display. In 1996, we developed Korea's first Blue LED, and we transferred this technology to LG Innotek for mass production. In 1998, we developed Korea's first Full Color 4" OLED, and this is the base of current OLED TV by LG Display. Also, we developed Korea's first MEMS in 1998 and also some new solar technology in our lab as well (Figure 11).

I will show you some examples of our achievement. For MEMS, we made some R&D infrastructure during the early and mid-90, and we launched some sensors based on MEMS technology. For example, we developed IR sensors for air conditioners, microwave auto-cooking sensors, alcohol sensors for mobile phones, and humidity sensors for washing machines. Also, we expanded our application for displays like laser scanning. Also, we applied MEMS technology for wafer level package (WLP) of LED devices (Figure 12).

By utilizing MEMS scanner technology, we developed laser TVs with very large screen and high-density image. Based on our optic design technology, we developed this kind of large screen at very short optic distances. We exhibited this product at the 2013 CES show, receiving the innovation award. Also, we made the world's first, very compact, full high density LED TV in the year 2013 (Figure 13).

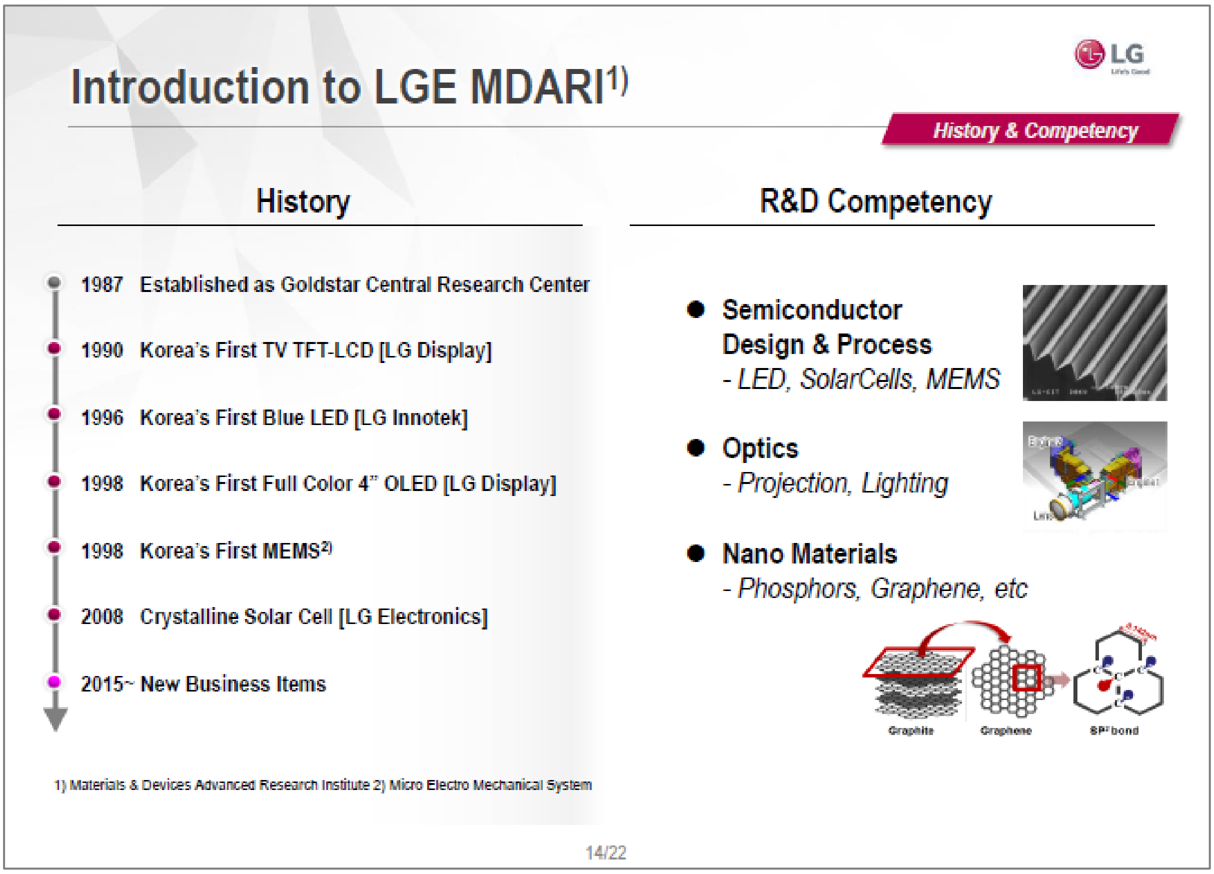

Figure 11. Introduction to LGE MDARI

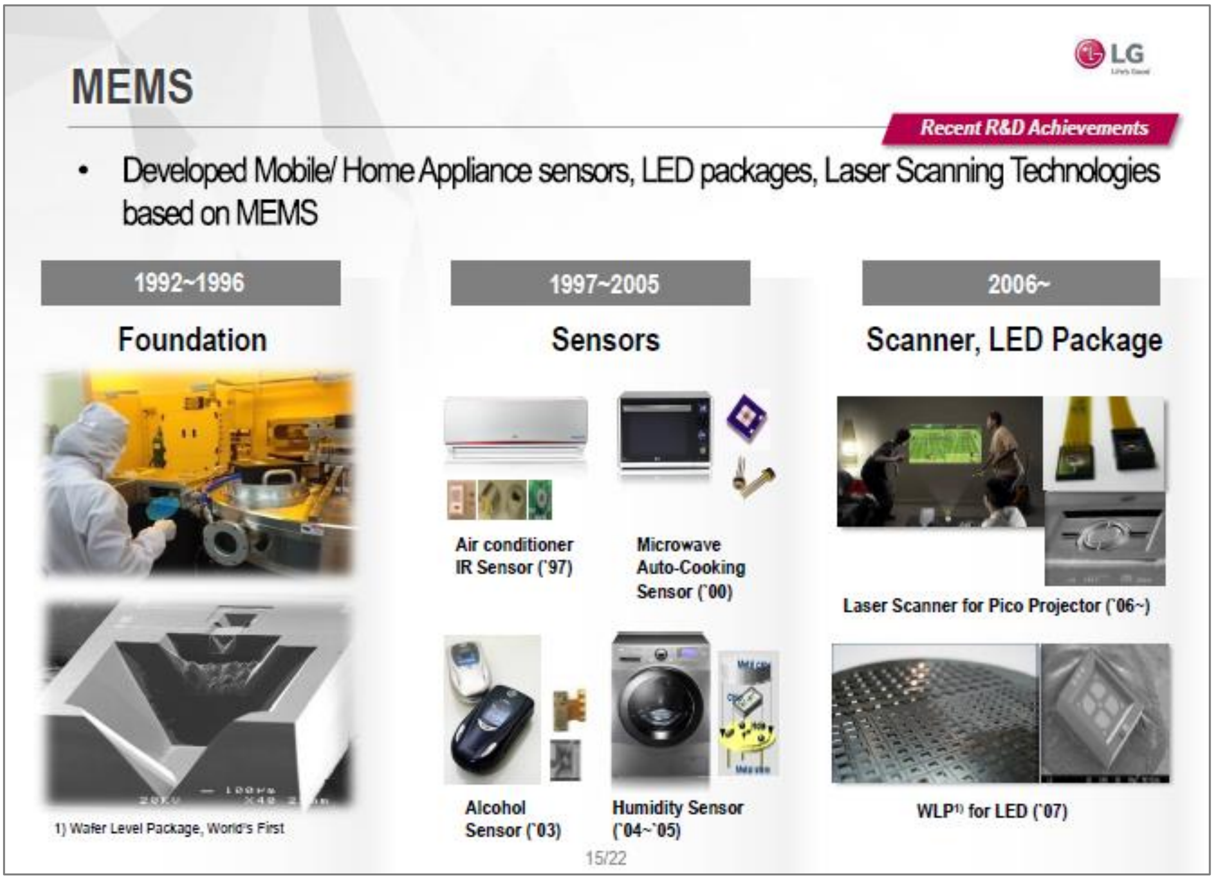

Figure 12. MEMS

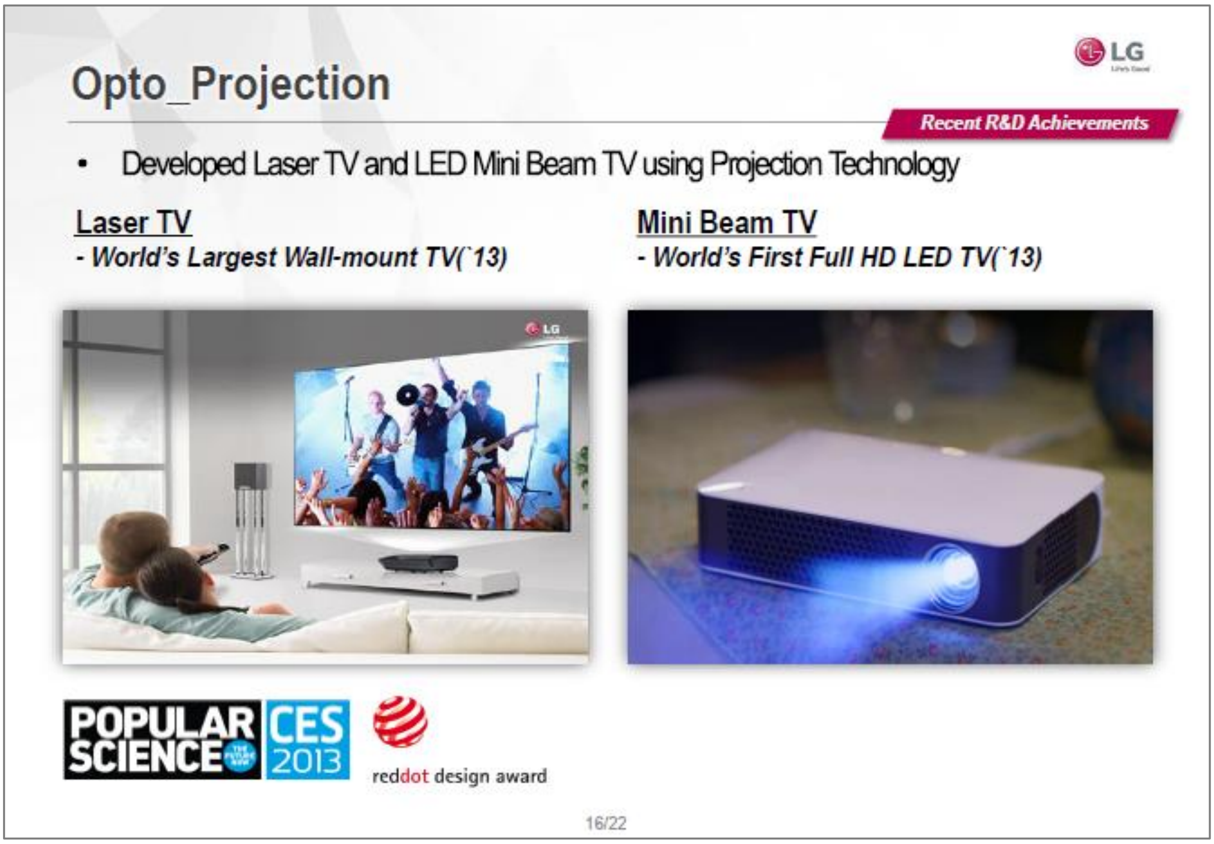

Figure 13. Opto_Projection

For the optoelectronics, we have a long history of the development of LED and solar devices. As I have mentioned previously, we developed Korea's first Blue LED in 1996, and we have our original patent for vertical LED technology. And as some of you well know, this LED device technology is very critical for the high power applications, for example, street lamps and head lamps for vehicles. Also, we have a long history of solar cell device development. For example, we developed silicon thin film solar cells, achieving world-record efficiency certified by NREL (Figure 14).

And recently, we have paid great attention for the development of nanomaterials including graphene and phosphor. We have applied graphene to the mobile phone for the heat dissipation, and we have developed phosphors, that are very stable at very high power applications including street lighting and car head lamps (Figure 15).

I think that the automotive industry maybe the next-generation platform for electronics companies and we have great interest for the application of our technologies to vehicles. For example, based on our optics technology, we are now developing a head-up display, a new concept head lamps and rear lamps. For your understanding, I have prepared some special video clip, so please pay attention to this video. This is our vision for the future vehicle. I believe that MEMS, optics, or nanotechnology may play a very important role for the development of future vehicles (Figure 16).

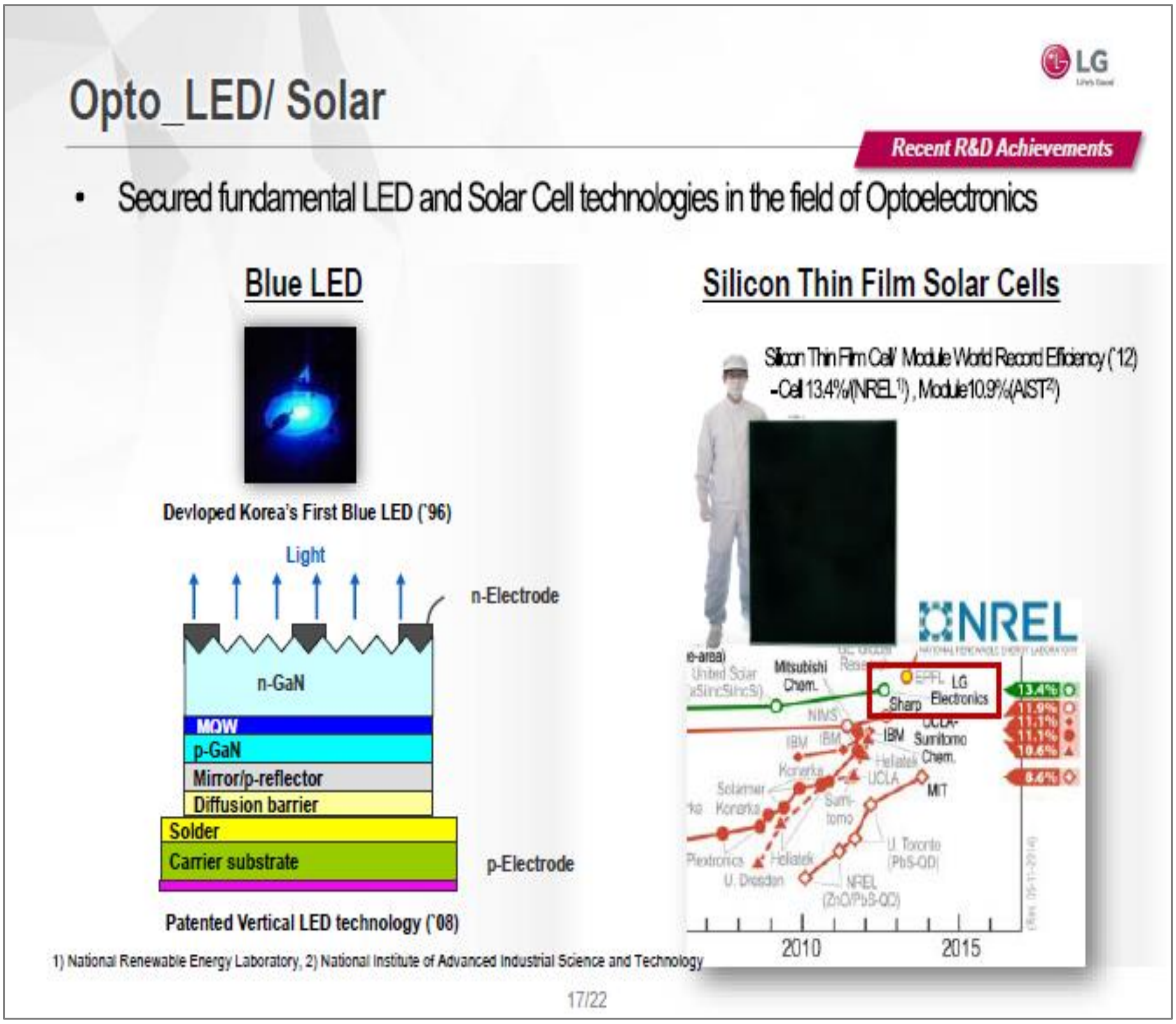

Figure 14. Opto_LED/Solar

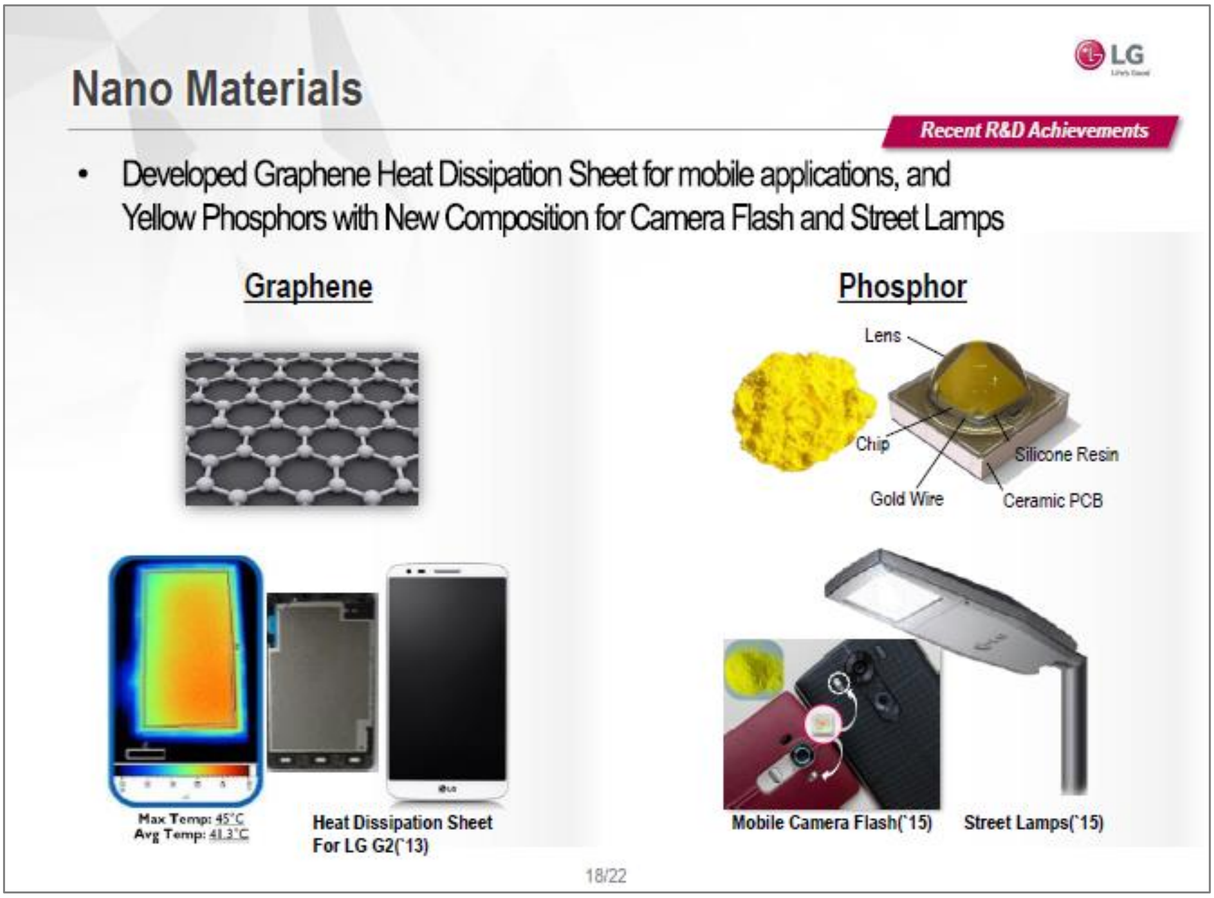

Figure 15. Nano Materials

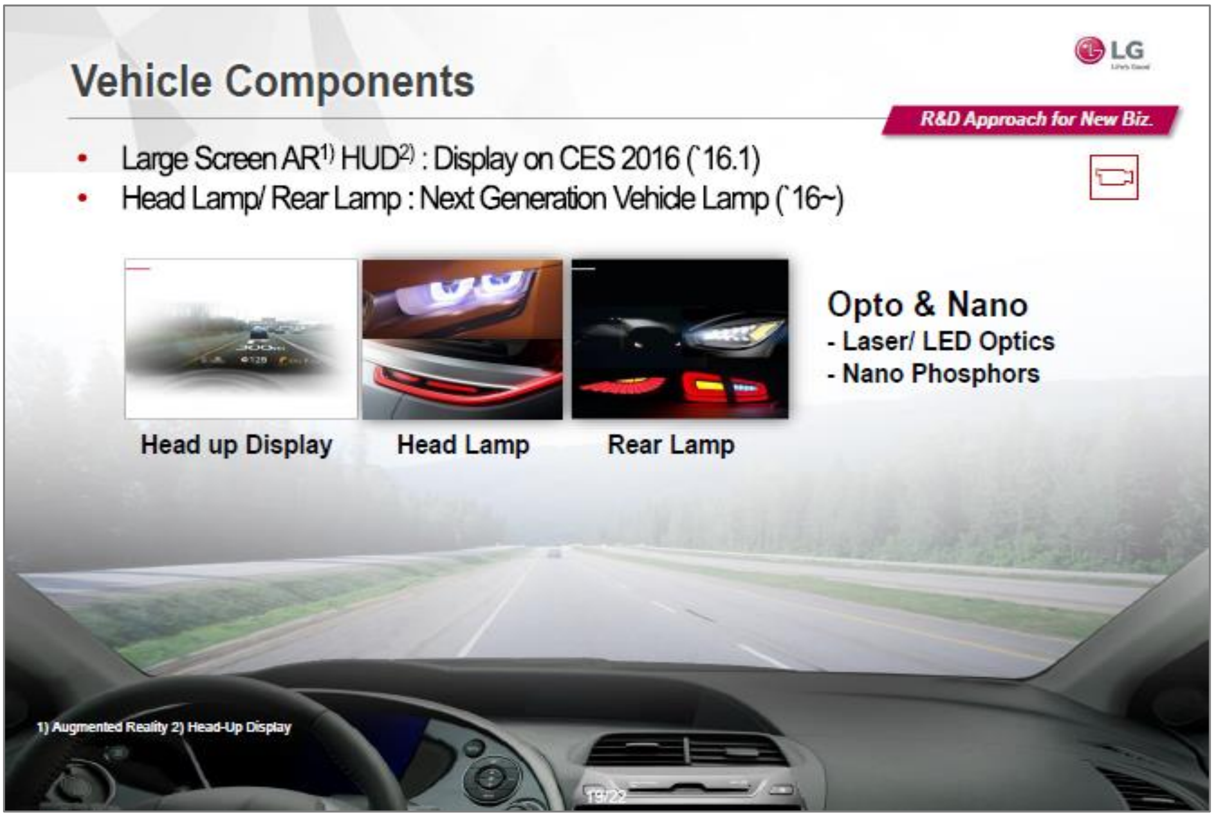

Figure 16. Vehicle Components

Another good example of application for the MEMS scanner technology is the B2B area. We have developed a special concept of new shelf display for the market with a MEMS scanner. And we are also developing future signages with advanced opto- and nanotechnology (Figure 17).

And for the energy and environment, we are now working on the next generation technologies. Currently, our solar business is based on silicon wafers. However, due to intrinsic materials characteristics, it cannot exceed 400 watts for the panel. In order to exceed 400 watts, we have to change the material and we think that a wide band gap material, such as Gallium Arsenide (GaAs) is a good candidate. Currently, we are developing solar cells based on GaAs technology. And last year, we have achieved world record efficiency certified by NREL.

Environment is also a very important area for LG Electronics. As you know, there is a problem of fine dust in the atmosphere. We are currently developing a new type of air purifier using nanomaterials (Figure 18).

Conclusion

Today, I have shared some of our recent R&D activities for the MEMS, opto- and nano-technology. I believe that we can achieve good innovation with these technologies, and this can be the key role for the success in our new business areas including B2B, energy, and vehicle components. And we believe that, to gain competitiveness, we cannot do it only by ourselves; we need some collaboration with outside partners. So we are looking for open innovation with national research centers and universities. So I hope there would be opportunities for future collaboration (Figure 19).

Thank you.

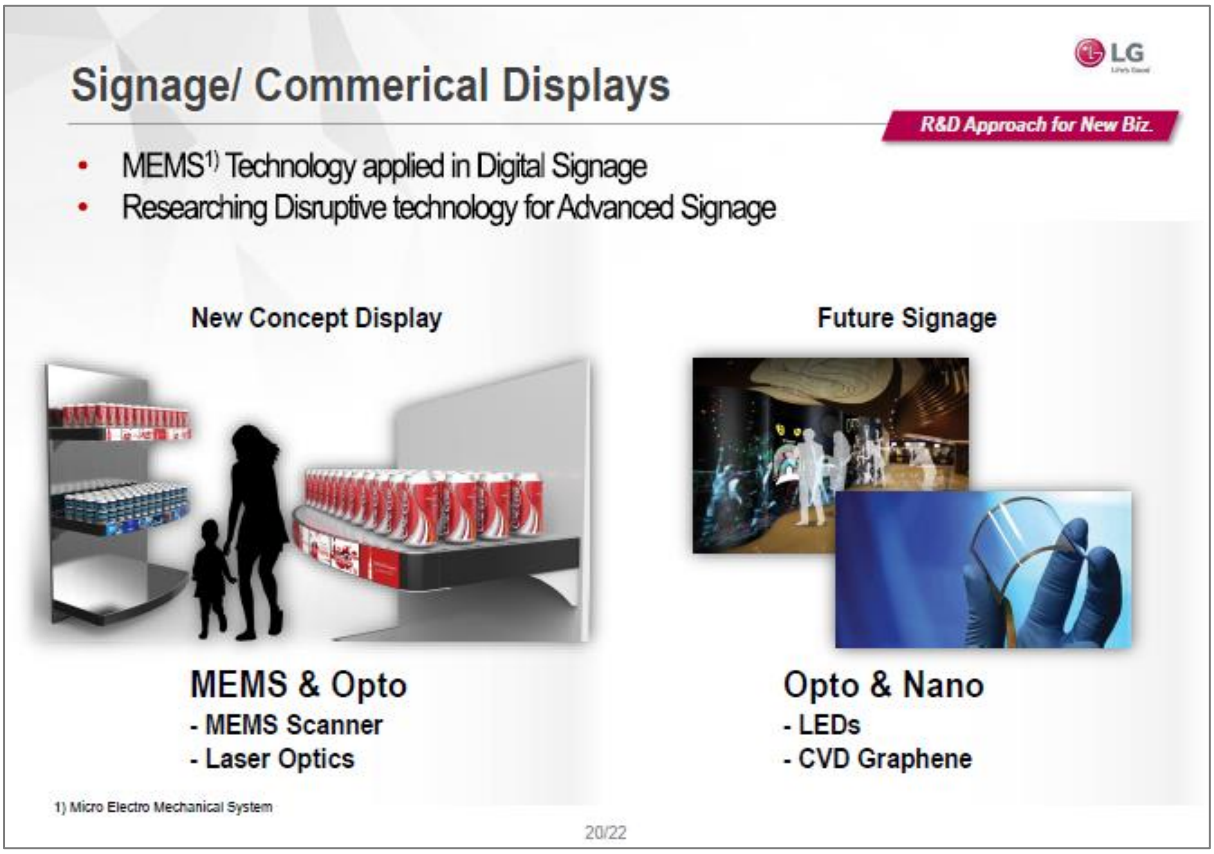

Figure 17. Signage/Commercial Displays

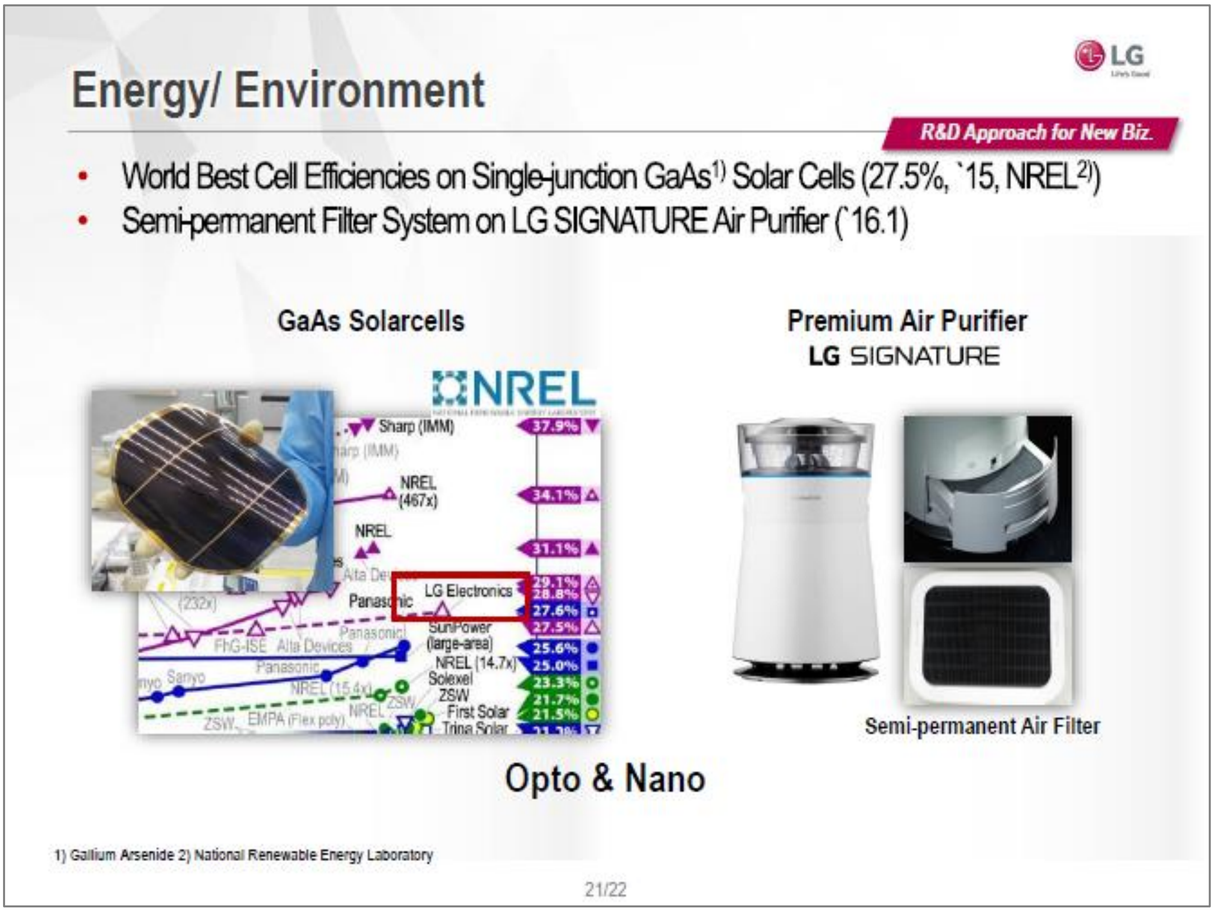

Figure 18. Energy/Environment

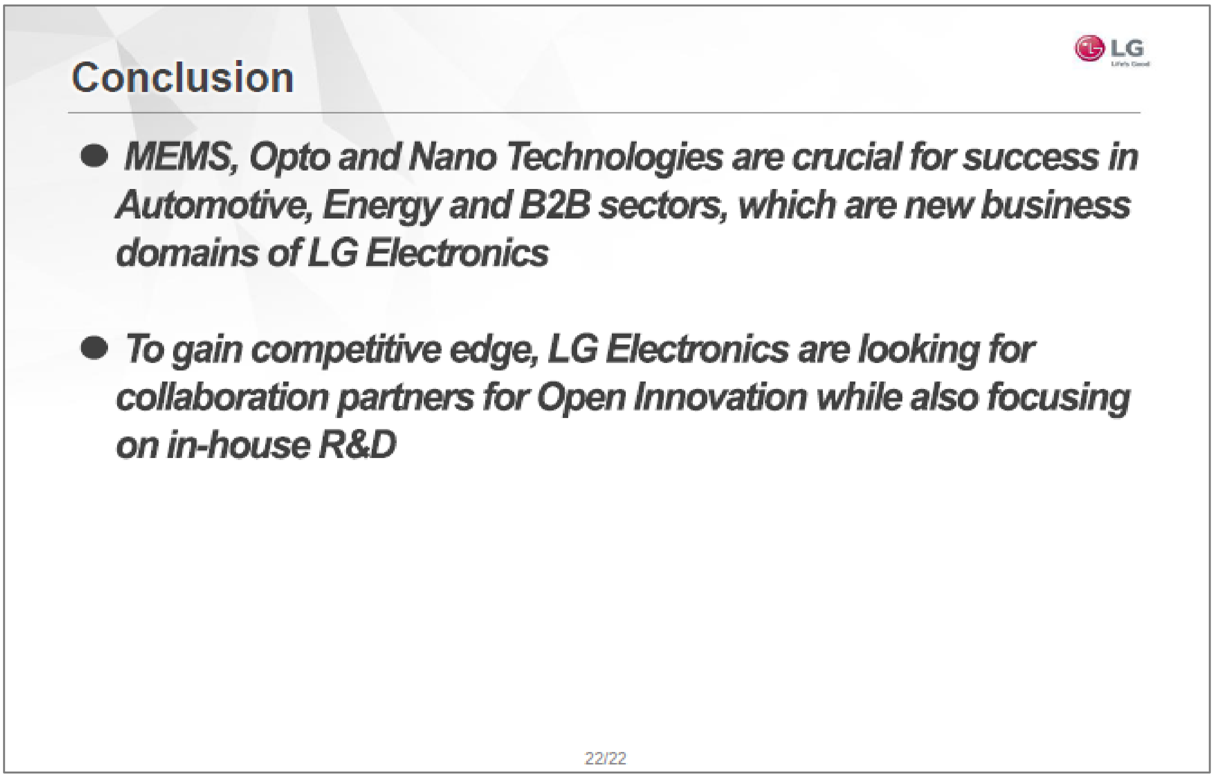

Figure 19. Conclusion

Q&A

Q1: Why do you think the electronics for automobiles are the next direction to go? The market is obviously there, but is the technology ready for those?

A1: Yes. Actually, a great portion of technologies are already ready. And we think that, within two or three years, I believe that we can make a real product.

Q2: With self-steering and 60% of electronics, but still have a piston engine under the hood, exhausting dangerous gases. So that's what I am trying to say is, "We should consider the systems; not only parts of the system."

A2: I fully agree. Not only for the material and device technology, but also the system design is very important. We should all work together. I agree.

Laser Welding in High Volume Production

Dr. Peter Hoffmann
Professor & Managing Director of
ERLAS Erlanger Lasertechnik GmbH

Today, laser technology is essential for flexible industrial production by means of a kind of process that can be used for high volume production as well as for prototyping. So today, I would like to focus on laser welding, because time is short, I only have 30 minutes, and I decided to have this topic here, "Laser Welding in High Volume Production." I would like to give you an idea of how laser welding technology can be used in high volume production and how laser welding technologies allow new product designs which were not possible in the past without this new beam technology.

Introduction

I would like to make some remarks on the advantages of laser welding as compared to other welding or joining technologies. First of all, laser welding is a very fast and precise welding process: twenty meters per minute. Welding speeds up to 20 meters per minute are feasible in cheap metal material for one-meter thickness, for example. And how is laser welding different from other welding technologies? The laser only needs access to some part of the materials and from only one side. If you think about spot welding, you need clamping for both sides, but laser welding is feasible with access from only one side. So, the laser is working contact-free with minimum heat input, which means low distortion of the assembly. Last but not least, laser welding allows the production of weld seams which are small and have deep penetration, and you can produce, for example, a butt weld as shown in this figure here or fillet welds, which would not be possible with other welding technologies. This method of welding allows us to combine materials in really complicated assemblies; for example, sheet metal parts, with sintered parts or with machine parts in one assembly (Figure 1).

Laser Welding

In the course of the last year, laser welding has become important also for power train components. In this figure two examples are shown; it's a gear shift controller and a shift fork which are made of a high number of child parts. This gear shift controller, for example, is built from seven parts and has 17 weld seams which are scattered all over the component. What is common for both applications is that the welded assembly has to be kept in the narrow tolerances for functional measurements. For example, the distance between the shift fingers is tolerated to 0.05 millimeters. So small tolerances can only be achieved if the assembly is welded in one fixture in one clamping (Figures 2 and 3).

Robot-Guided Welding

For doing such a welding, special machines are necessary. One solution which is useful for such an application is shown in this figure here. It's a robot-guided system. So, a robot has a welding head in its hand, moving the welding head towards the relative movement of a workpiece. So, a workpiece itself is in a clamping which is rotating, so you get access from all sides of the workpiece. This machine is manually loaded; that means there is a turntable in front of the robot. The turntable carries two identical stations. The robot can produce one assembly, while the operator is feeding the parts for the next assembly (Figure 4).

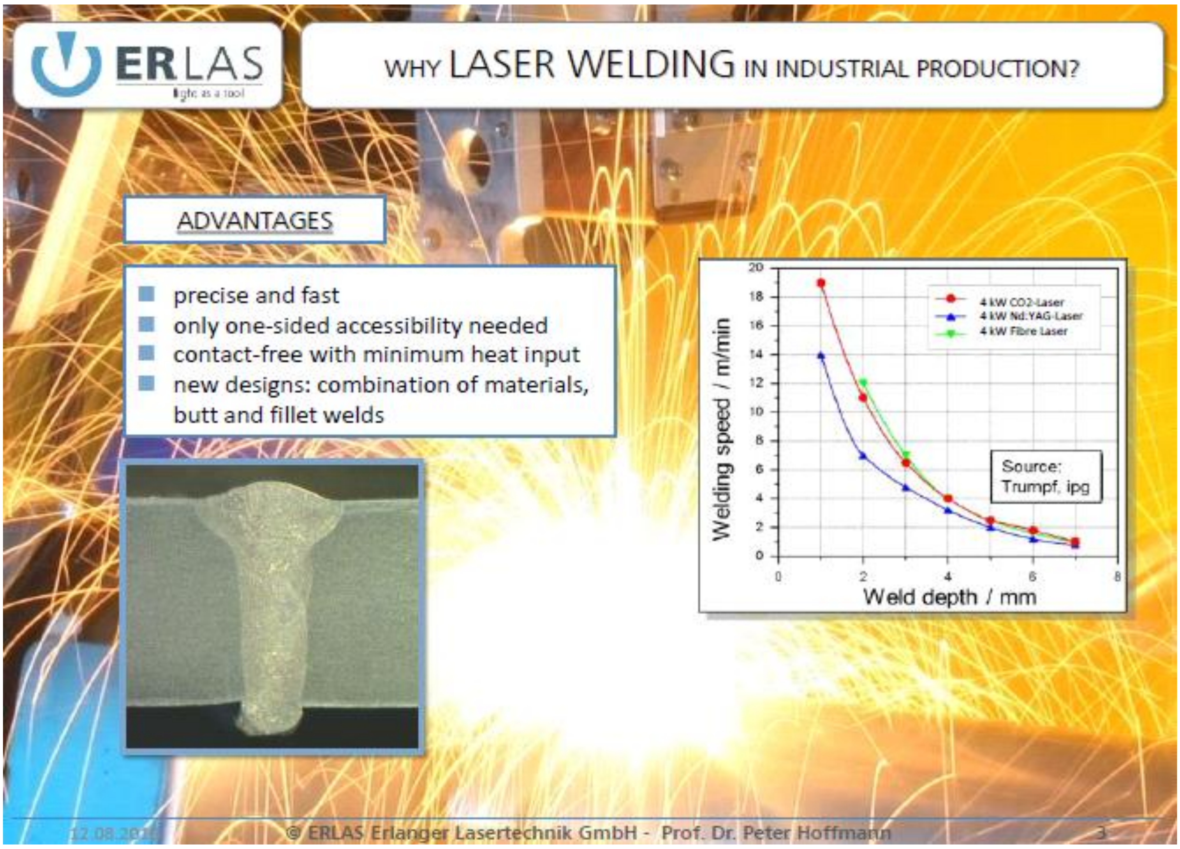

Figure 1. Why Laser Welding in Industrial Production?

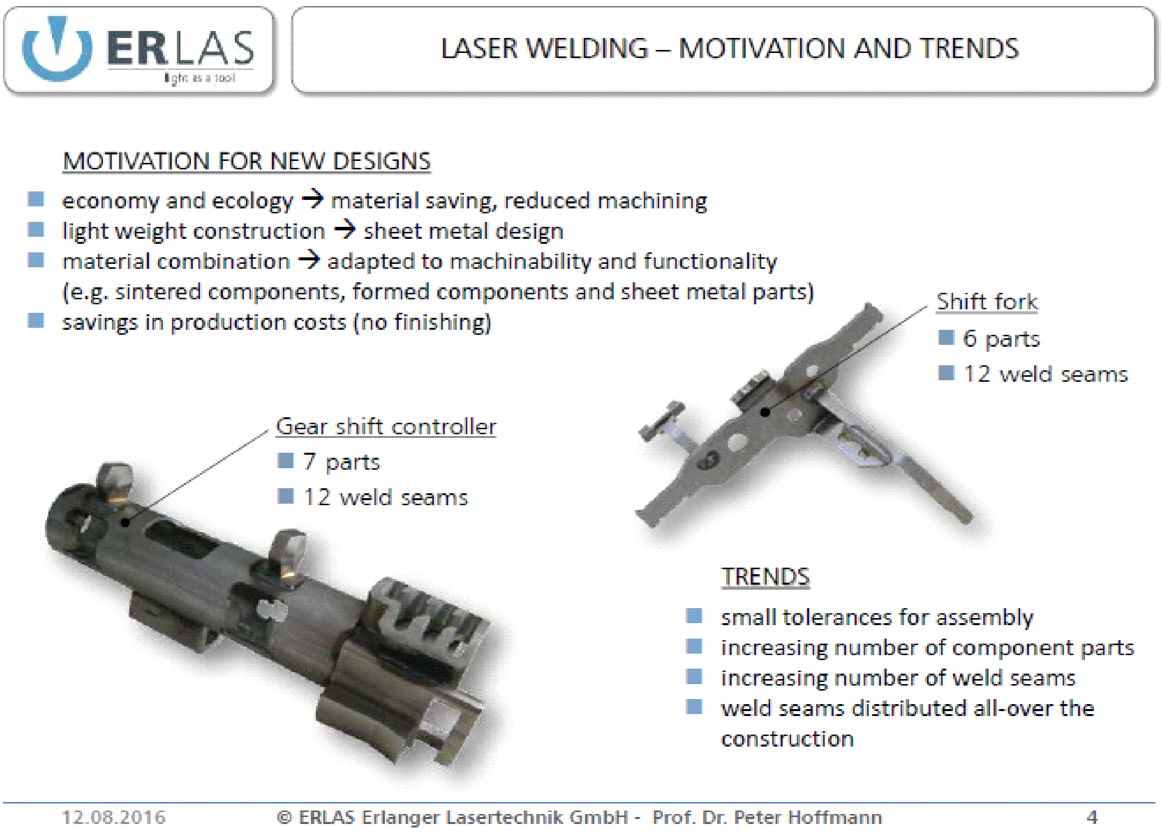

Figure 2. Laser Welding - Motivation and Trends

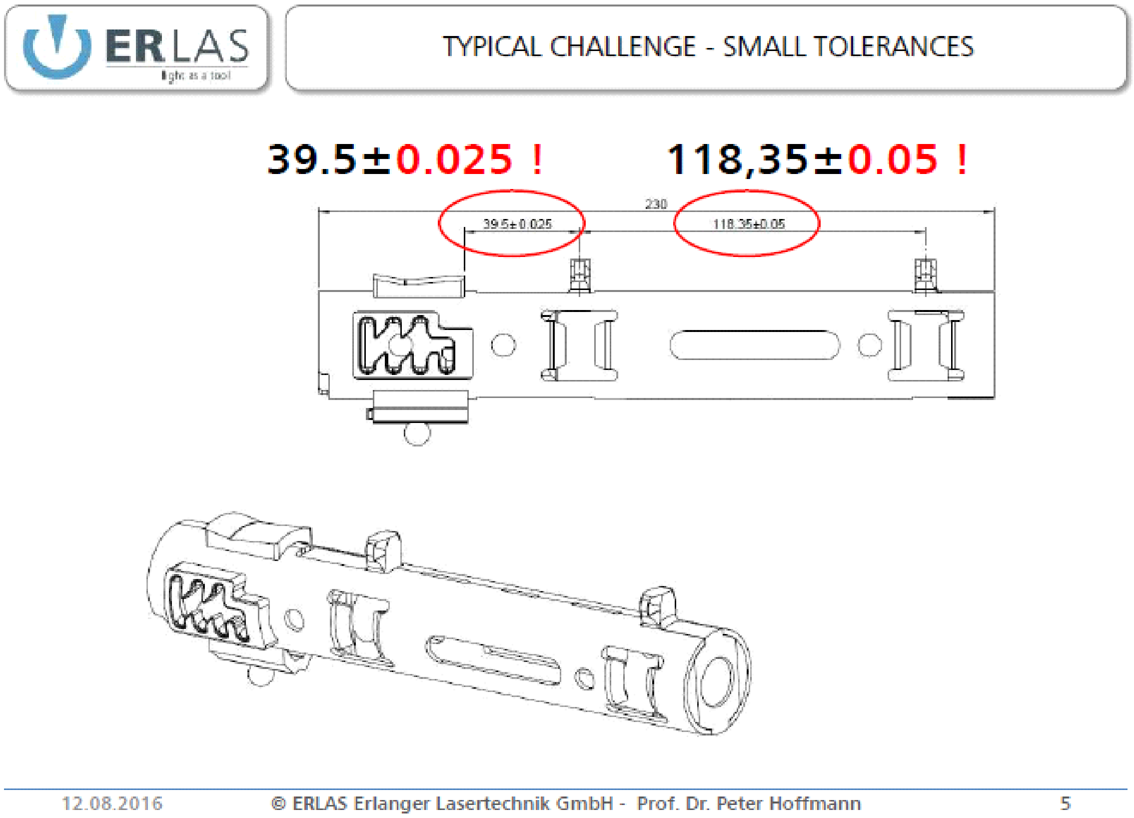

Figure 3. Typical Challenge - Small Tolerances

Figure 4. ERLASER® Weld Robot - Robot-Guided Welding

I have a short video which shows the production of such shift forks. Here, on top, on the left-hand side, you see child parts which have to be brought into sub-clamping. (Please start the video clip.) See the operator entering the safety area now. The clamping opens automatically. The operator enters the safety area, takes out the completed assembly, and brings in six child parts. The clamping closes automatically. All the CCT cams check that all parts are in the right position. The operator has to confirm sets from outside of the safety area so that the table can turn. During this exchange of parts, the robot is welding one assembly inside. As I told you, laser welding is fast: 20 meters per minute. Now it is obvious that producing the shift fork is only possible with laser welding. Its limiting factor is the robot, the positioning of the laser head towards the workpiece. So, that's the reason why the cycle time of this machine is 25 seconds. It only takes 25 seconds to produce one shift fork. A shift fork is part of a double clutch gear of the Volkswagen concern, and each double clutch gear needs four types, four variants of shift forks. That means the total demand is 1.6 million shift forks per year. This can be done with four such machines and three daily work shifts (Figure 5).

(The video clips are uploaded on the Forum website: forum.kimm.re.kr)

Development of Motor-Vehicle Production

Now let's have a look at the development of the market for vehicles during the last year. So, the market volume is rising very, very fast, especially in China, and also here, in Korea. Today, even more than 90 million vehicles are produced per year. Korea, for example, has a share of 8 million cars, which are produced under the Korean brand (Figure 6).

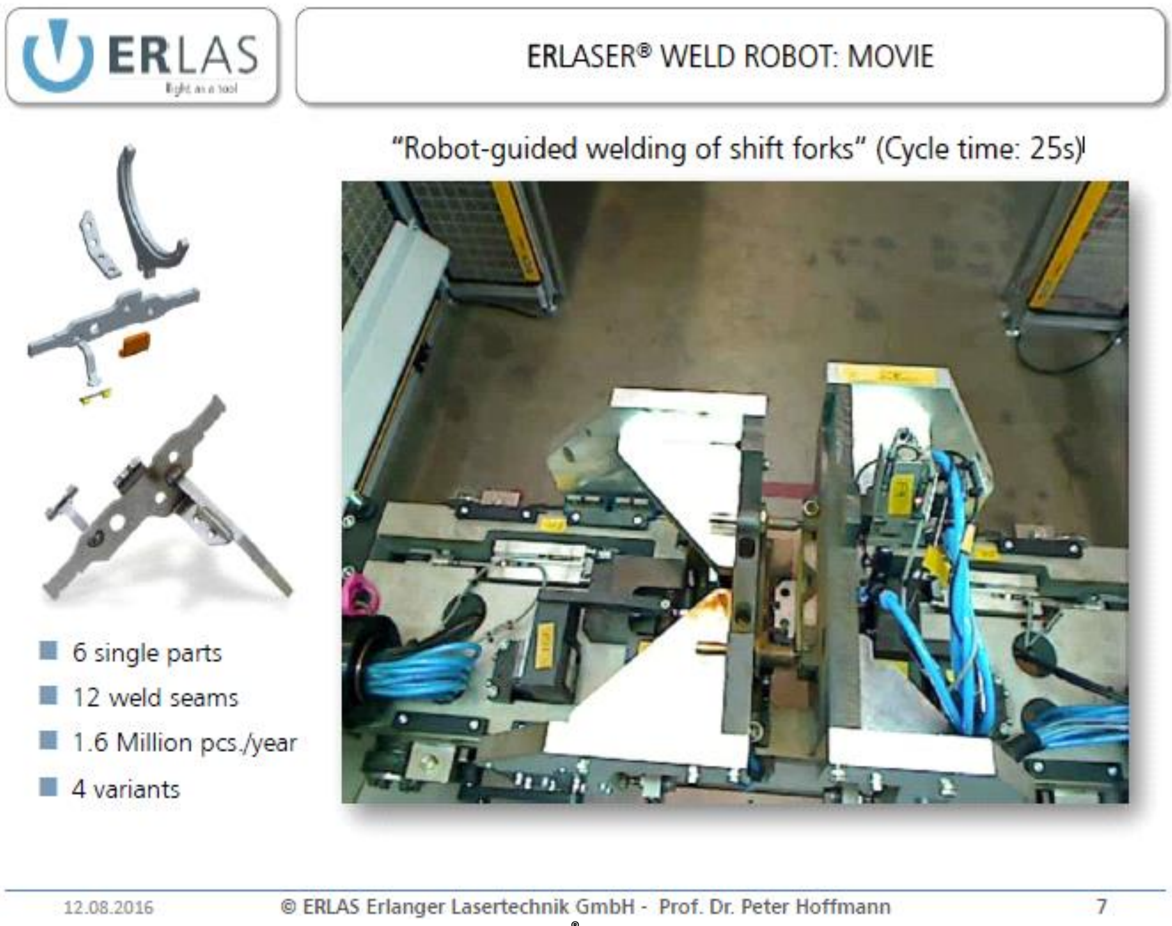

Figure 5. ERLASER® Weld Robot: Movie

With this background, it's important to have new production technologies and the old quote by Henry Ford becomes very important again. Henry Ford said "Any customer can have a car painted any color that he wants, so long as it is black!" So, in 1923, he realized a production line which was capable of producing more than 2.2 million cars per year. So it's important to have standardized products in manufacturing. That's a possibility to decrease the unit cost. It's an old idea, but it's getting important again (Figure 7).

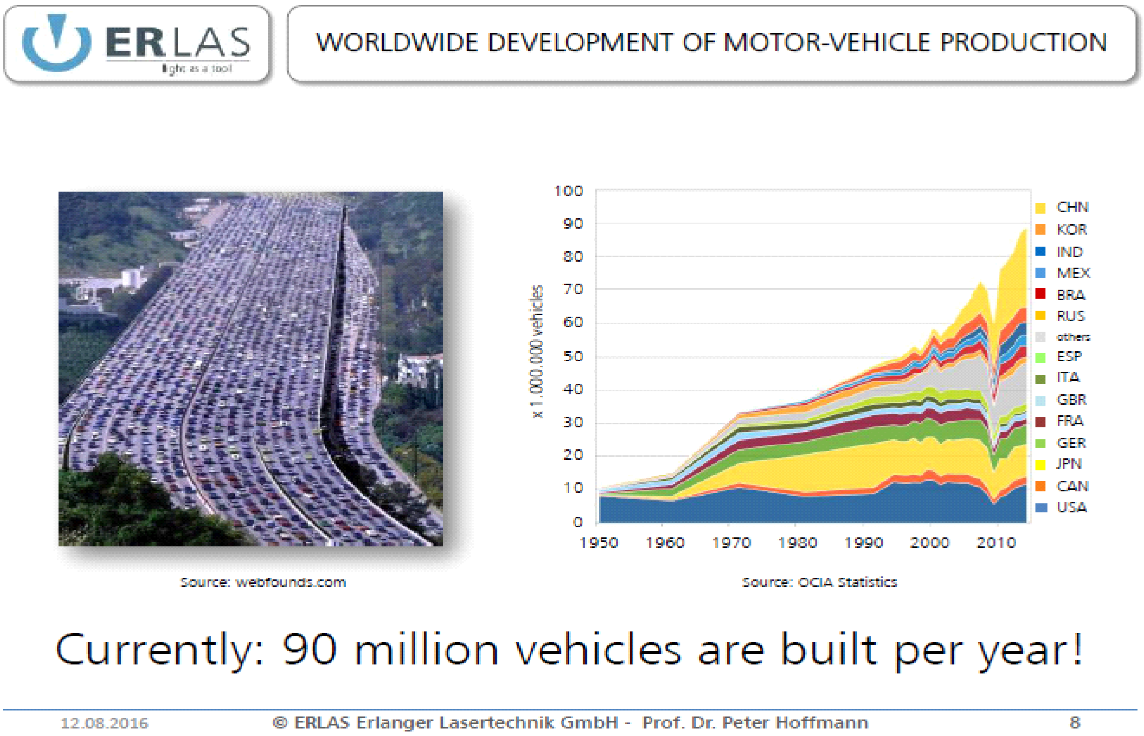

Figure 6. Worldwide development of motor-vehicle production

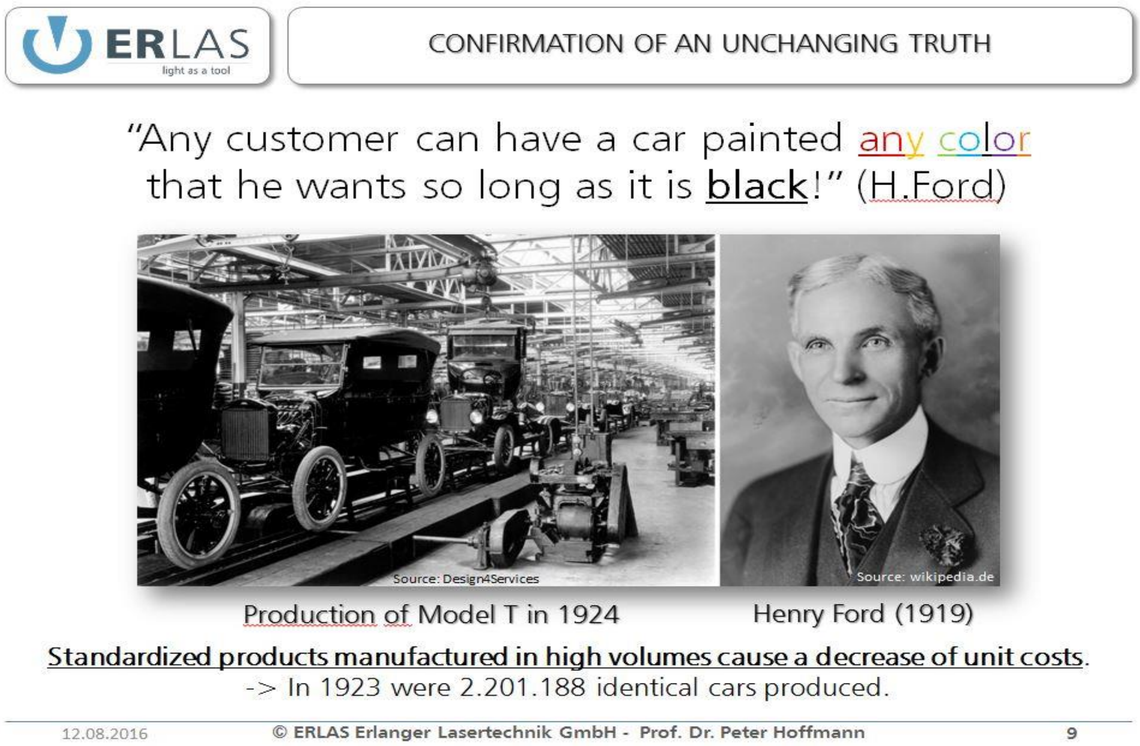

Figure 7. Confirmation of an Unchanging Truth

Model Variants

It’s a little bit in contradiction to that what you see here. People want to buy an individualized car. That’s the reason why the manufacturers of cars have different classes of cars and different types, models of cars. So you can get a sedan or coupe, any size you want, and you can pay any price for a car. However, what’s the truth? All cars are based on similar platforms. And this platform strategy means that all cars have the same modules such as gear shifts or steering columns. This makes it necessary to produce these components in very, very high numbers per year (Figure 8).

Again, yes, one of the largest platforms currently is the platform of Volkswagen. Volkswagen is working on a platform with a total of 40 models, and the idea is to have technologies that can be used for upper class models as well as volume models; and the goal, long-term goal, is to produce all models with the same technology worldwide and realize competitive prices by doing that. The models look different inside, although they are all black (Figures 9 and 10).

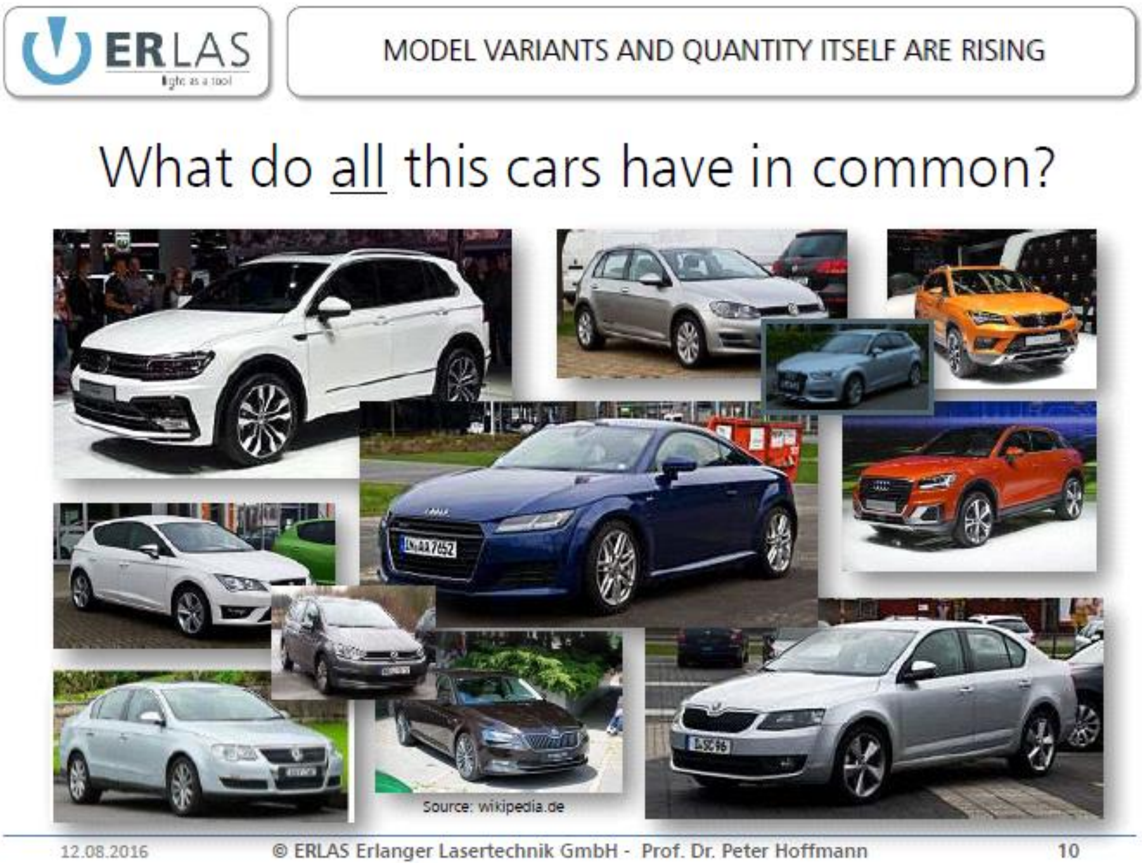

Figure 8. Model Variants and Quantity Itself Are Rising

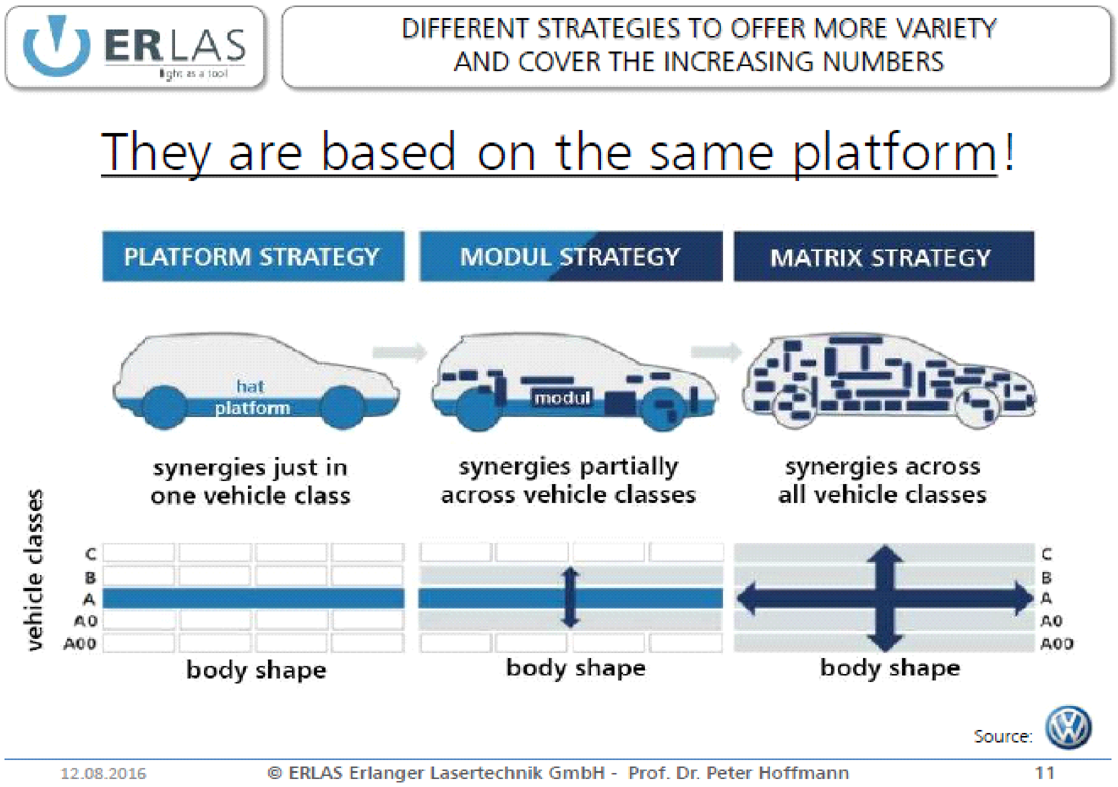

Figure 9. Different Strategies to Offer More Variety and Cover the Increasing Numbers

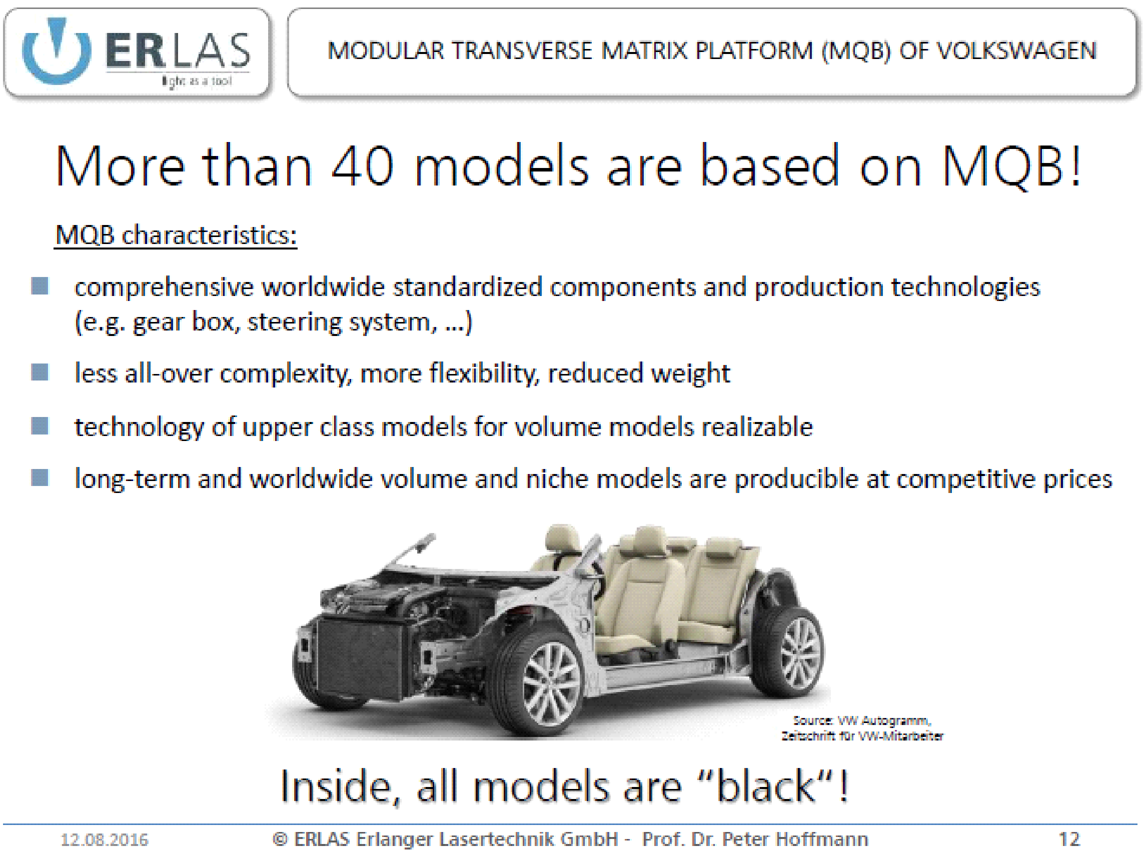

Figure 10. Modular Transverse Matrix Platform (MQB) of Volkswagen

The Real Challenge – High Volume Production

Here is one example of the strategy. It's the steering of the car. One of the most complicated components of the steering is the so-called column jacket or bracket. This bracket is produced out of eight metal sheet parts and five plastic parts. This bracket needs to be joined by 26 weld seams. The yearly demand is 9 million components. So, let's get back to the example I showed to you before, the shift forks, with 1.6 million pieces per year, twelve weld seams and, four applications - four machines are sufficient. If you make a rough estimation on how many machines would be necessary to produce such brackets, you will realize that 49 machines would be necessary to produce the same product. I think that's not a solution of interest and a new way of producing such components has to be found (Figure 11).

In 2012 we started this task, and we decided to have a new system technology which is based on two key ideas. One is that, in the future welding should be done with a laser scanner. A laser scanner offers the possibility to position very fast. The highest speed you can move with a laser scanner, i.e. with a laser beam, is 70 meters per minute. So, you can reduce the primary processing time drastically. The second idea was that the preparation of assemblies should not be done manually and direct in front of machines but outside of the machines with so-called mobile workpiece carriers, where the assemblies are prepared automatically (Figure 12).

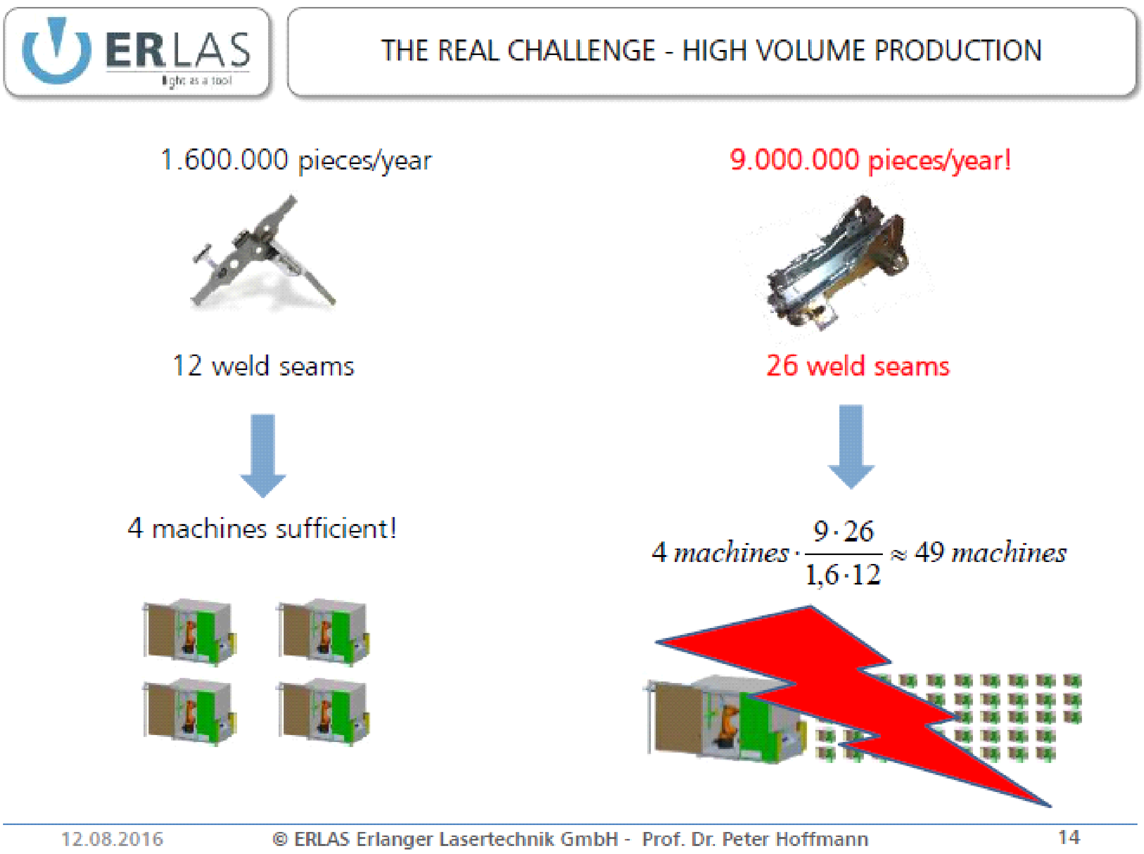

Figure 11. The Real Challenge - High Volume Production

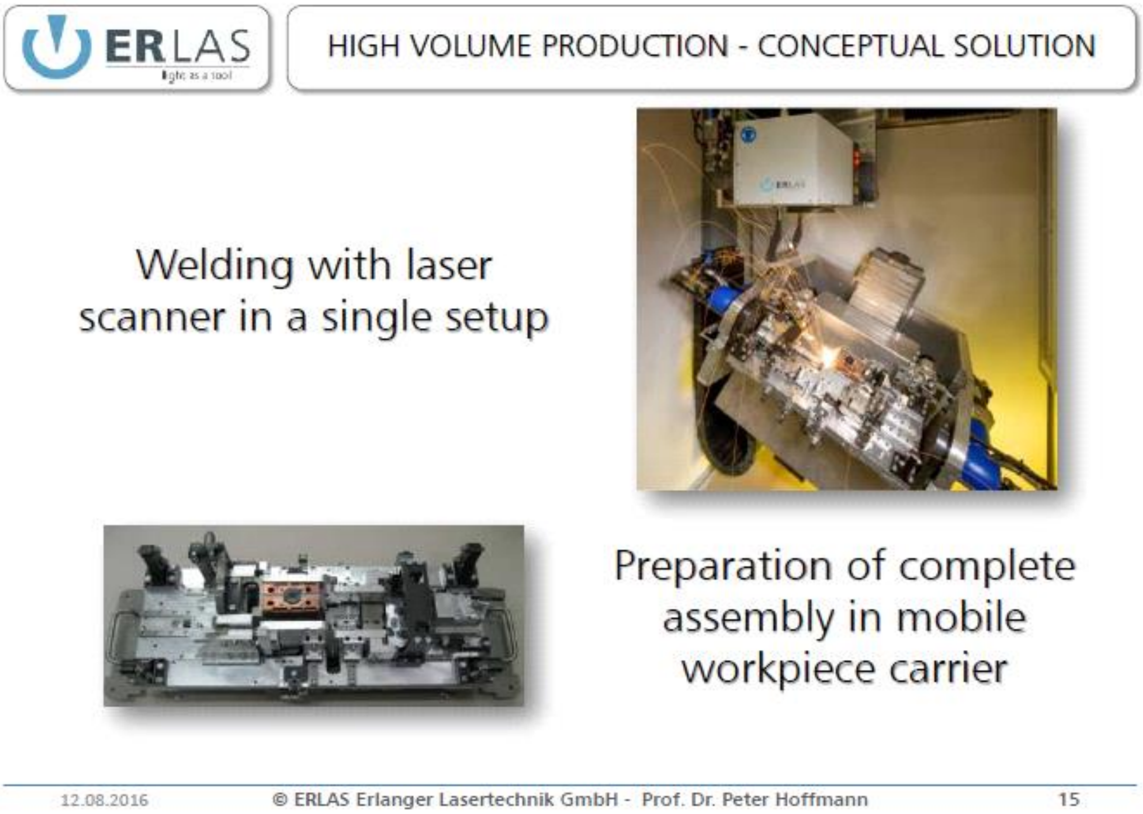

Figure 12. High Volume Production - Conceptual Solution

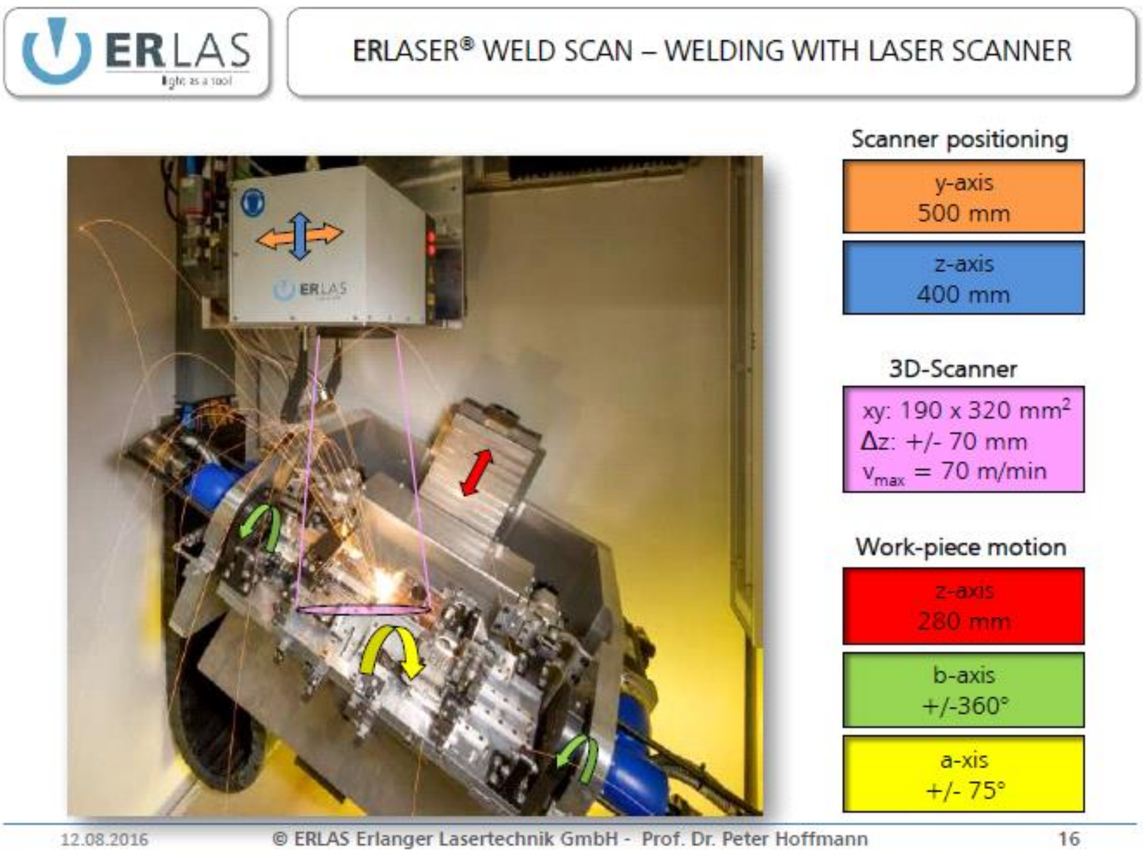

Figure 13. ERLASER® Weld Scan - Welding with Laser Scanner

Weld Scan - Welding with a Laser Scanner

Let's have a look at a welding cell. The white box you can see is a laser scanner. It's a 3D scanner which has an application field of 320 millimeters by 190 millimeters, and the focus can be shifted 70 millimeters up or down. So, you have three-dimensional work volumes with this laser scanner. The scanner itself is mounted on a cross table so it can be positioned towards the workpiece. The workpiece itself, the workpiece carrier can be moved by tilting and rotating axes. So, in this case, we have hybrid kinematics which allows high-speed welding with high precision (Figure 13).

In this short video, you can see how 26 weld seams are made in only 7.5 seconds. We have a shuttle with a double gripper technology, so, the workpiece carrier exchange is very fast. As soon as the workpiece carrier is inside the machine, the process starts, and now 26 weld seams are welded. Of course, it's impossible for a worker to feed 8 metal parts in seven seconds, so we had the idea of using these mobile workpiece carriers. The workpiece carriers are very special; they have a very special design. They have only passive clamping elements; no actuators are used on this clamping device (Figure 14).

(The video clips are uploaded on the Forum website: forum.kimm.re.kr)

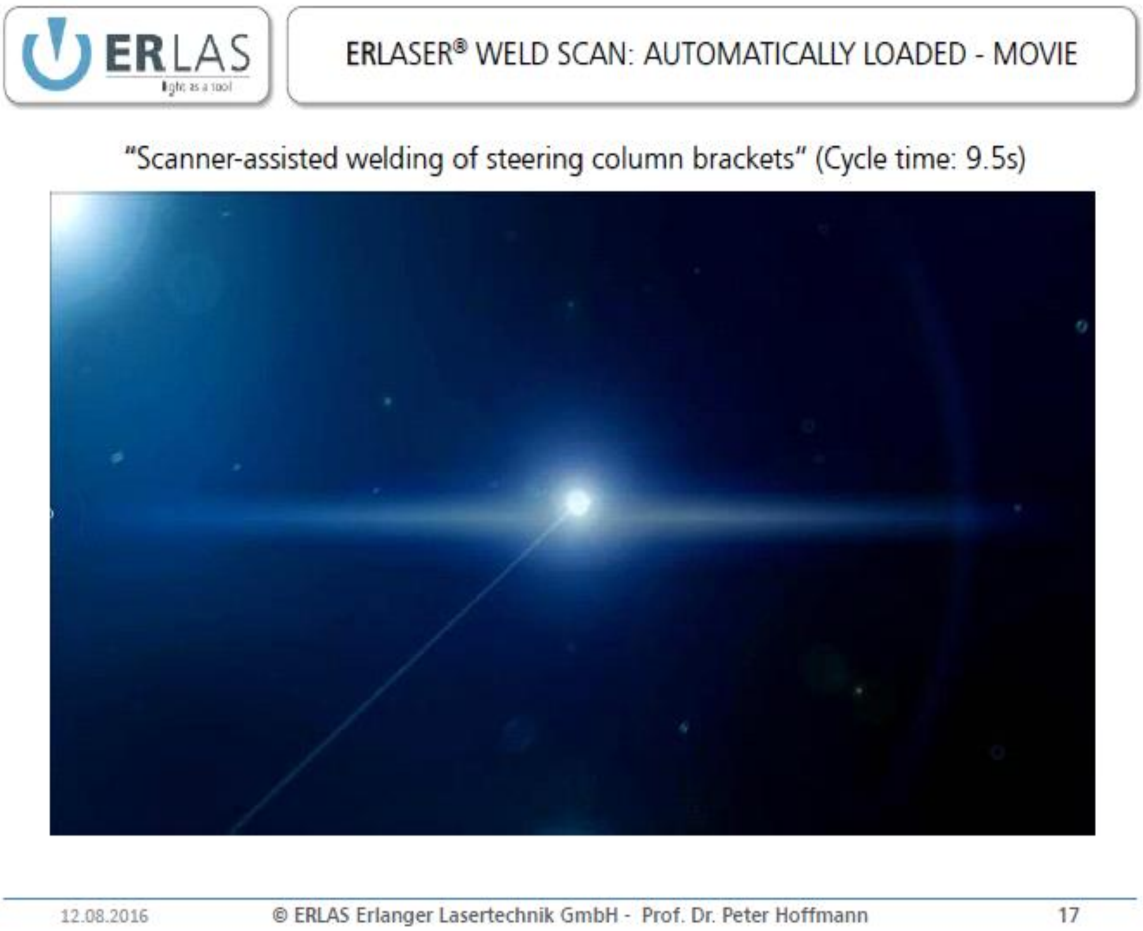

Figure 14. ERLASER® Weld Scan: Automatically Loaded - movie

For the handling of the workpiece carrier, we have a locking technology, and this figure, this picture on the right side shows the bottom of this workpiece carrier with a gear which makes it possible to open and close all the clamping devices on the workpiece carrier. I have another video which shows how those workpiece carriers are prepared for laser welding. There are four robots working together, and on the left side, you can see the actuator plates which are opening and closing the workpiece carriers. The transfer system, the shuttle, brings the workpiece carrier in front of two welding cells, wherein welding with the laser scanner is done. This workpiece carrier moves inside the welding cell (Figure 15).

(The video clips are uploaded on the Forum website: forum.kimm.re.kr)

These two pictures also give an overview of the whole production line. It's a totally new machine concept for remote high-speed welding. With this kind of technology, in this case, we integrated two welding cells which have additional opportunities of workpiece orientation. The system is running with ten mobile workpiece carriers also for preparation for the assemblies in parallel with laser welding. You can see seven articulated robots handling and feeding child parts. In addition we have integrated 54 numerical controlled axes which are working synchronically via leading axis technology and controlled by motion laws. This means the movement of the axes is reduced in jerk. You can run the machine at high speed. With this machine concept, it's possible to produce almost two million pieces per year with one machine. This means, to cope with all worldwide demands for those components, you only need four or, maximum, five machines (Figure 16).

These brackets exist in four variants for different models. There is a mechanical variant as a long version; there is a flange. It's in a different position to the mechanical variants for the short version. And there are also two other variants for electrical applications. But what's important? The machine presented to you can switch between short and long variant without an interruption of production (Figure 17).

Figure 15. Automated Feeding of Workpiece Carrier - Movie

Figure 16. ERLASER® Weld Scan - Automatically Loaded

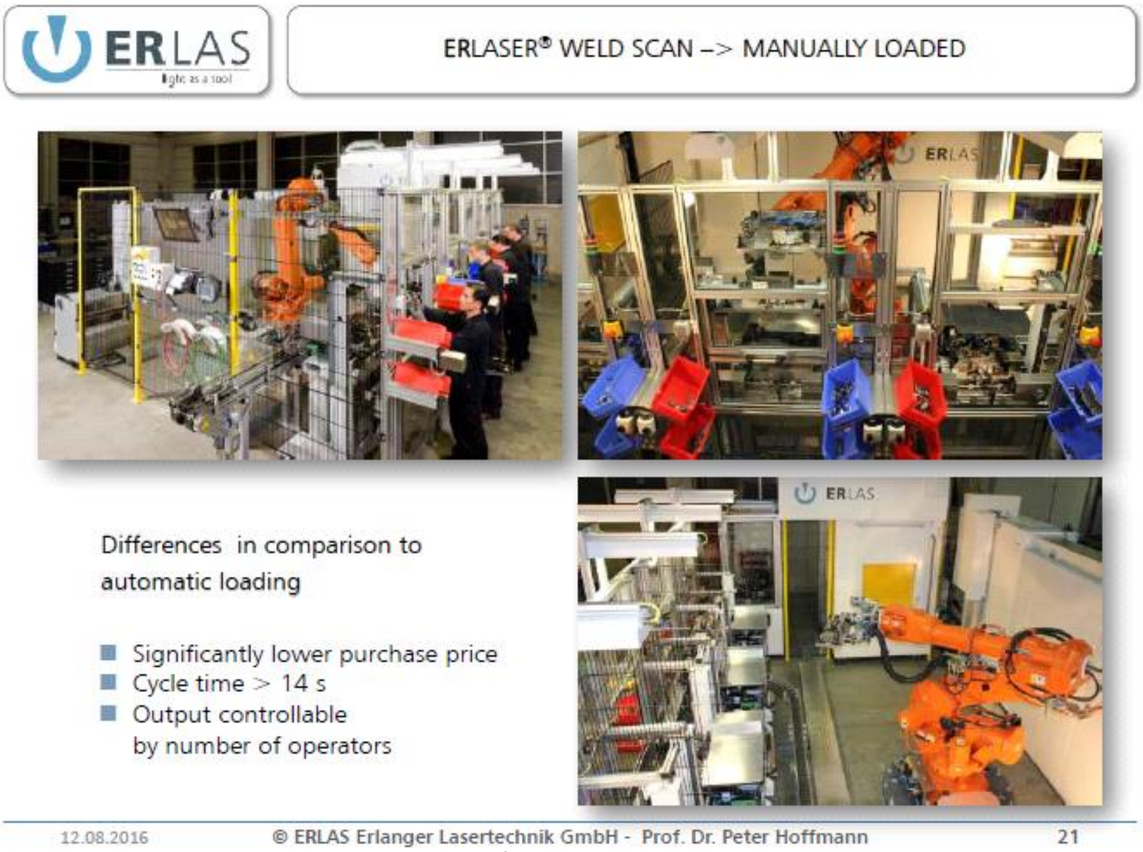

Figure 17. ERLASER® Weld Scan - Manually Loaded

Figure 18. Reflection at the End

Conclusion

Ok. Let me finish my talk with another quote by Henry Ford: "Almost anyone can think up an idea. The thing that counts is developing it into a practical product!" Thank you for your attention (Figure 18).

Q&A

Q1: Is it possible to have the laser go through optical fiber so that it can go around the corner?

A1: Of course, it's state of the art to guide the laser with an optical fiber. Indeed, we use this technology. All lasers which have a wavelength of 1 micron can be focused into an optical fiber and transported with this fiber. At the end of the fiber, of course, you again need an optical element to create a focus of the laser beam. But this guidance of laser radiation with fiber optics was a real innovation for laser technology. In the beginning, when we only had CO_2 lasers, the systems were very complicated. They had to integrate the beam guidance into the machine, and the machines were complicated and expensive. Today, for fiber guided systems, you can use a simple guiding machine like a robot, as I showed to you in one of the videos. The low-cost solution was a robot, but they have one disadvantage. A robot is not precise enough to use it for flexible applications or for applications where the demand for guiding behavior is very high. For example, butt seam welding or fillet welding was a robot-guided application. In the end, if you have a scanner mounted to a robot, it will not be able to realize the butt seam welding. You can realize overlap welding. It's not complicated. But in many cases, a robot is not precise enough. So, you have to decide, from application to application, which kind of guiding machine will fulfill the demands you have.

Q1': So, my interest was to, hmm, be able to weld, for example, inside pipes or around the corner. So I guess the answer is possible, but it's expensive.

Q2: I am interested in laser 3D scanners. Laser 3D scanner focus should be moving the jets' direction, right? So, my question is, did you use the 3D cad data or did you use some measurements to the 3D profile?

A2: The 3D movement of laser beam is realized with moving lenses integrated into scanner.

Q2: So how much should you move the jet direction; you should decide how much you change that direction focus, right?

A2': We check the levels of the focus for doing different weld seams in our design department. And today, unfortunately, the laser scanners have to be taught. You have no offline programming system for a laser scanner, there is really lacking reliability. So, also, the weld seams you saw in the video were taught and for a more flexible application, you have to develop new methods for integrating laser scanners and machines. Today, the controller for laser scanner is only a slave of the controller of the machine. So, the machine gives a signal to a laser scanner to start any program. It's not the interpolated movement of all of the axes together.

Nanostructured Materials for Improved Mechanical Response

Prof. Don A. Lucca
School of Mechanical and Aerospace Engineering
Oklahoma State University

Good morning, ladies and gentlemen. It's indeed a privilege for me to be here at KIMM to make this presentation, which, I understand, is being recorded for the 2016 IFAME that will be held here in KIMM in August. I'd like to thank, needless to say, my colleague and good friend, Professor Im and the Department of Nanomechanics and Dr. Kim for their kind invitation for me to give this talk.

Introduction

In this short talk today, what I would like to do is just to touch on two examples of how we can use nanostructuring of materials to improve their mechanical response (Figure 1).

So this is the outline of my talk. Again, we will look at two different materials: multilayered composites and metallic glasses (Figure 2).

Figure 1. Nanostructured Materials for Mechanical Response

So we will focus on nanostructuring these materials with enhanced mechanical behavior for advanced applications, and there are two distinct applications. The first is nanoscale multilayered composites for radiation tolerant materials. So these are high potential applications for nuclear reactors, next-generation nuclear reactor materials. And we need to think of these as simply alternating layers of nanometer-scale materials that are stacked on a substrate. The second example is nanostructured metallic glasses using ion irradiation in the hope of improving ductility (Figure 3).

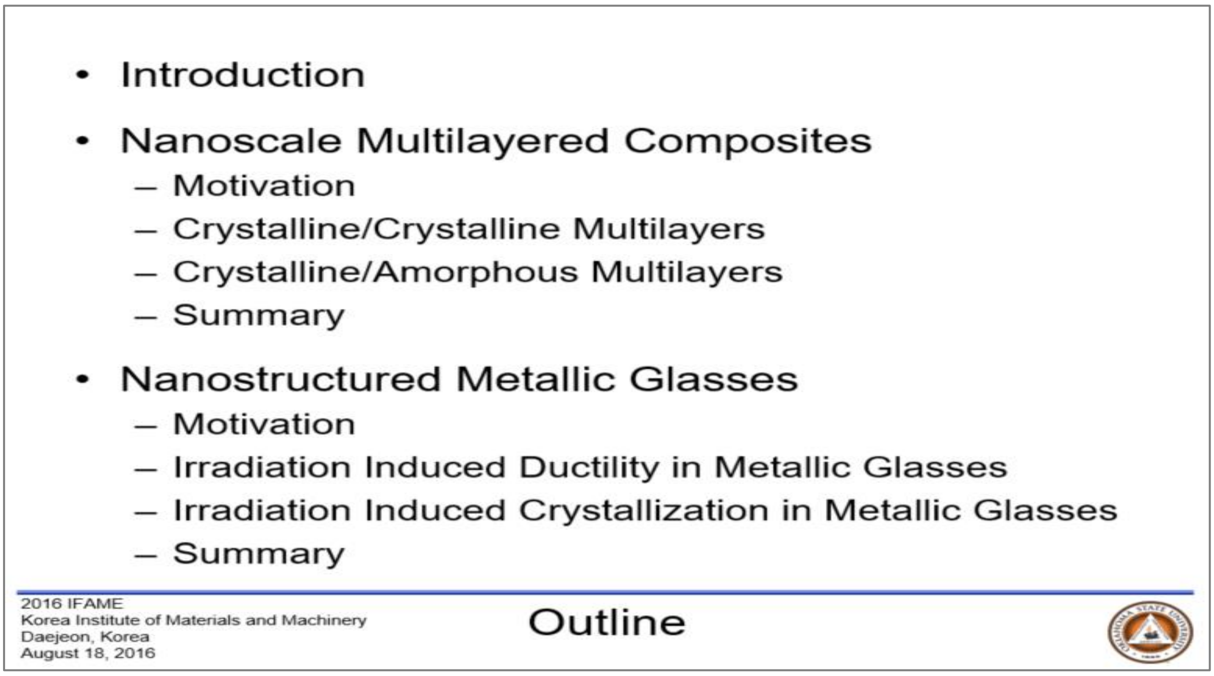

Figure 2. Outline

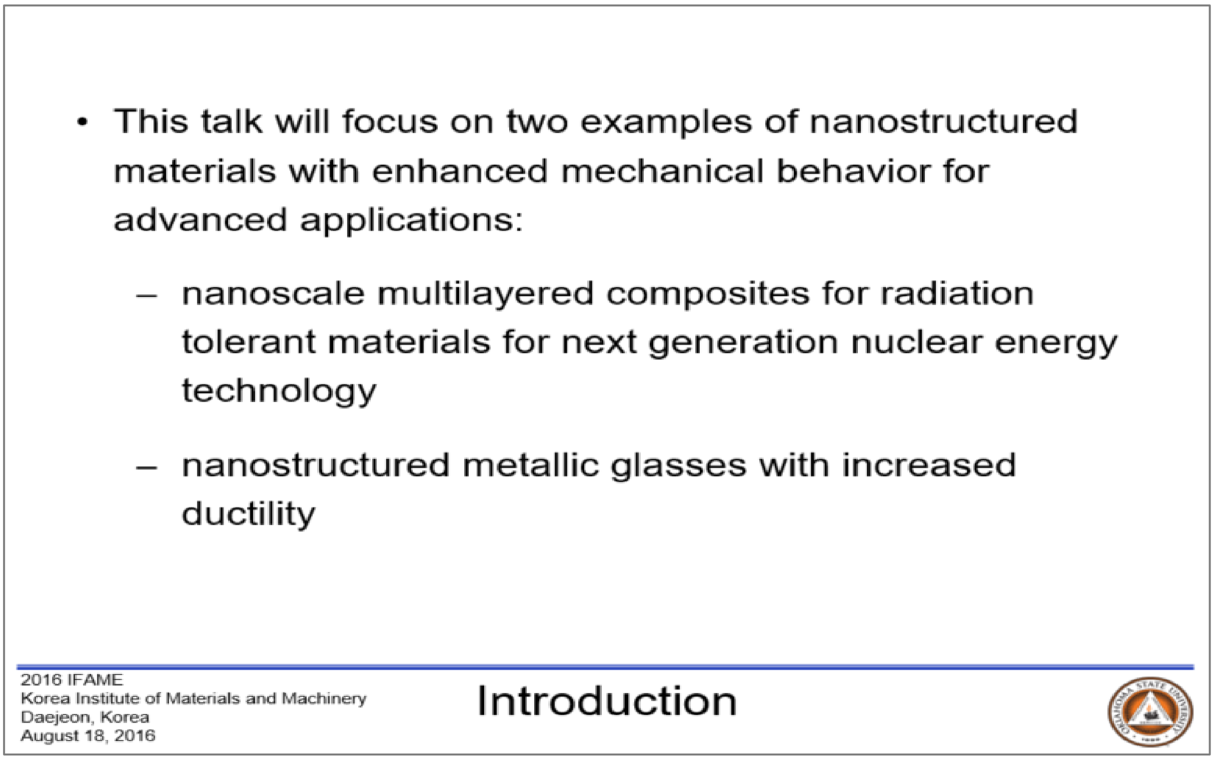

Figure 3. Introduction

Nanoscale Multilayered Composites - Motivation

So firstly, some words on multilayered composites. So next-generation nuclear energy technology really requires materials which are radiation tolerant. These materials in these applications undergo harsh environments, or harsh chemical environments, elevated temperatures and are subjected to neutron irradiation. And we know that neutron irradiation introduces a variety of point defects which can lead to blistering and ultimate failure. We also know, for basic materials, that grain boundaries and interphase interfaces play fundamental roles in material science. We learned this as undergraduates that these grain boundaries and interfaces affect strength, the fracture toughness, work hardening, and damage evolution under radiation. So there is hope then that we can use multilayered composites which basically have a large volume fraction of interfaces for potential application in these radiation-tolerant materials (Figure 4).

Nanoscale Multilayered Composites – Crystalline/Crystalline Multilayers

So we will look at two types, first, crystalline/crystalline multilayers and crystalline/amorphous. Here, I show a plot of hardness versus 1 over the square root of layer thickness. So this is a Hall-Petch plot. This has been reported in the literature. It is from Dr. Misra originally from Los Alamos and now University of Michigan, and his group looked at these various multilayered composite crystals, copper nickel, copper niobium, and copper chromium. And the point of this plot is the following. Here, since we are plotting 1 on the square root of h, layer thickness decreases as we go to the right in the plot. The dotted lines are the rule of mixtures hardness that we would expect. And what we see is, once we get below a couple hundred nanometers, in all cases, these layered composites exhibited hardnesses substantially higher than the rule of mixtures would suggest. And it was found that the governing material parameters are the layer thickness and the structure of the interfaces themselves between the layers. And in this work it was found that the tensile strengths of these metal-based multilayer composites achieved maybe one-third to one-half of the lower bound of the theoretical strength of the material. So this is a substantial strengthening caused simply by the layered composites (Figure 5).

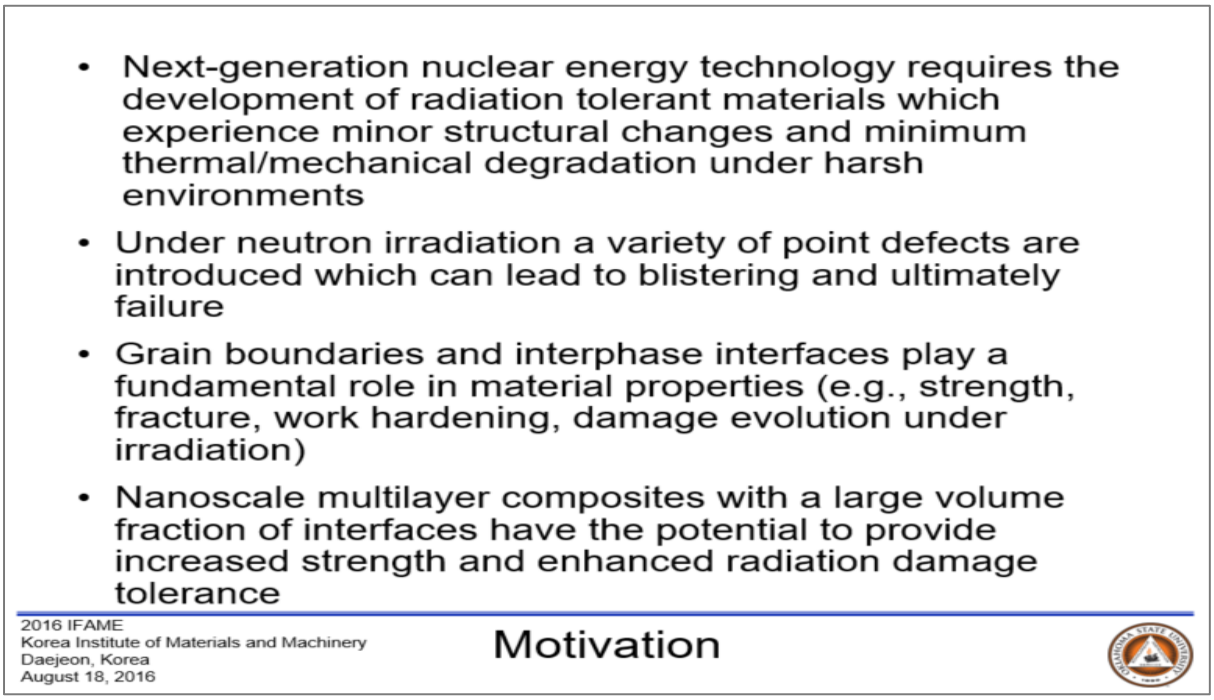

Figure 4. Nanoscale Multilayered Composites – Motivation

We can explain this by the following if we look at a strength versus layer thickness plot. At large layer thicknesses, we have scenario one, that's here, where a dislocation pile up model governs the yield strength of the material. So basically, the Hall-Petch equation works, and the yield strength is proportional one over square root of the layer thickness. As we go to layer thicknesses that are smaller, a few nanometers to tens of nanometers, we find that a confined layer slip model is appropriate. This basically means that dislocations do not cross the interface, but rather single dislocation loops glide along the individual layers and are bounded by the interface. So you have this dislocation line hardening type of effect, as shown here. Finally, when we get to scenario C, we see that we have layer thicknesses one to two nanometers, and here, the yield strength is not a function of the layer thickness but depends on the strength needed to transmit a single dislocation across the interface. And so that's this third region (Figure 6).

This is the result of two different works but basically by the same group. In the first case, if we look at the lower portion of the figure, this is considering copper niobium as a crystalline/crystalline layered composite. This is a simulation; this atomic simulation is showing the collision cascades that result from, in this case, a 1.5 keV knock-on energy. And these thicknesses of the layers are for about 4 nanometers. So if we look at the individual cascades for copper, we see, and this is time in this direction, we see the generation of large cascades, which then ultimately diffuse out to give us three remaining Frenkel or interstitial and vacancy pairs. For the case of niobium or similar situations, we see the large cascades formed, the dispersion of those resulting in finally seven Frenkel pairs.

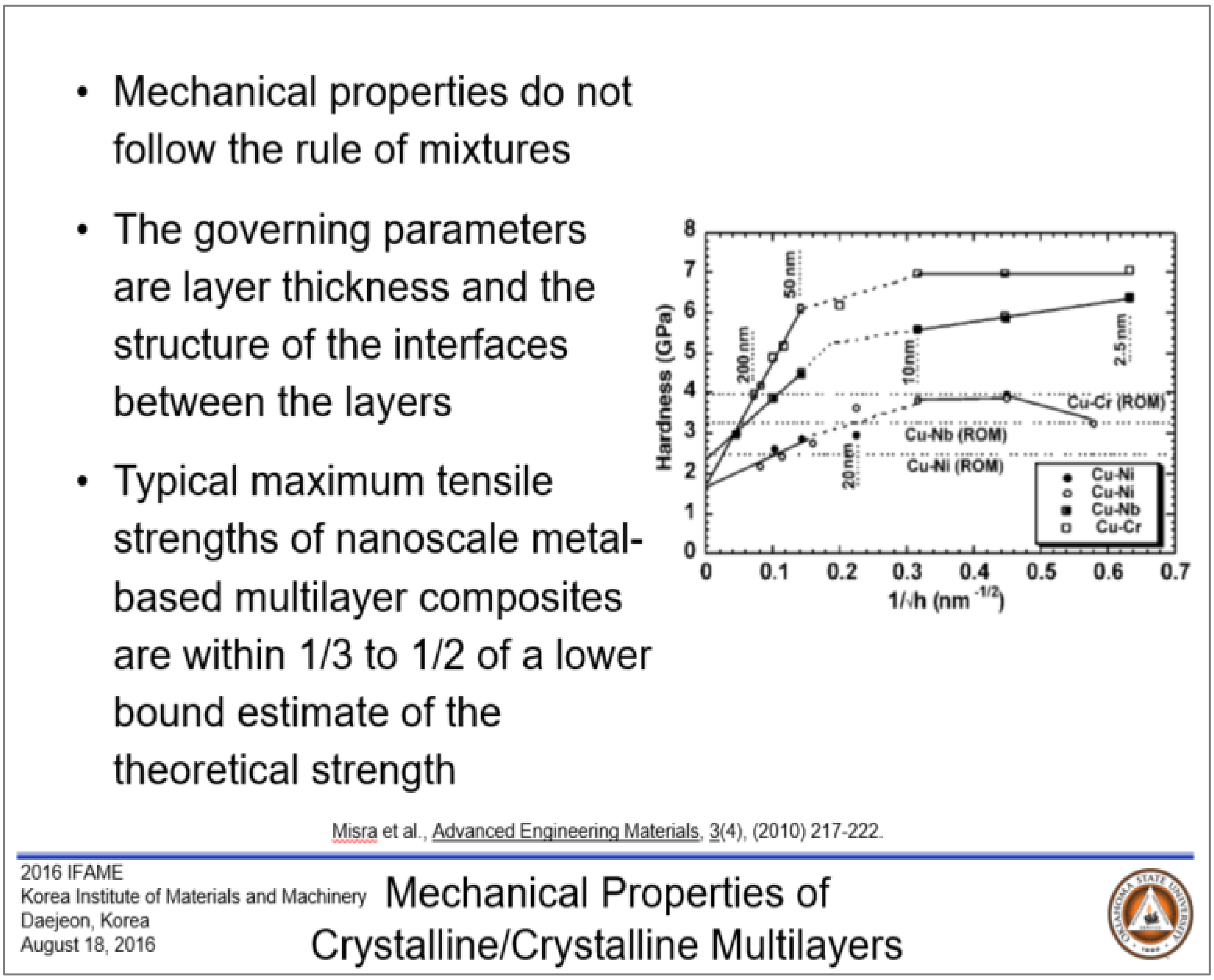

Figure 5. Mechanical Properties of Crystalline/Crystalline Multilayers

And when we have a copper niobium interface, we find that, again, the knock-on ion comes in, defects are created, energy is dissipated, but the interface itself quickly absorbs these defects, and after 2ps of simulation time, you see no damage remains. This can be explained by the fact that, if one looks at the vacancy formation energy versus distance to and from the interface, the vacancy formation energy is much lower than the interface. So the interface acts as a very efficient sink for these defects and as they diffuse to the boundaries they are annihilated. This work here, that's represented by this image, is for irradiation of copper niobium multilayers with 150 keV helium ions and, one can see, here is the silicon substrate and, as we all can see from the surfaces as we go down towards the substrate, there is damage but less damage as we get closer to the substrate and, in fact, we see that the layers are intact all the way to the substrate. So there is no interlayer mixing (Figure 7).

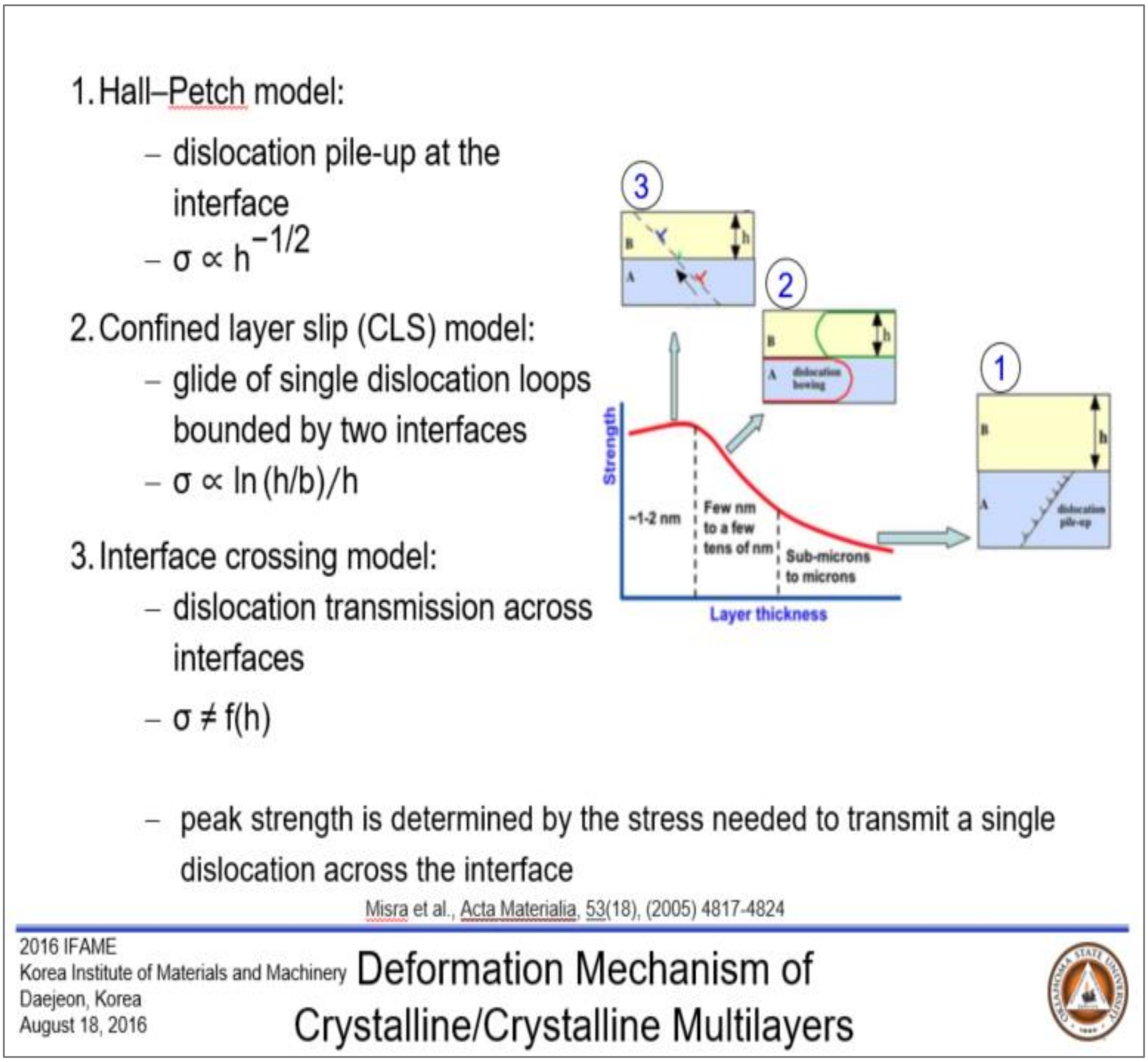

Figure 6. Deformation Mechanism of Crystalline/Crystalline Multilayers

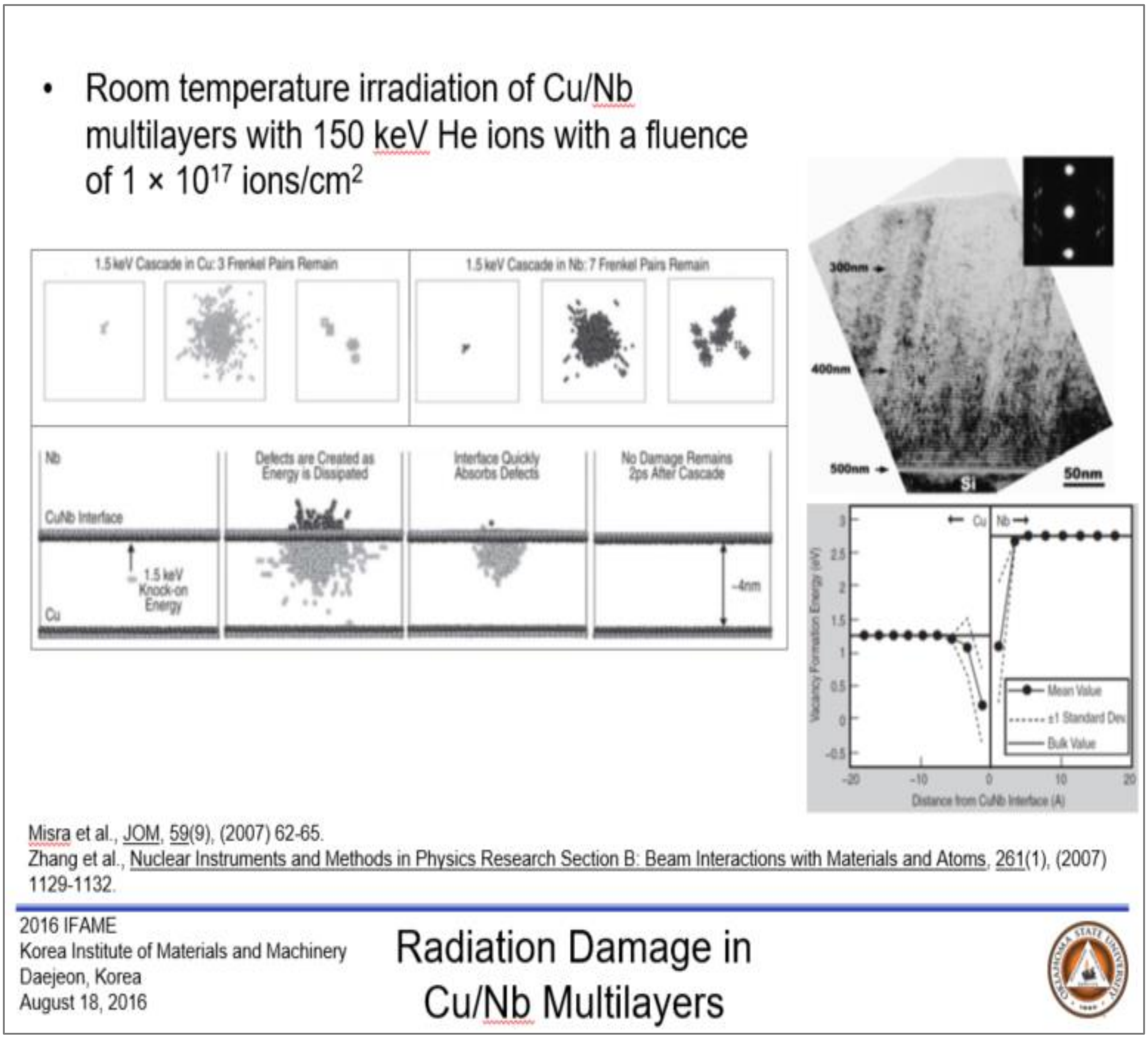

Figure 7. Radiation Damage in Cu/Nb Multilayers

Now another case. This is for aluminum niobium that is subjected to 100 keV helium ions with a fluence of 6 x 10^{16} at room temperature. This system after irradiation leads to the formation of this intermetallic compound along the interface of the aluminum and niobium. And so, instead of just alternating layers of aluminum niobium, we have alternating layers of three materials. And if we plot hardness as a function of one over the square root of layer thickness, as we start out, we see that, for the large layer thicknesses, Hall-Petch applies. And as we go to smaller layer thicknesses, we see that the as-deposited film pretty much levels out, but we have irradiation hardening that's substantial. And we can explain this by the next slide. OK, well, it will be the final slide. This irradiation hardening actually, just to make a comment here, this irradiation hardening really results from the fact that as we go to smaller and smaller layer thicknesses, the interlayer, the interface layer becomes a larger part of the total composite. And as a result of the fact that the intermetallic is harder than either of the two elements, we get the irradiation hardening shown here. We will see this further in another slide coming up (Figure 8).

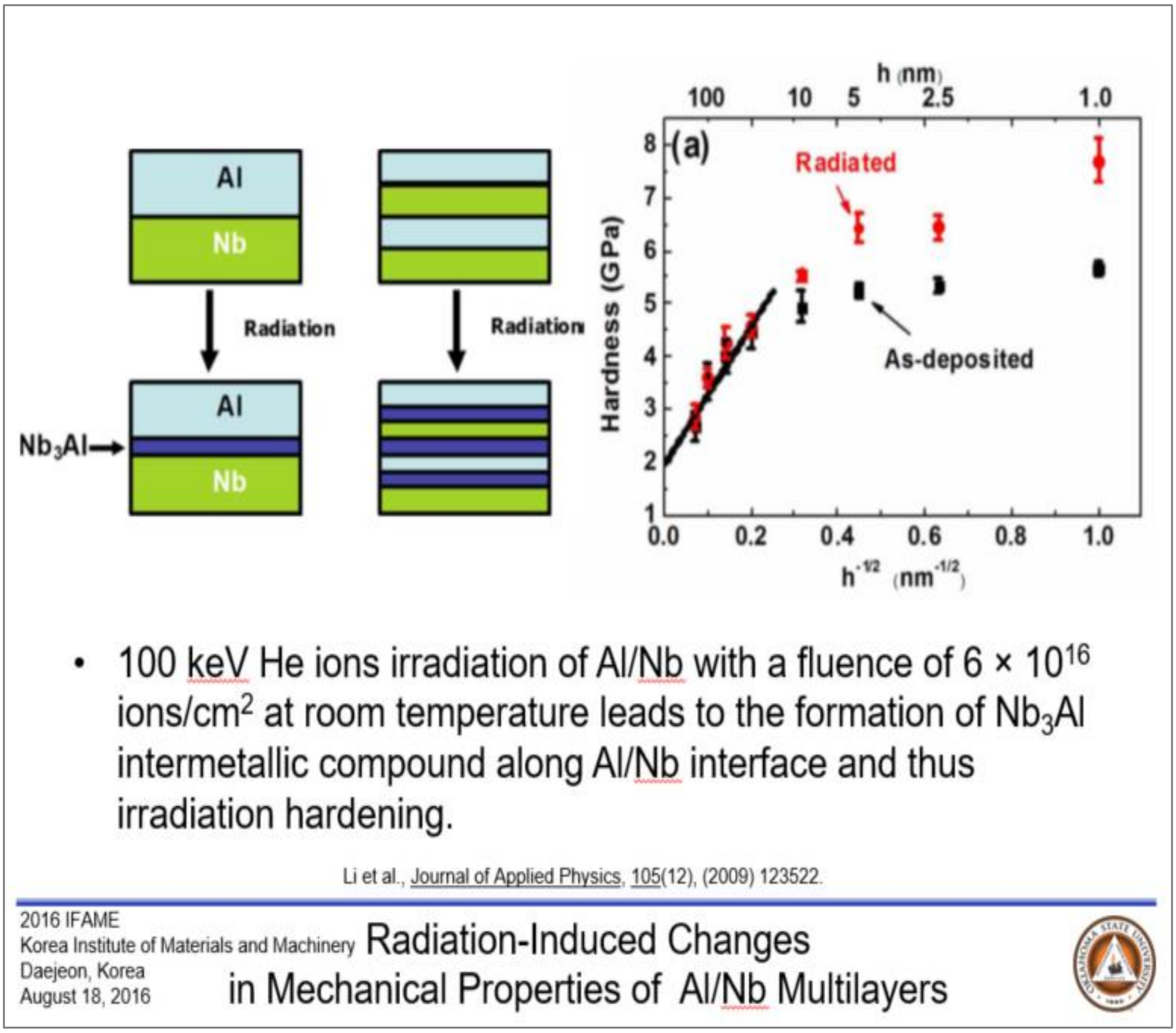

Figure 8. Radiation-Induced Changes in Mechanical Properties of Al/Nb Multilayers

Nanoscale Multilayered Composites – Crystalline/Amorphous Multilayers

And now we look at crystalline/amorphous layers, and we see the following. This is for two cases. This is for looking at a copper zirconium multilayer so crystalline/crystalline layer, and then a crystalline/amorphous layer, so a crystalline/metallic glass multilayer. The dotted line shows the representative hardnesses of copper polycrystals or zirconium and metallic glass. And we see that at large layer thicknesses, basically, the two systems behave the same. We have an increase in the hardness as we go to smaller layer thicknesses, consistent with the argument that was just presented. But then as we get to a certain point below 5 nanometers, we see that there is a softening that occurs for the metallic or the crystalline/crystalline layer, whereas we don't see that hardening in the crystalline/amorphous layer (Figure 9).

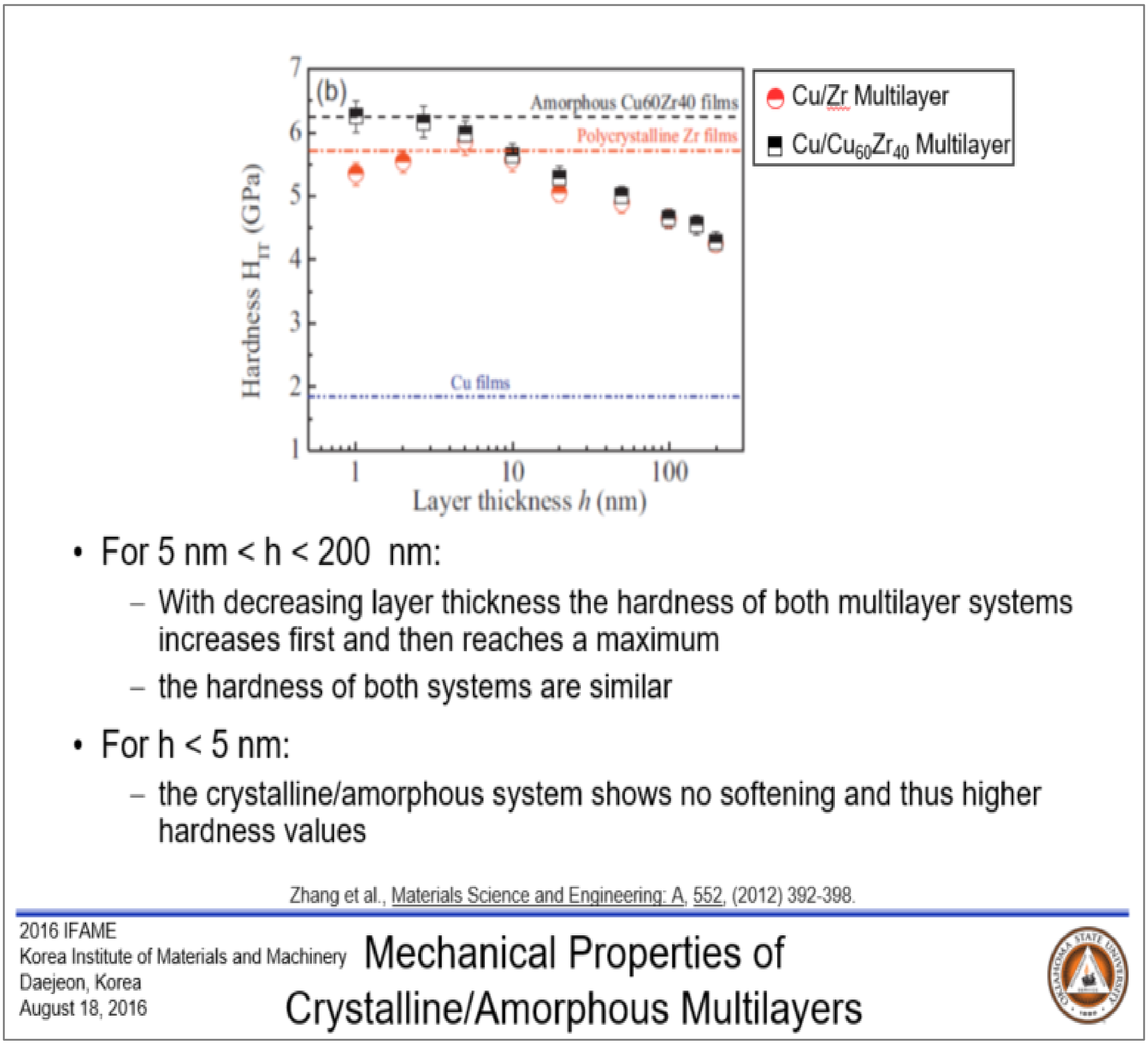

Figure 9. Mechanical Properties of Crystalline/Amorphous Multilayers

And we can think of this in a very similar way to the model that was previously presented, and that is, for large layer thicknesses greater than 50 nanometers, Hall-Petch applies. You can see the linear slope here. And it's the ductile phase of copper that really governs the change in the hardness as a function of layer thickness. When we get to this intermediate layer, again, this confined slip layer model applies. We have this dislocation glide within each confined layer. And in fact, both materials follow that model. But as we get to layer thicknesses less than 5 nanometers, so in this region and beyond, we see this softening of the crystalline/crystalline layer and no softening of the crystalline/amorphous layer, and this can be explained in two ways. One, as the crystalline/crystalline layer gets smaller, the actual dislocation loops can cross over an individual layer, and therefore, we'd expect to see this softening. And that's coupled with the fact that as the layered thickness gets smaller, in the amorphous region, the critical thickness for the propagation of shear bands is not met, and therefore the amorphous phase governs the change in hardness. That's the reason why we see this maintained (Figure 10).

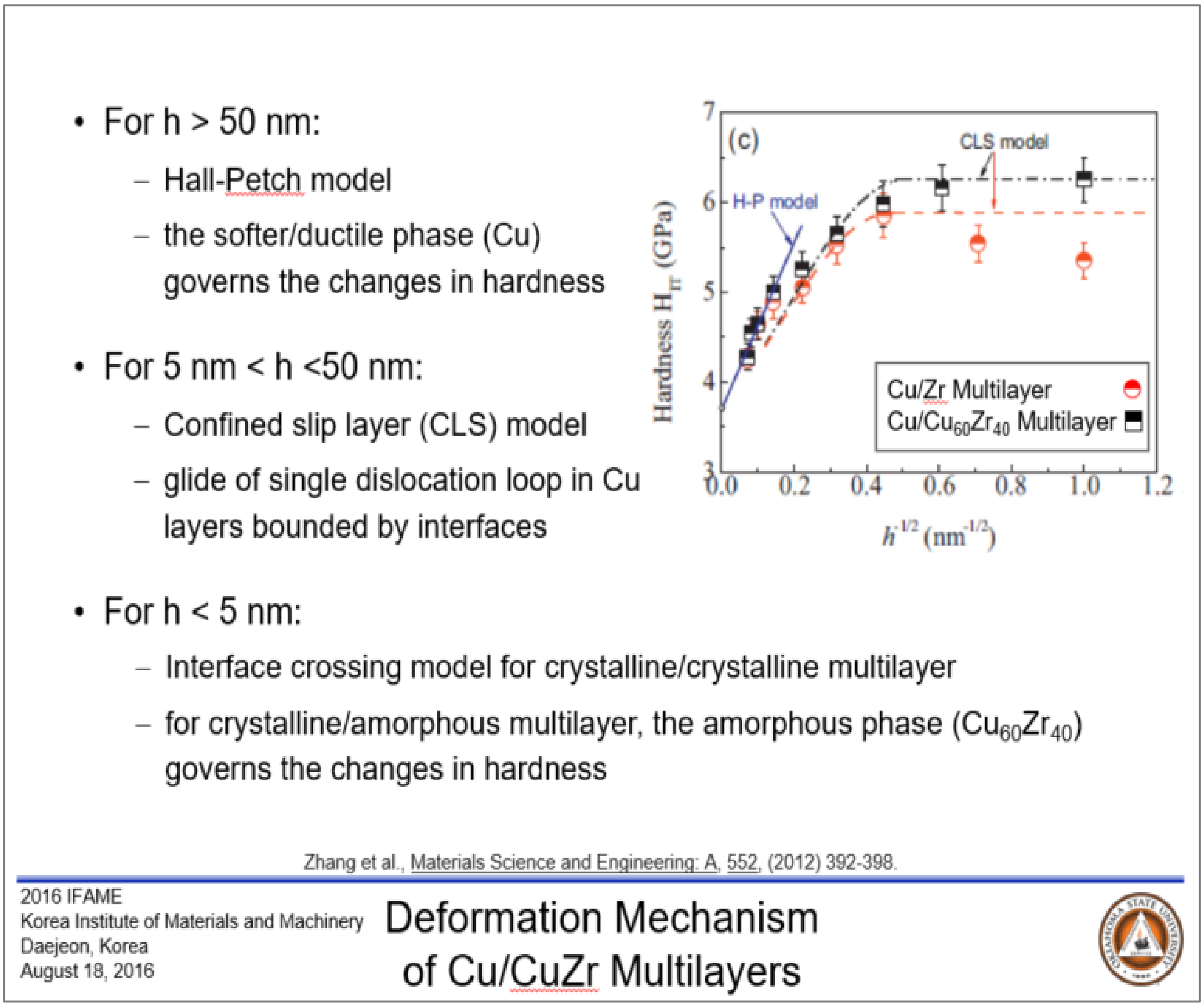

Figure 10. Deformation Mechanism of Cu/CuZr Multilayers

OK. We have just begun some work with a group at the University of Nebraska, Professor Nastasi's group, and here is some work that they just published this year that shows the type of films that we're investigating. These are alternating layers of iron. OK, so, BCC iron and SiOC, which is amorphous. And in this case, these layers were thin, 14 nanometer-thick layers, alternating layers, and thick, 60 and 80 nanometer-thick layers, they were subjected to one MeV krypton ions, and these are cross-sectional TEM images that show the actual layers. Other irradiations are shown here. And the irradiation was performed at 50K, room temperature and then at elevated temperature here. And what we see is that, we see interatomic mixing very clearly here, even at room temperature. Whereas when we get to elevated temperatures, we see that the layers actually remained intact, and we can explain this in terms of the positive heat of mixing that occurs as we get to elevated temperatures. And now when we look at the thick films, we see that in the particular case of a low temperature radiation, it was found that an intermetallic layer, an intermixed layer, was formed at the Fe/SiOC interface but only for those temperatures. And then we see that both at room temperature and the elevated temperatures, the layer integrity stays intact. We are currently performing nano-indentation on these films to start to understand how the evolution of mechanical properties occurs with these irradiations (Figure 11).

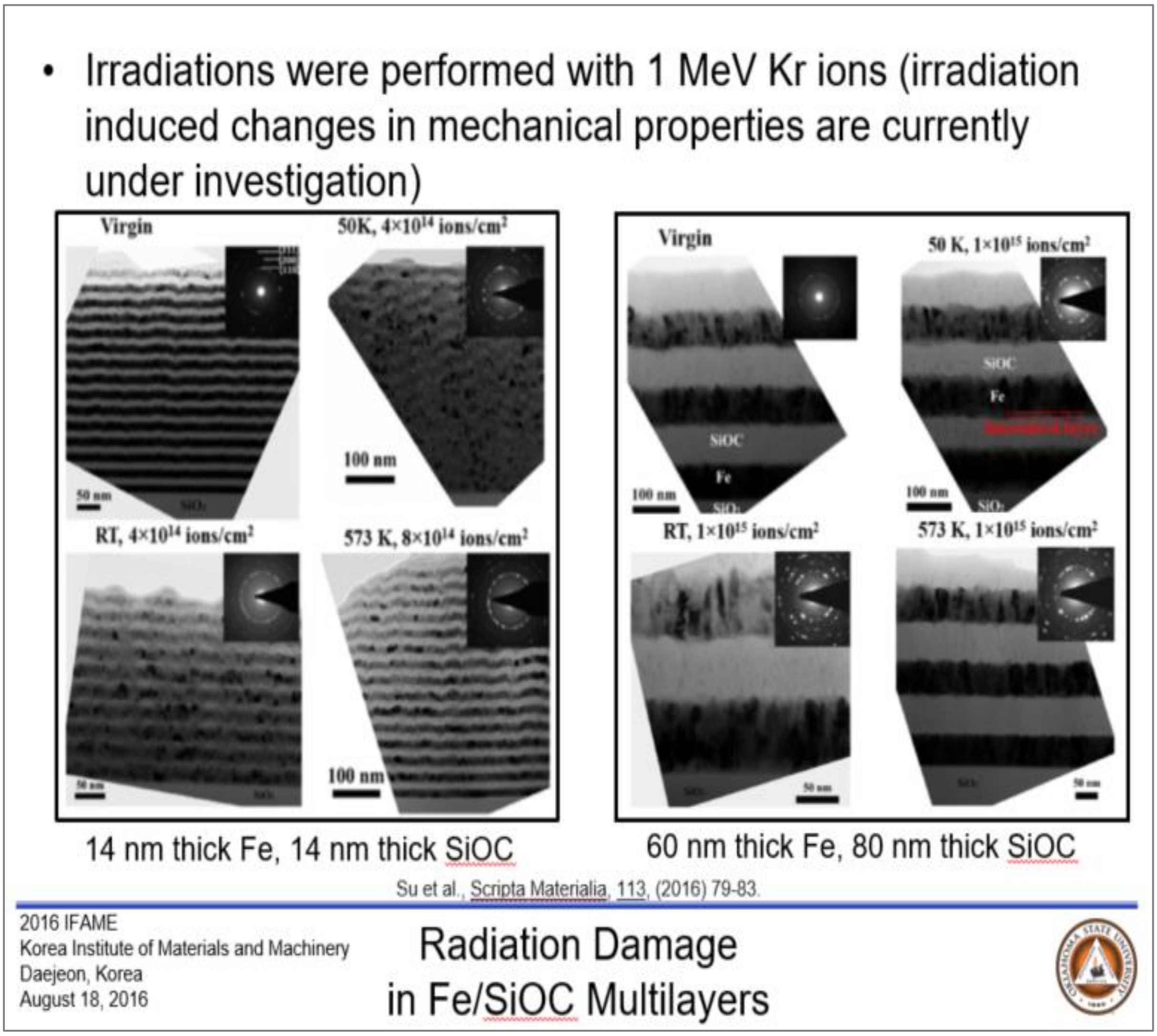

Figure 11. Radiation Damage in Fe/SiOC Multilayers

Nanoscale Multilayered Composites – Summary

OK. So, to summarize the multilayered composites, both crystalline/crystalline and crystalline /amorphous multilayer composites show an increase in strength with a decrease in individual layer thickness, and we presented some reasons why that is. And they also displayed enhanced radiation tolerance as a result of interfaces that act as efficient sinks for the point defects. And as such, both are potential candidates for next-generation radiation tolerance applications (Figure 12).

Nanostructured Metallic Glasses – Motivation

Now on to the metallic glasses. We all know that the absence of structural features in metallic glasses whether dislocations or grain boundaries make them desirable for a lot of engineering applications due to high corrosion resistance, high wear resistance, high hardness, and yield strength. And in particular, nickel-free titanium-based MGs show good biocompatibilities. So one of our interests in my lab is looking at these materials in terms of potential applications of bio-medical components. The problem of course is that it is well known metallic glasses are significantly limited by their intrinsic low ductility. So the question is "Are there ways that we can maintain the good aspects of the metallic glasses and yet increase their ability for ductile response?" (Figure 13).

- Both crystalline/crystalline and crystalline/amorphous nanoscale multilayer composites:
  - show an increase in the strength of the material with decreasing individual layer thickness
  - display enhanced radiation tolerance
  - are potential candidates for next-generation nuclear energy applications

2016 IFAME
Korea Institute of Materials and Machinery
Daejeon, Korea
August 18, 2016

Summary

Figure 12. Nanoscale Multilayered Composites – Summary

- The absence of structural features (e.g., dislocations and grain boundaries) in metallic glasses (MGs) leads to desired engineering properties such as high corrosion and wear resistance, high hardness, and high yield strength
- Newer classes of MGs such as Ni-free, Ti-based MGs offer good biocompatibility and have potential applications in biomedical components
- The application of different types of MGs is typically limited by their intrinsic low ductility at room temperature
- Nanostructured MGs with improved ductility have the potential to expand the application of this class of materials

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Motivation

Figure 13. Nanostructured Metallic Glasses – Motivation

Nanostructured Metallic Glasses – Irradiation Induced Ductility in Metallic Glasses

We will look at two ways that we do this: one by irradiation of the metallic glasses to introduce free volume into the material and the second is irradiation to introduce crystallization.
So just as a sort of background, we know that with applied shear strain, the material response is accomplished by atomic rearrangement of atoms resulting from these so-called shear transformation zones or STZs. These STZs are localized. This shape allows the material that includes small clusters of ions, when subjected to shear, and if free volume in the material exists, it can accommodate the shear quite well. So if these STZs are homogeneously deposited throughout the entire volume of material, we see the mechanical response of the material as homogeneous. In counter distinction to that, if, in fact, they are not distributed uniformly, and we have limited free volume, the application of shear strain results in large distortions around the STZs. And basically we see that localized shear bands occur, leading to ultimate failure of the material (Figure 14).

So, work on the irradiation of metallic glasses has shown that irradiation introduces free volume into the material. And it's also known that sites with higher free volume accommodate local shear strain more readily through the formation of these STZs. So, we developed a program to look at ion irradiation of these metallic glasses to see if we can increase ductility response (Figure 15).

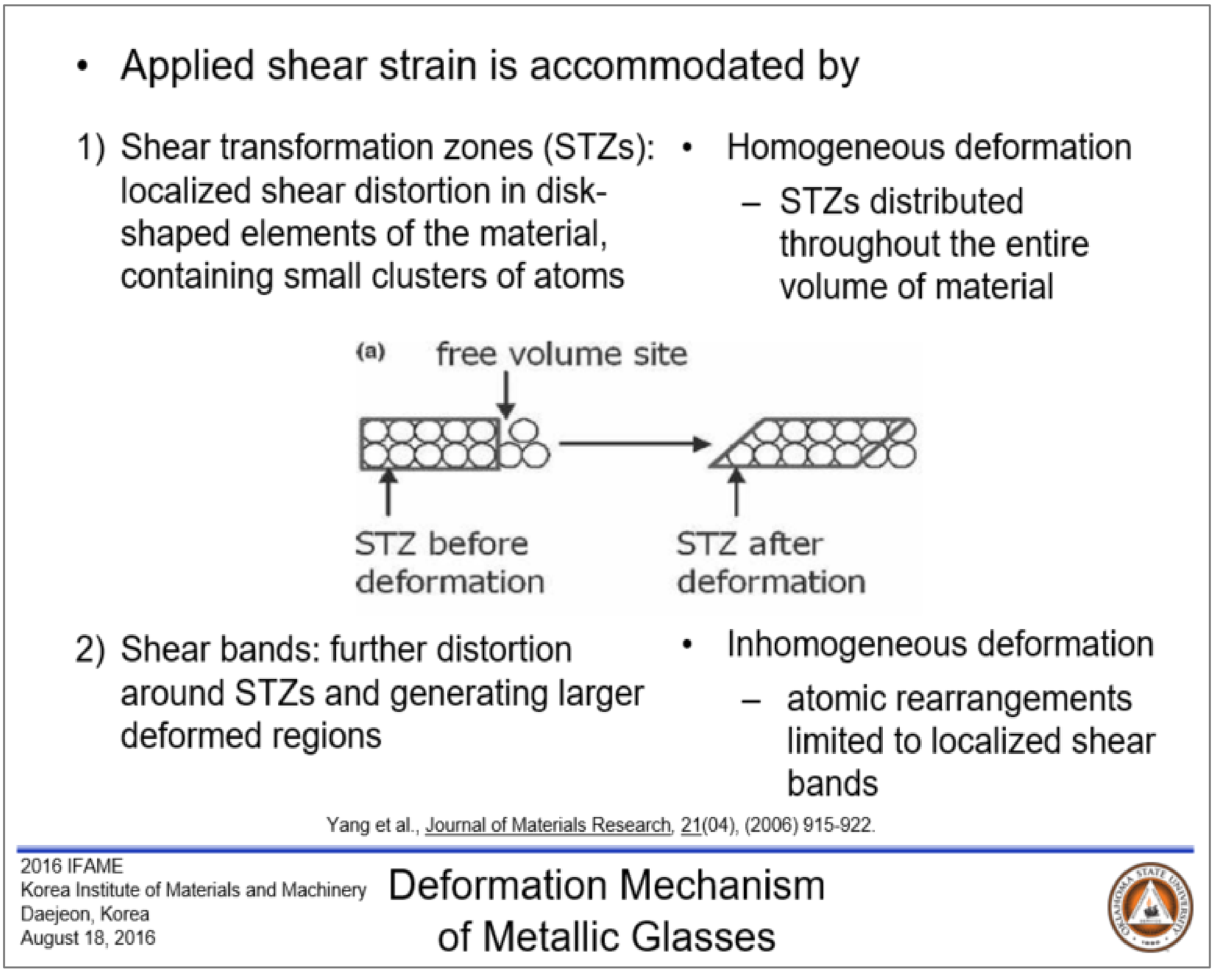


Figure 14. Deformation Mechanism of Metallic Glasses

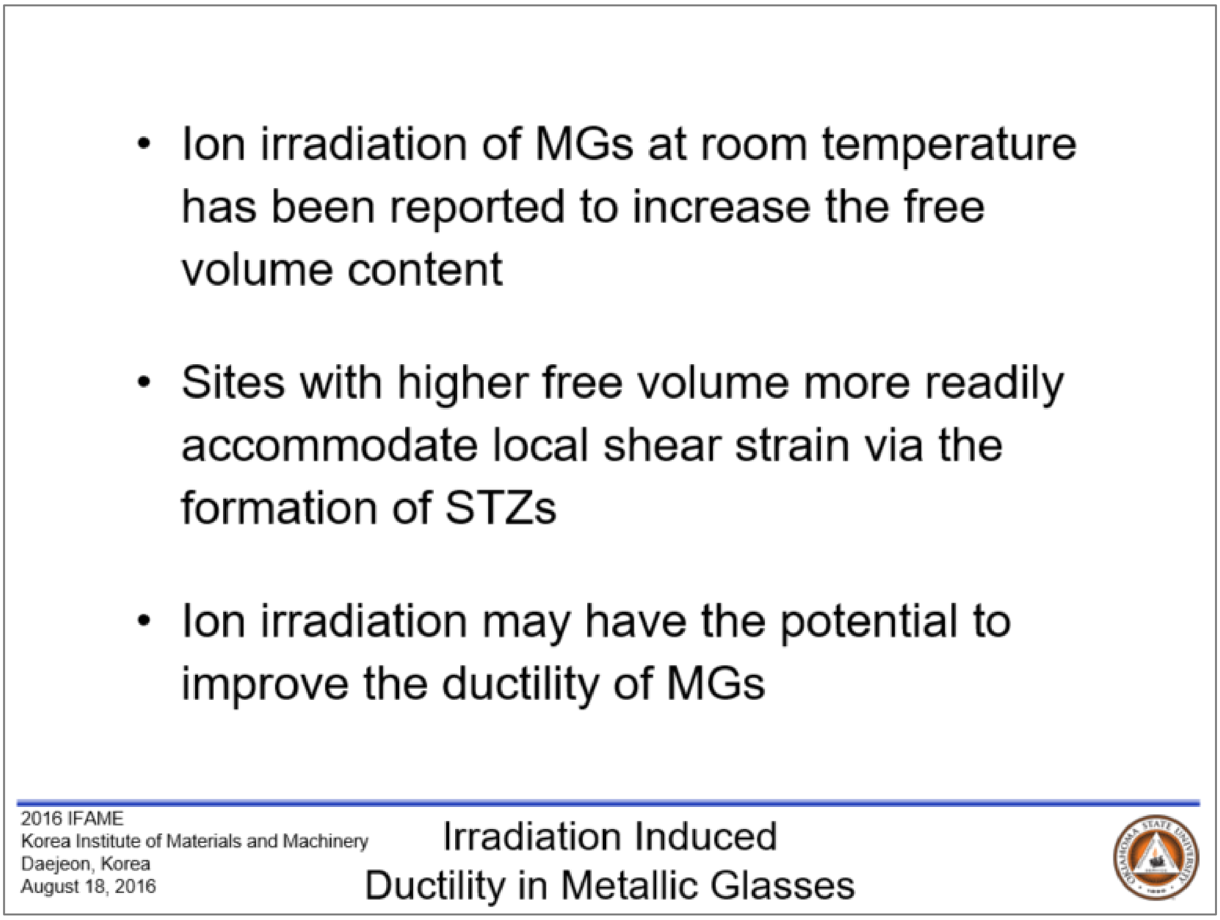


Figure 15. Irradiation Induced Ductility in Metallic Glasses

Here is some nanoindentation data where we are plotting force versus penetration depth. These were nanoindenting experiments that were done by a Berkovich nanoindenter at room temperature on this titanium-based metallic glass. These were ribbon specimens. And we performed the indentations on both as-spun material, and then the material that was irradiated at different fluencies, $10^{13}\ \mathrm{Fe^{2+}/cm^2}$ and $10^{15}\ \mathrm{Fe^{2+}/cm^2}$. So first, if we look at the room temperature irradiations, we see the reduced elastic modulus and the hardness shown here for the as-spun specimen. And then irradiating at room temperature we see, as we increase fluence, we see that we reduce both the hardness and the elastic modulus. If we then take for $10^{13}\ \mathrm{Fe^{2+}/cm^2}$, and perform irradiation at elevated temperatures, we see that, again, there is a reduction of the yield strength, the reduced modulus and hardness, but as we increase the temperature, we see that we start to recover both the modulus and hardness. OK? And we can see how that affects the mechanical response. For the as-spun specimen, especially at higher loads, we see that we have these bursts which occur due to the fact that shear bands are being formed for the as spun. For the irradiated curves, we see a reduction in the displacement burst both for 10^{13} and $10^{15}\ \mathrm{Fe^{2+}/cm^2}$. So that's one indication that we may be improving the ductility (Figure 16).

We can look further. These are experiments that were performed with a spherical indenter. The idea of using a spherical indenter is to emphasize the elastic portion of the loading curve. Therefore, we can look at the first displacement. The first displacement bursts then correspond to the initial yield point of the metallic glass. So, we can look at the force versus depth curve. We confirmed that loading up to this first displacement burst was purely elastic. We then unload with no residual impression. And so, the area within this curve is the elastic work that was performed. And we can then look at the displacement burst, both the force that have occurred and the volume of material that was displaced during the burst. And, in fact, others have shown that this ratio of the plastic work to the volume that was displaced by that or the plastic deformation energy is an indication of the ductility of the material (Figure 17).

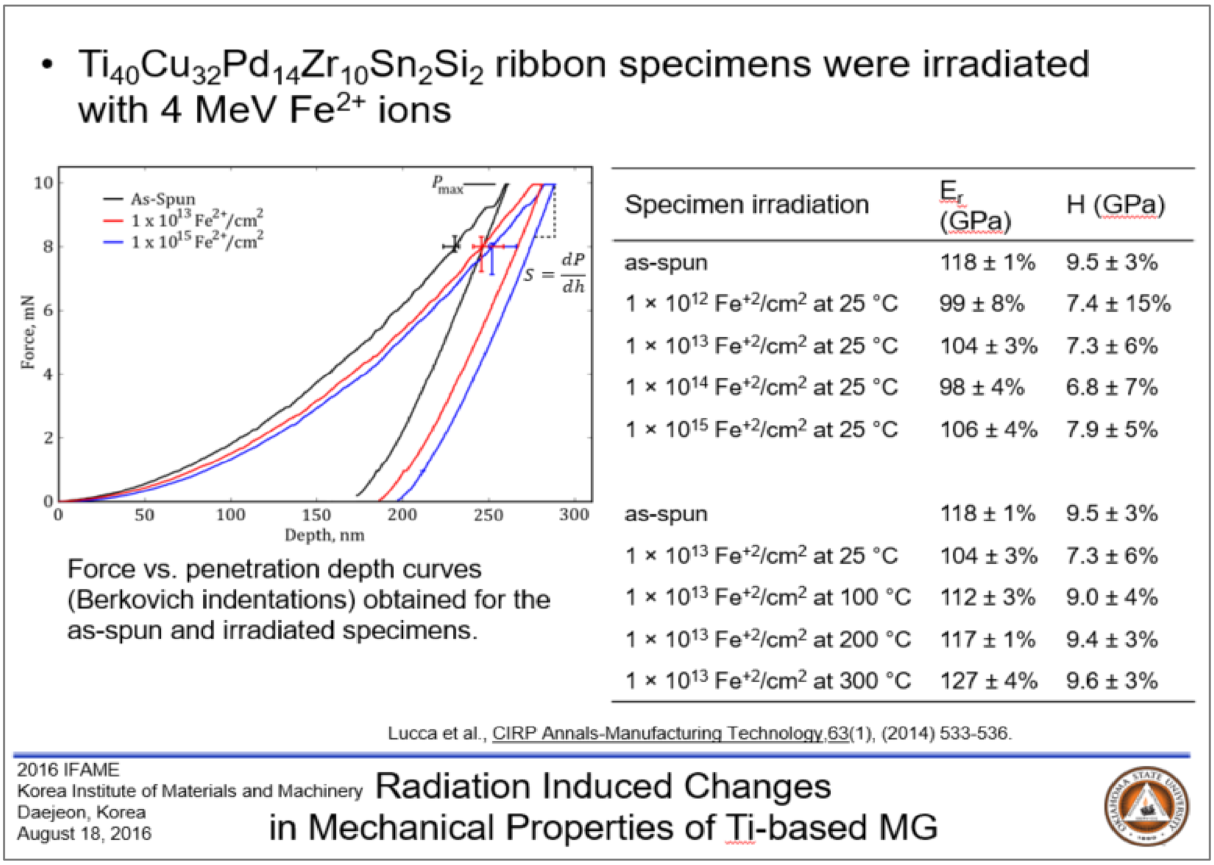


Figure 16. Radiation Induced Changes in Mechanical Properties of Ti-based MG

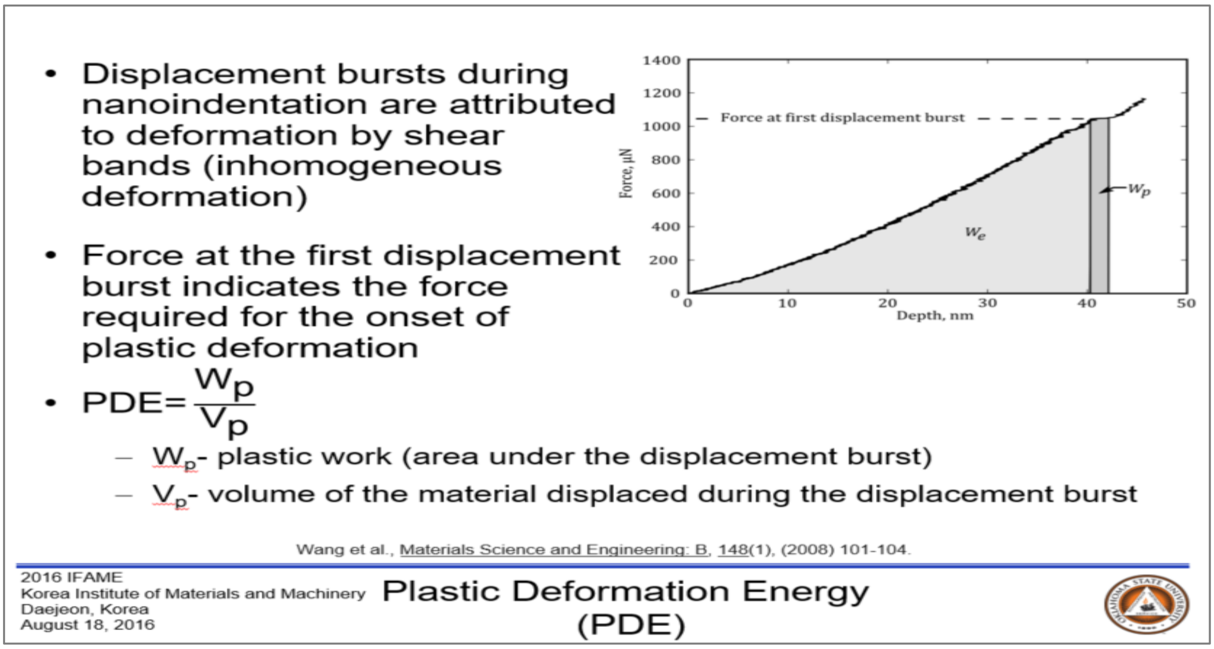
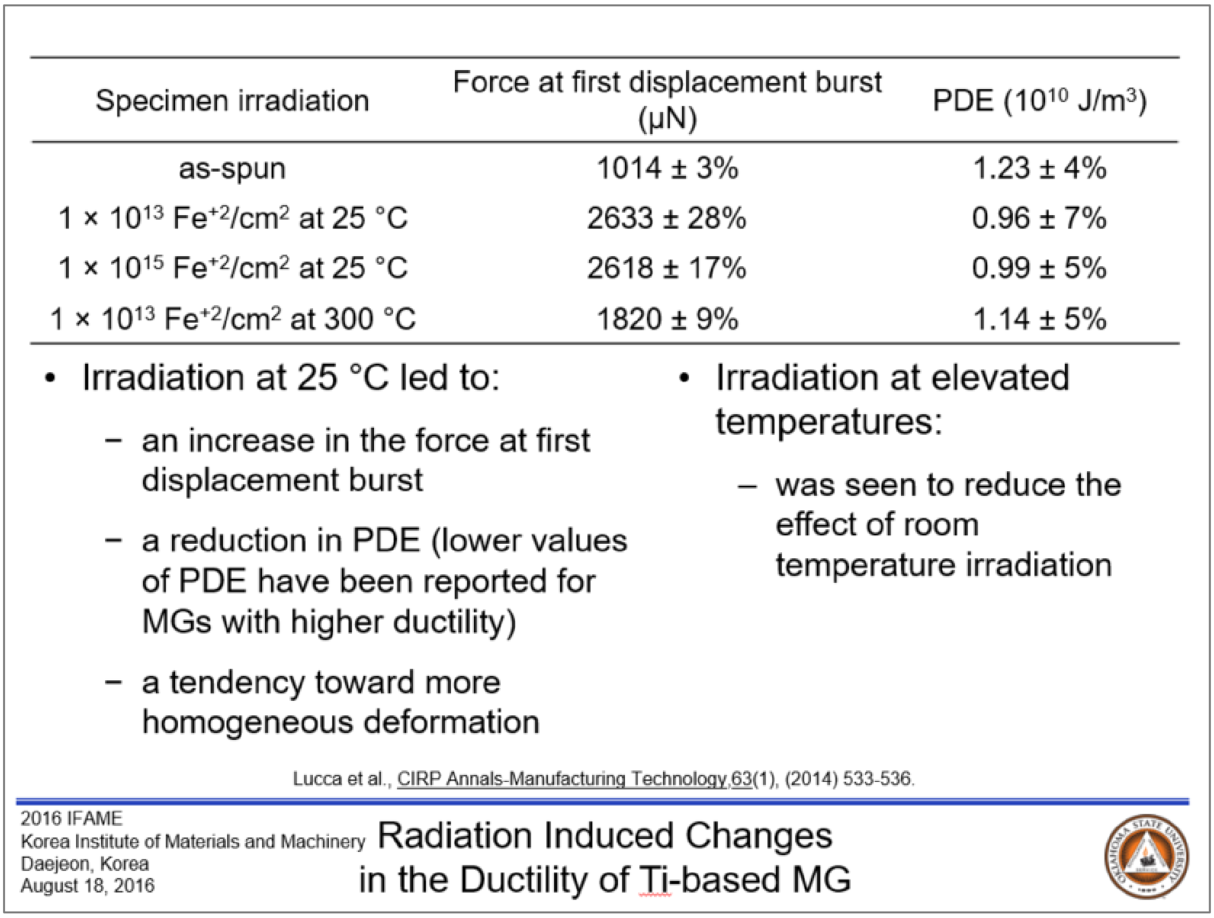


Figure 17. Plastic Deformation Energy (PDE)

And, so we look at some results here. Here is the as-spun specimen, the force at first displacement, and plastic deformation energy. And then we see, as we go to room temperature irradiation, we see the plastic deformation energy reduces. Again, what that infers is that we have less displacement per volume of the material displaced. And as we look at this data, we see that a reduction in PDE values indicates an increased ductility and a tendency towards more homogeneous deformation. We'll see evidence of this in the next slide (Figure 18).

If we take a look at the force versus depth curves and we subtract out the displacement burst, so we look at, the red curve is the actual data that was collected. You can see the displacement burst here. This is for the as-spun specimen. And then, if we simply take out the displacement burst removed and look at the loading and unloading curves without those displacement bursts and we take the ratio of that inhomogeneous deformation to the total plastic work (so the ratio of this inhomogeneous deformation to the total plastic work), that gives us this percentage of inhomogeneous deformation. We see for as-spun, we have numbers like 20% as we irradiate with 10^{13} and 10^{15} at room temperature, and this ratio goes down to 12 and to 9. And then, we see, if we go back and irradiate at 300 degrees C, we go back up to a large amount of inhomogeneous deformation and a ratio that is, in fact, greater than the original material that started out. So, basically, what we are doing is, in the case of the elevated temperature, we are basically annealing out free volume as it's being put in. So the free volume remains at room temperature, higher fluences yield higher free volumes, more free volume leads us closer to homogeneous deformation. At elevated temperatures with irradiations shown here, we anneal out the free volume, simultaneously, as it's being put in. We cannot, we don't see the benefit of the irradiation (Figure 19).



Specimen irradiation	Force at first displacement burst (μN)	PDE (10^{10} J/m^3)
as-spun	1014 ± 3%	1.23 ± 4%
1 × 10^{13} Fe^{+2}/cm^2 at 25 °C	2633 ± 28%	0.96 ± 7%
1 × 10^{15} Fe^{+2}/cm^2 at 25 °C	2618 ± 17%	0.99 ± 5%
1 × 10^{13} Fe^{+2}/cm^2 at 300 °C	1820 ± 9%	1.14 ± 5%

Figure 18. Radiation Induced Changes in the Ductility of Ti-based MG

One last confirmation that this is, in fact, what we are seeing, we can look at the residual impressions. And this is what we see. This is the as-spun residual impression of the Berkovich indenter. And what we see is, we see very localized terraced pile-up on the edges of the indenter, so indicating sort of shear localized material flow. For irradiation of 10^{13} and 10^{15}, we start to see plastic flow that is more homogeneous and more extensive beyond the actual indent in this case. And again, when we irradiate at elevated temperatures, we see that the final response is more indicative of the original material, and that is these terraced shear localized deformations. So, again, a further indication that we can increase the ductility by irradiating, but we then can anneal it out by irradiation at elevated temperatures (Figure 20).

Nanostructured Metallic Glasses – Irradiation Induced Crystallization in Metallic Glasses

Now, some work that we are just starting is looking at the irradiation of these metallic glasses that can include the introduction of crystallization. We saw that ductility in previous results was improved, but it was at the expense of reduced modulus and hardness. So you remember that modulus and hardness were found to decrease. But it's been shown that ductility in metallic glasses may also be improved by introducing, for example, nanocrystal matrix composites into the metallic glass. So if we can introduce nanocrystals, again, in our case by ion irradiation, we may have the possibility to deflect shear bands and, as a result, increase ductility in response. And of course, we can tune this by looking at the ion species, the size of the nanocrystals, the fluence, and the like. So that's our next work (Figure 21).

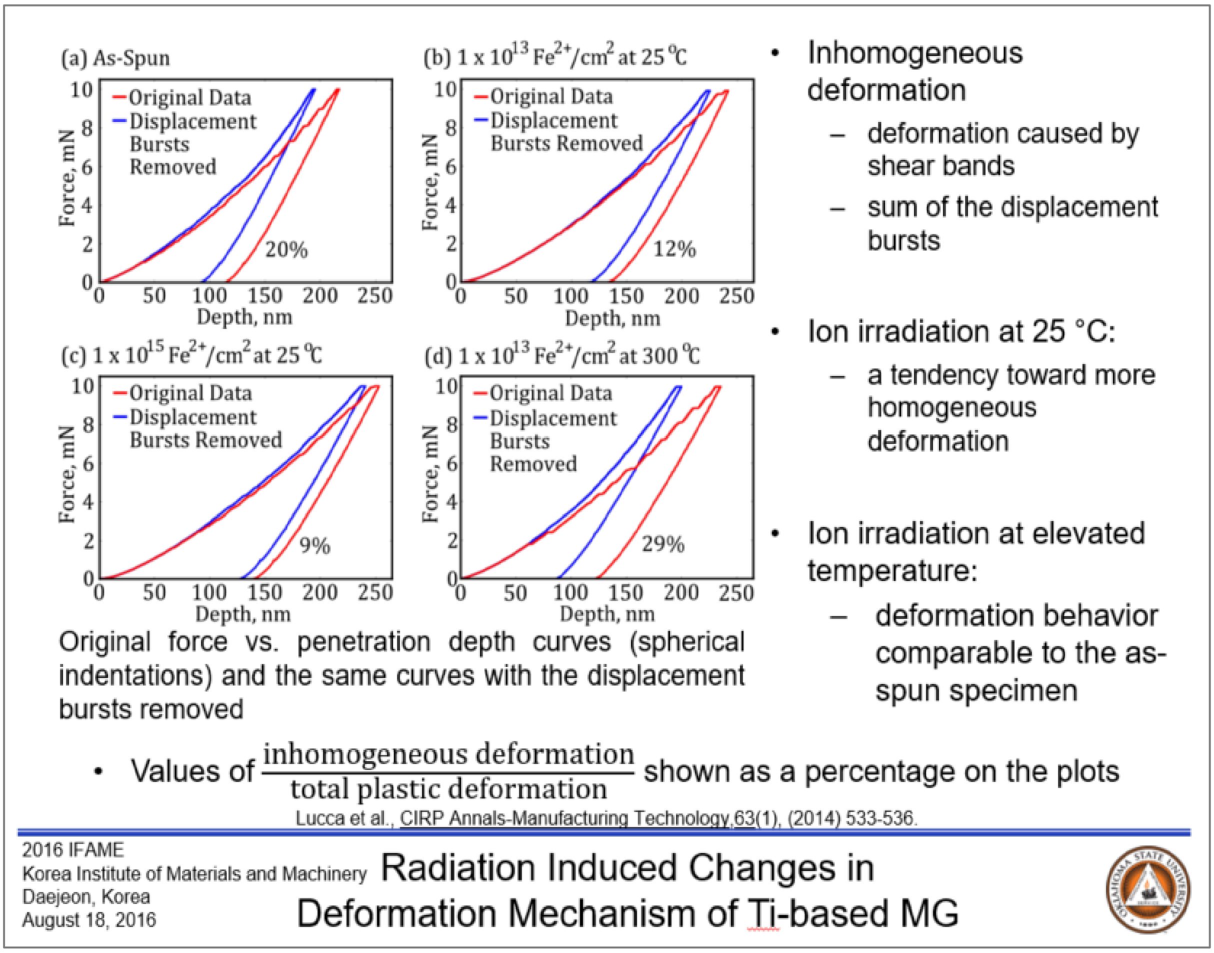


Figure 19. Radiation Induced Changes in Deformation Mechanism of Ti-based MG_1

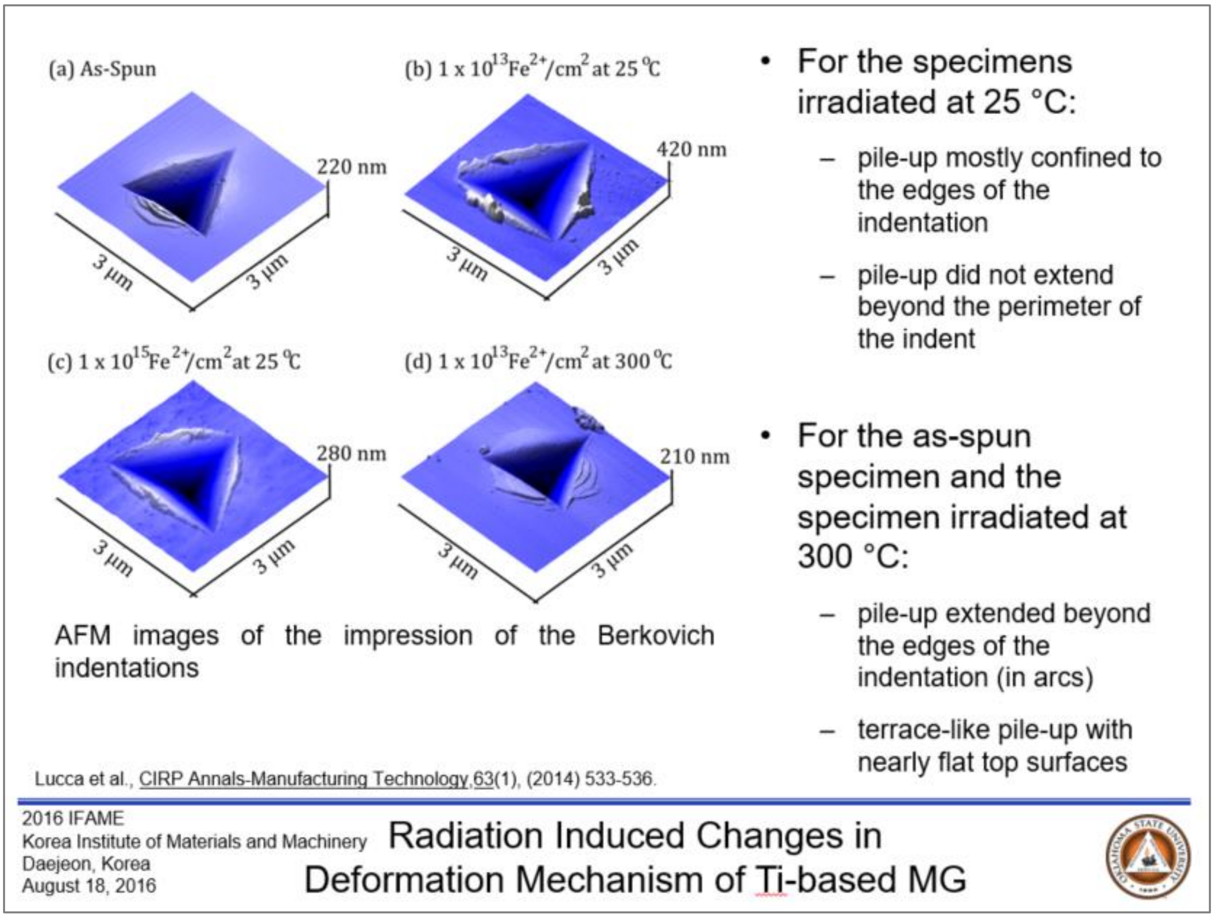


Figure 20. Radiation Induced Changes in Deformation Mechanism of Ti-based MG_2

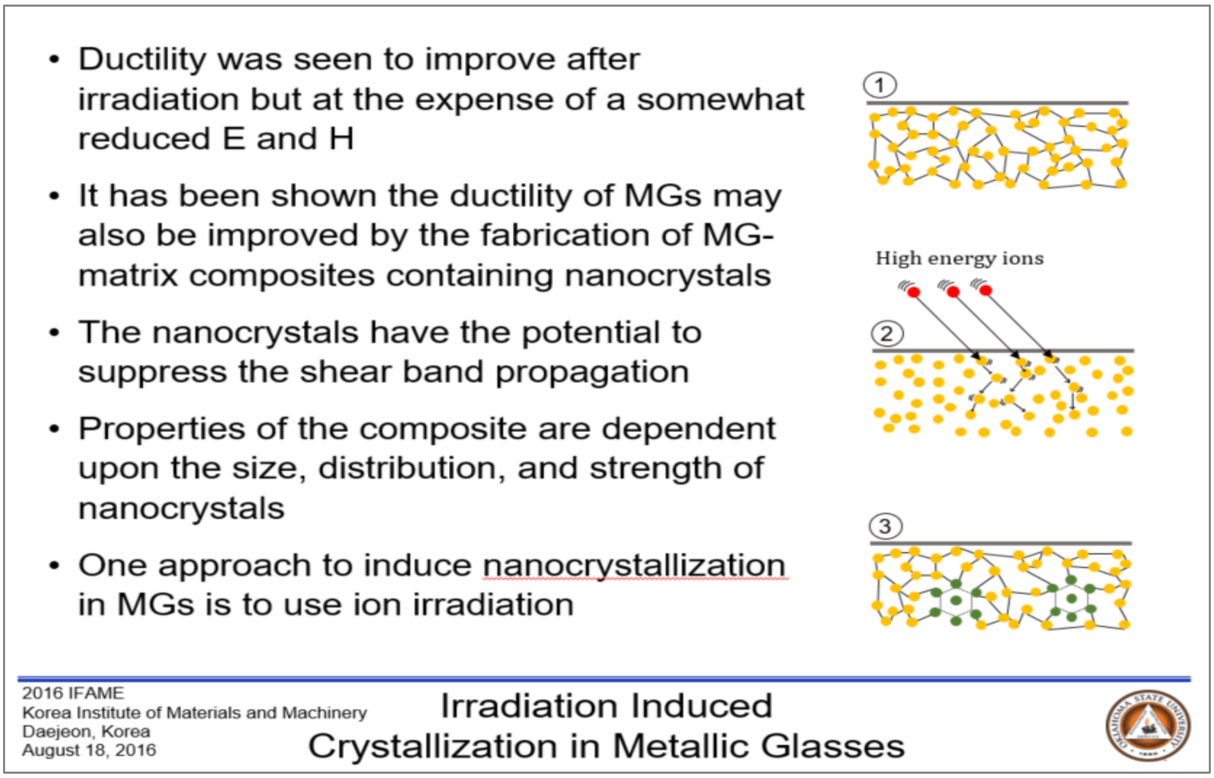


Figure 21. Irradiation Induced Crystallization in Metallic Glasses

And we have done irradiations but are now in the process of evaluating mechanical response. This is what the material looks like before the irradiation, so we have an amorphous matrix, amorphous material. And these are nickel-based metallic glasses. And then, after irradiation, we see three regions. The amorphous matrix and the region that contains precipitates and then nanocrystals developed within this Region 2. And we hypothesize that this is due to the increased mobility that the atoms have due to the introduced free volume. So now we are in the process of looking at how these materials behave mechanically (Figure 22).

Nanostructured Metallic Glasses – Summary

So, finally, ion irradiation in these metallic glasses was able to increase the free volume of the system and demonstrated more homogeneous deformation as a result of the introduction of that free volume. And creating these matrix composites by the formation of nanocrystals seems to show promise for deflecting or interrupting the activation of shear bands (Figure 23).

Conclusion – Acknowledgements

This work is a result of several different collaborations. There is my Ph.D. student. Arezoo Zare is working on metallic glasses, and she has put this presentation together. Our colleagues, Professor Nastasi at the University of Nebraska and his group are working on the crystalline/amorphous layered composites. And Professor Shao and his group at Texas A&M are collaborating with us on the metallic glass work. And of course, this work is funded by the US NSF, DOE, and the DOE Center for Integrated Nanotechnologies. So with that I thank you for your kind attention, and I will be happy to answer any questions (Figure 24).

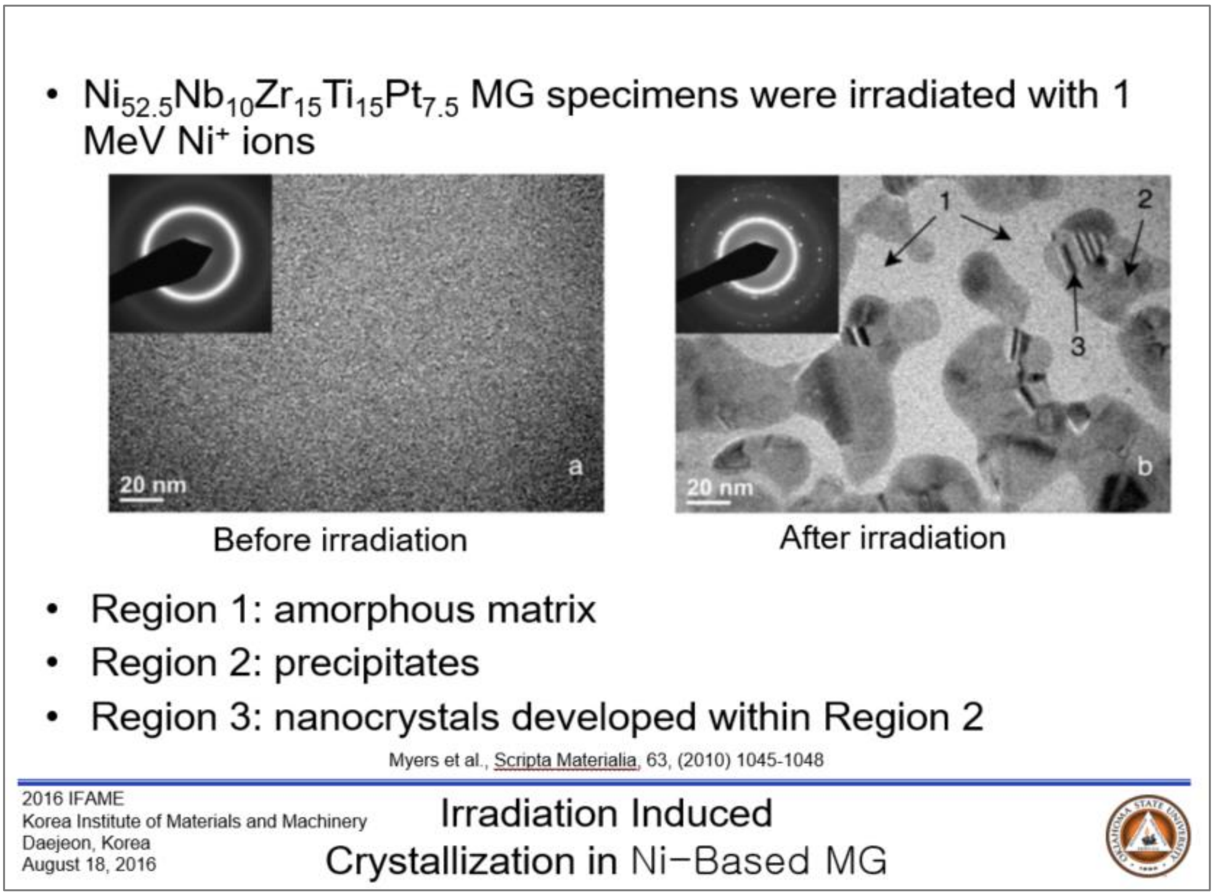


Figure 22. Irradiation Induced Crystallization in Ni-Based MG

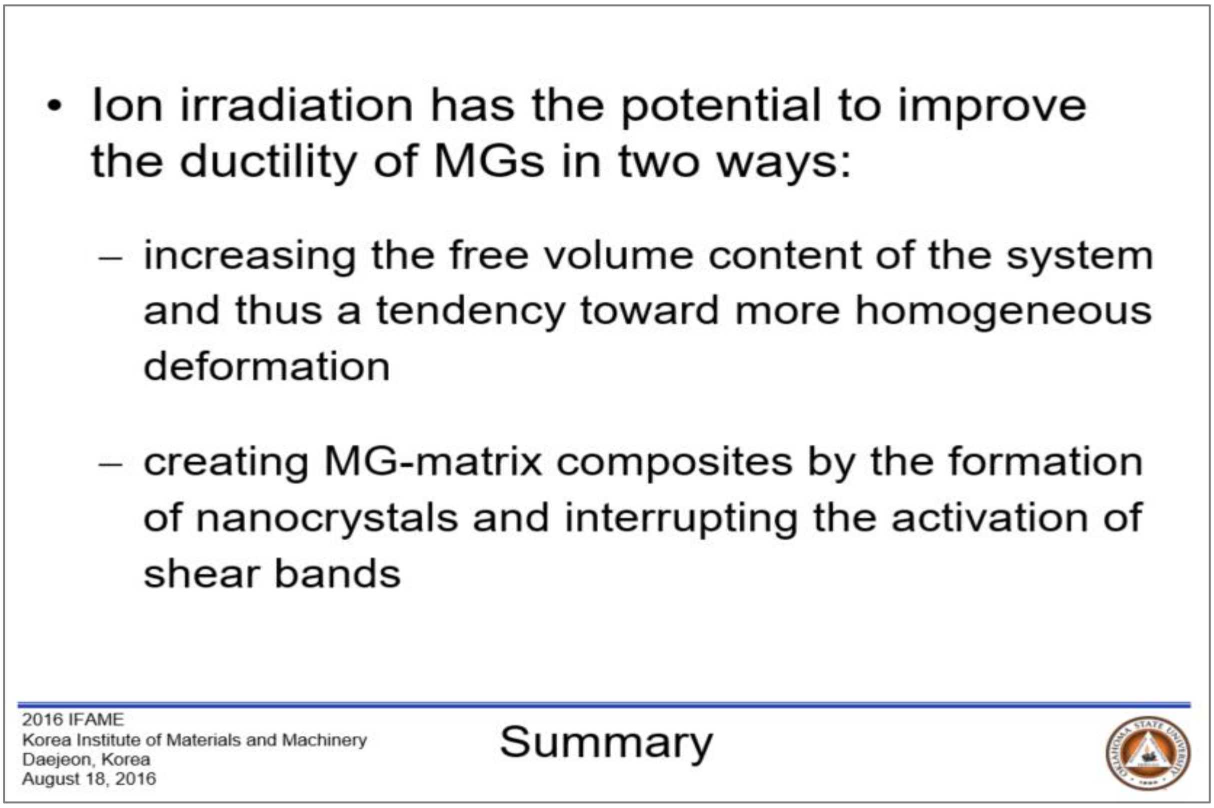


Figure 23. Nanostructured Metallic Glasses – Summary

Figure 24. Acknowledgement

Q&A

MC: This is the official presentation for our IFAME Conference which will be held in next month. So, is there any question?

Q1: Thank you for presenting your research results. Actually, in your first presentation, you showed us the hardness as a function of thickness. Usually, hardness is not a mechanical property. It's just a resistance to deformation. In addition, you tested the multilayered structures, and you used nano-indentation. But in case of a multilayer, this only a surface; it can obtain the surface result instead of the average or being averaged out. What do you think about it?

A1: These are good points. The first is agreed: hardness is not a mechanical property; it's just resistance to indentation. But I think it's well accepted that we can correlate hardness to the yield strength. I mean, for example, Taylor's equation says that three times the yield strength can be shown to be roughly the hardness. These multilayered composites actually behave slightly differently, and it's been shown that the yield strength for people who have done other experiments, I just presented nanoindentation results, but the groups in the first part of the talk have looked at these materials under uniaxial tension and uniaxial compression. And then they find that the hardness is between two and three times the yield strength. So there is this correlation that we can see between the two quantities. So that's what allows us to compare back to Hall-Petch, for example. In the second case, it's agreed that nanoindenting is only looking at the near surface response. I probably didn't mention, most of these layers are typically a micron or so in total thickness. So they're deposited either on silicon. We are in the process of actually looking at whether we can deposit them on steels, for example. So we have one micron of alternating multilayered thickness. We typically go in and use permanent, I would say, an indentation depth maximum of 200 nanometers. And for the thin layers, like 20 nanometers, if you go in 200 nanometers, you are still getting some bulk mechanical property of the layer, OK? Not being affected by the substrate. And I remind you, we also are cognizant of the fact that we want to be looking at the hardness that has been fully irradiated. So typically these films are irradiated, and the ion range is maybe one to two microns. But we are going to do, I didn't present these results today, but we are currently using a focused ion beam to create pillars of these stacked structures. And we are in the process of doing nano-compression experiments both *in situ* in the SEM and *ex situ*.

Q1: OK. Thank you. One more question. Actually, as you know, for the Hall-Petch equation, we should arrange data as a function of grain size instead of thickness because if the grain size is small and large, but the thickness is the same, then, the mechanical properties should be different. You showed us as the function of thickness, instead of grain size.

A1: Well, but the thing that… OK, that's true; there is a convolution of grain size. If we change both at the same time, then we have a problem because we do have to consider the grain size on the mechanical property of the material. But, for example, if, in fact, where we see that the major variable is the thickness, then, in fact, it's the thickness and it's been shown too by TEM that, in fact, it's the thickness and it's changes in those three regions, whether it's Hall-Petch or then once you get into confined slip. And it's the thickness that's governing the mechanical response. But I agree with you. The presumption is that we are not changing two things at once.

Q2: I also have a question. Thank you very much for your nice presentation today. Actually, the topic is a little bit different for me. But I am very interested about layered structures. I want to know how to make this metallic glass and where can you adapt the metallic glass. Maybe those materials can be used for several types of applications.

A2: Yes, that's a good question. And so scale up becomes an issue here because what we are really doing is irradiating; I think the range of irradiation is two microns. So we are really looking at the real near surface response. However, this work is funded by the US National Science Foundation. So whereas we imply that if we can understand, for example, the interaction between shear bands with these nanocrystals that we've developed some fundamental understanding can be potentially used for more real world applications. But we have our sights at this point purely on trying to develop an understanding of how nanocrystals, for example, or how the free volume affects the mechanical response. And we can do that by looking at the first micron of the materials. But I hear you. If there is going to be some practical use of this, then one needs to figure out. We also argue that there are certain cases where you would like to have ductility perhaps only in the surface layer. So in that case, this may be appropriate.

Session 2

Materials, 3D Printing, and Sustainability

Accelerating Materials Deployment and Manufacturing via Multi-Scale Modeling and Genomics
Dr. Pamir Alpay

Hyundai Steel's Challenge toward "Automotive Steel Specialized Steelworks"
Dr. Man-Been Moon

The R&D Prospects of Additive Manufacturing (AM) Technology at MIRDC
Dr. Jack Wang

Vision of Energy Sustainability
Dr. Choong-Sik Bae

Accelerating Materials Deployment and Manufacturing via Multi-Scale Modeling and Genomics

Dr. Pamir Alpay
Professor Materials Science & Engineering
University of Connecticut

Introduction

I wonder how many of you have seen this movie? It's usually "Hollywood gets things wrong." But in this case, they got a lot of things right. It's a 2008 movie called *Iron Man*. The guy is an entrepreneur, innovator and an arms dealer who get captured by the bad guys, and he has to develop some sort of a suit. So this guy has to develop a suit that will protect him from the bad guys. He comes up with this kind of design and he needs the right materials for it. So what he does is, in his lab, assisted by a computer interface called Jarvis, picking the right elements for that Iron Man suit. This is basically the premise of custom material development, in this case, for futuristic applications (Figure 1).

Figure 1. Accelerating Materials Deployment - the Iron Man Approach

Figure 2. Possibilities

Now, these are the possibilities. We have all the elements and we can combine them in an alloy form. We can combine them in terms of compounds. We have so many possibilities. There are so many possibilities that chemists, physicists, material scientists, and material engineers can develop (Figure 2).

But then we look at the history of materials for industrial applications. If you need high temperature applications, Inconel (718 or any other version) is your material. This is the material that has been used since the 40's that has undergone almost no change. This is developed for steam power plants and then adapted for turbine blade applications. And then you look at it. It contains 5-6 elements in it, and it's developed by expert intuition through experimentation. So you sprinkle a little bit of molybdenum into nickel alloy, just a little bit of vanadium (Figure 3).

If you're looking for a light alloy for aerospace applications you go to aluminum alloys. It is the same story. You are looking into the 2000, the 6000, and the 7000 series of precipitation hardened aluminum alloys. That's it. Seven-decades-old materials you are still using in industrial applications. So to realize better applications to come up with innovation, we need also the materials for it. And it's not going to happen by using the same material over and over again (Figure 4).

This is essentially what forms the basis for the Materials Genome Initiative that was launched. I think they got the idea from *Iron Man*. That was launched in 2011, and there are a number of US funding agencies that are supporting this effort. And it is basically to come up with custom-made materials and to do this in a short amount of time (Figure 5).

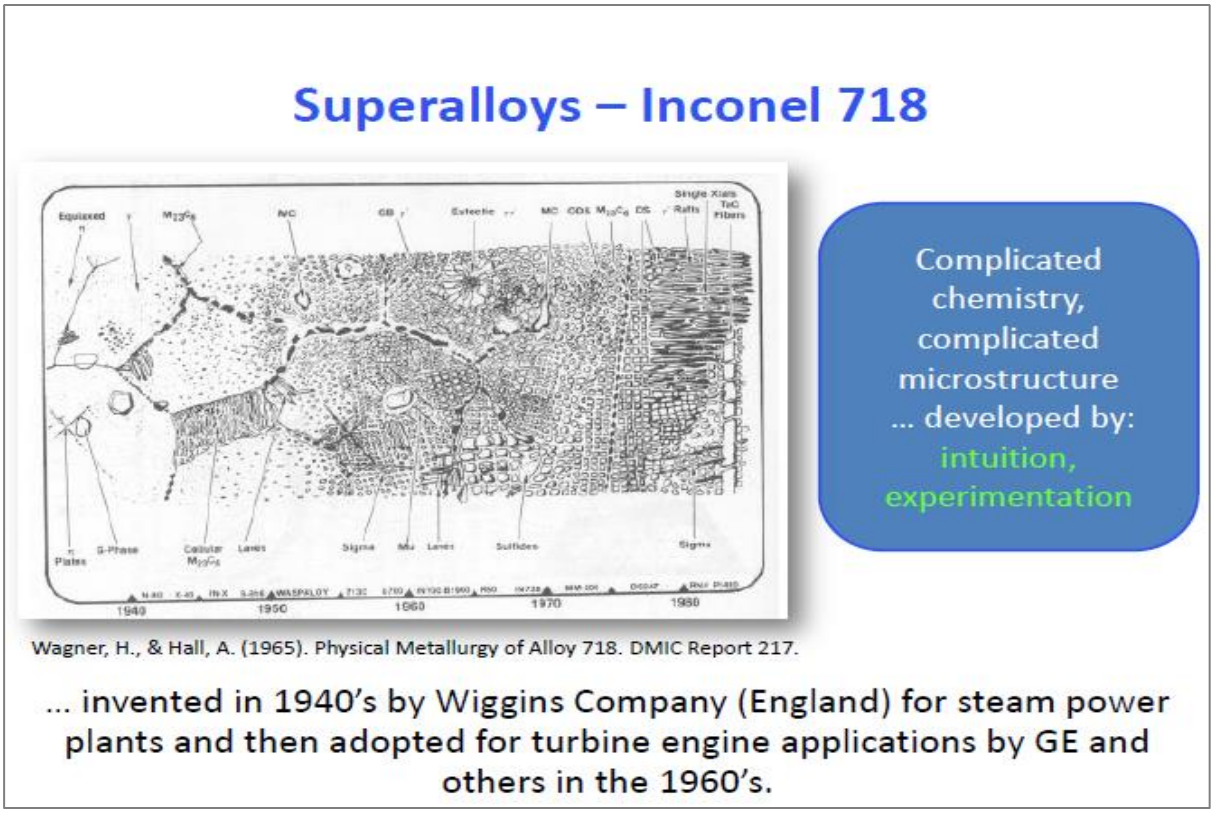


Figure 3. Superalloys - Inconel 718

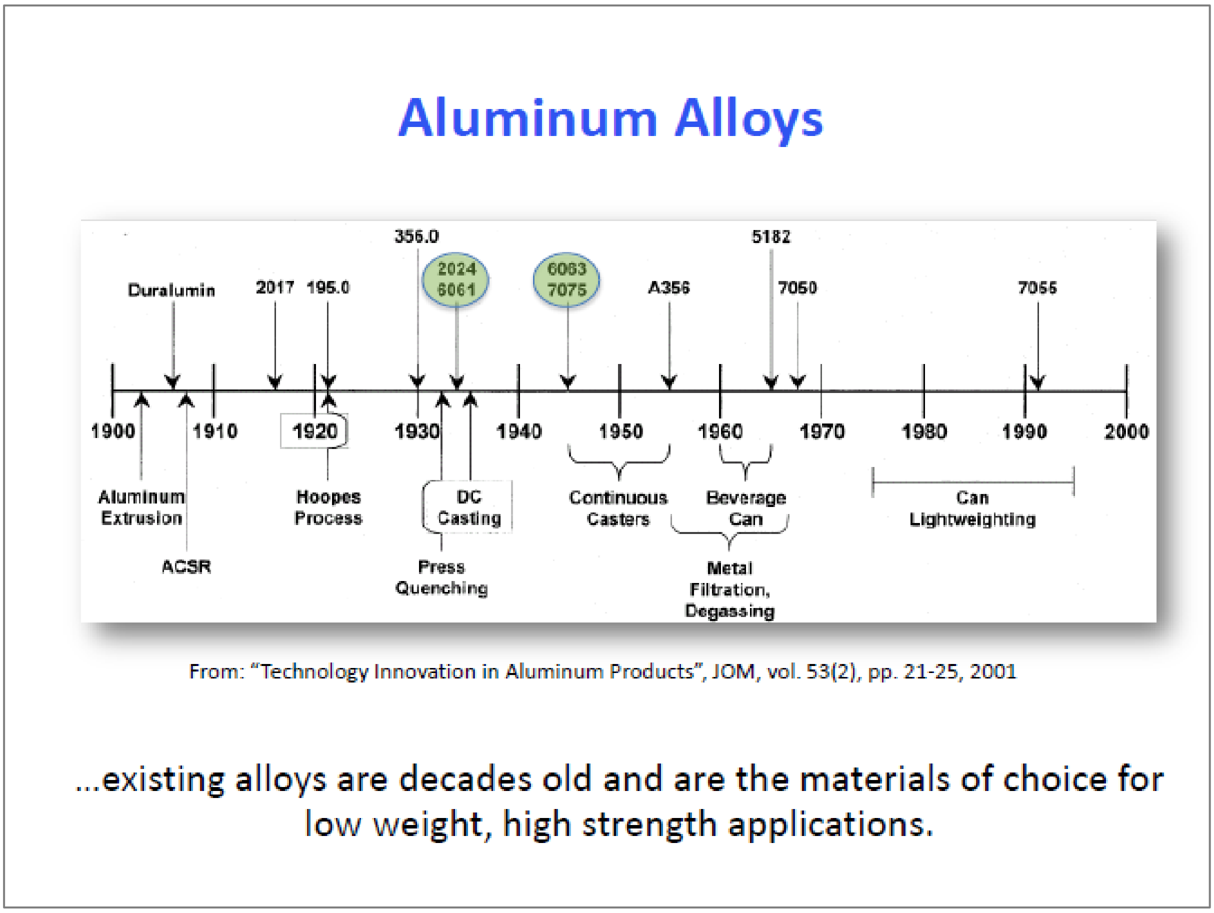


Figure 4. Aluminum Alloys

Figure 5. Materials Genome Initiative

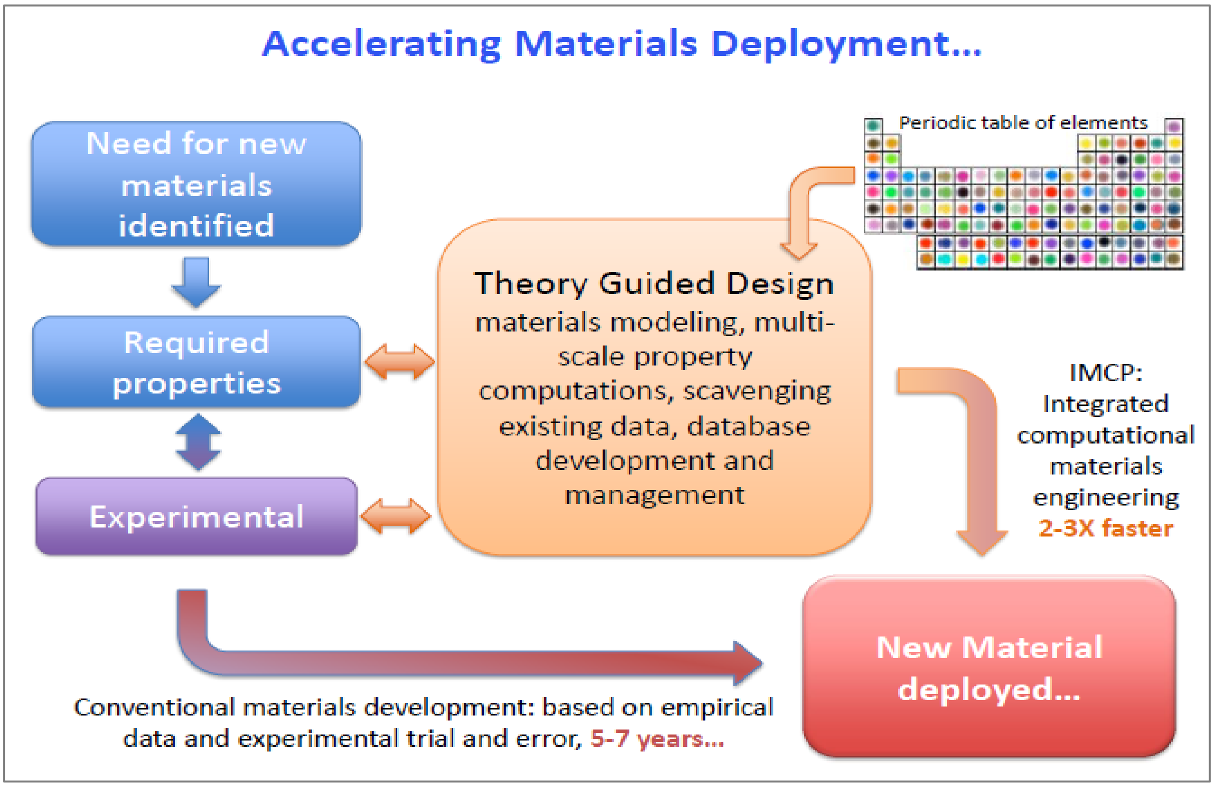


Figure 6. Accelerating Materials Deployment

The industry needs new a material. You identify the need, you have to come up with required properties, and you have to do experimentation, adding a little bit of this and a little bit of that and hoping for the best. This takes a lot of time; ~ 5 to 7 years of time (Figure 6).

So what do we do? Now we have tools available to us: theoretical tools. We have data analysis tools available to us that can help us accelerate this process of materials development and to come up materials that are customized for certain applications that are smarter, that are better, lighter, that make more sense, instead of using the same material systems over and over again that were developed in the moment of crisis during World War II. The essential tools for that, the theory part, are now very well laid out. We have increased the capability of computing extremely difficult relations starting from quantum mechanics. We can take it to the next level; we can take it to continuum-level modeling (Figure 7).

I am going to show you three applications wherein we have used these concepts to come up with better materials for industry. But before I get into those applications, I would like to thank President Im for the very kind invitation. It's a great honor to be here. Thank you very much. And I enjoyed walking through the labs of KIMM, and I was extremely impressed. He gave me a great opportunity to address the last M in KIMM, the materials development. I am extremely pleased to be here at KIMM.

Self-Healing, High-Reliability Electrical Contacts

Electrical contacts. Make and break type of contacts. We use them every day, when we are charging our phones, when we're looking into these circuit breakers in our basements. You go from something very cheap to electrical contacts in aircrafts; that's something more complicated and more expensive. So, this is the research theme that started off with funding from the army, the U.S. Army, and extended into United Technologies Research Center, and essentially, for the last 4 years, we were funded entirely by GE. We are looking into reducing the silver in their circuit breakers that go in our basements for residential applications (Figure 8).

Figure 7. Theory & Modeling

This is the team. We are doing joint research with the industry with our industry partners from GE Industrial Solutions in Connecticut to come up with the materials that are reliable that heal themselves under difficult oxidation and corrosion conditions (Figure 9).

So these are the materials that we have for the different types of electrical contacts that you can think of. And most of the time, the failure is when you make and break that contact. Usually the abrasion, fretting, the wear results in getting rid of the coating that exposes the base metal down, and then the base metal starts oxidizing and corroding. So how do we overcome this problem? Putting more coatings and reducing the contact resistance even further (Figures 10 and 11)?

Figure 8. Self-Healing, High-Reliability Electrical Contacts

Figure 9. People_1

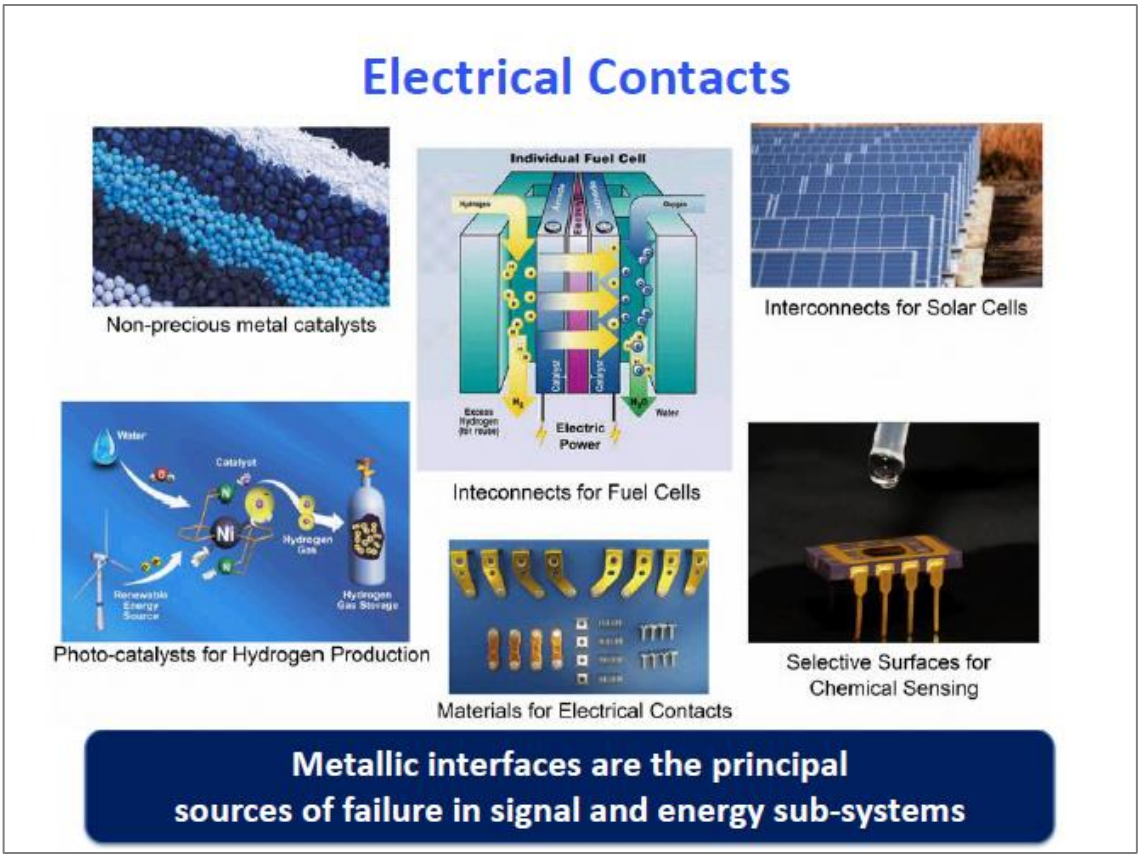


Figure 10. Electrical Contacts

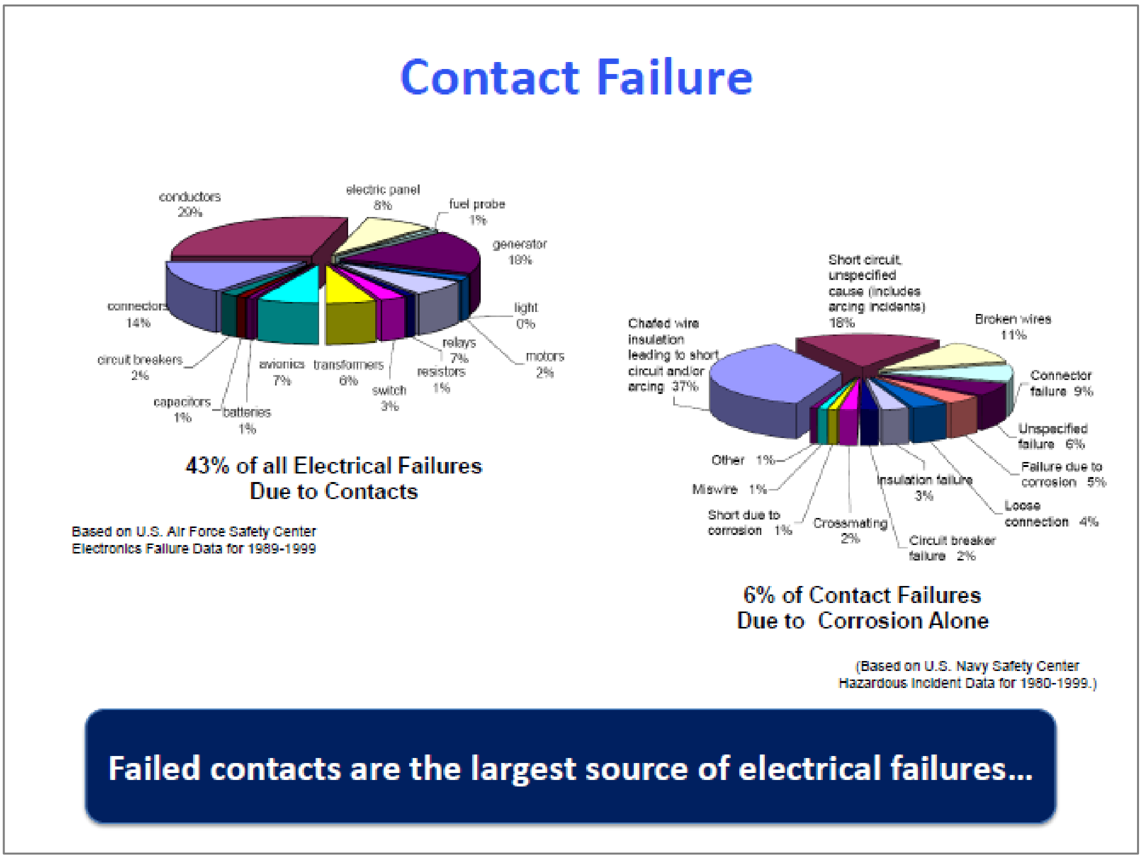


Figure 11. Contact Failure

So, there are different types of solutions. This is nothing new; we've been doing this since the 50's essentially. But a more elegant solution would be, "If the material frets, wears out, if that can be made conducting, then this is a self-healing solution that won't require maintenance (Figure 12).

This is the idea that we've been developing since 2008. What if you use base metals that when oxidized have electrical properties similar to metals? And there are several of them. And the analysis actually starts off with looking into phase diagrams, correlating the phase diagrams of the metals and oxides to conductivities. This study took us almost four years. We've developed several alloys that are dirt cheap compared to, say, silver (Figure 13).

Solutions – Pros and Cons…

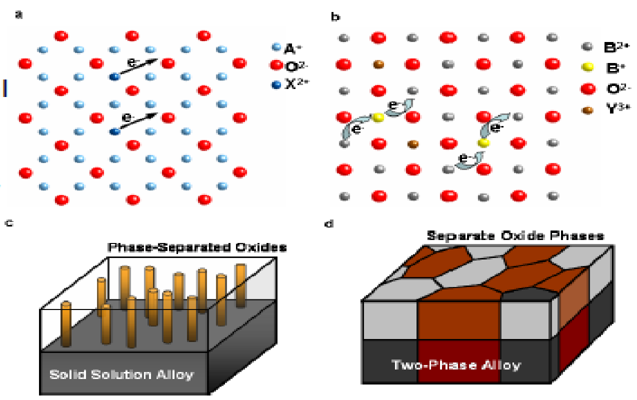
Alternatives and augmentations to base metal contacts…

Approach	Advantages	Disadvantages
Solder or Welded Contacts	Metallurgical junction	Field repairs difficult
Tin Coated Base Alloys (e.g. Brass)	Pliable surface that enables metal plowing	Fretting, fritting, whisker, and corrosion failures
Compression Contacts	High contact forces for low resistance contacts	Oxidation and corrosion at interfaces, high engagement forces
Encapsulates and Hermetic Seals	Large diffusion distances for oxidation and corrosion	Large connector footprint, limited field repair
Precious Metals (e.g. Au, Pt, Pd)	Good electrical contact, high corrosion resistance	Prohibitively high costs even for military applications

Figure 12. Solutions - Pros and Cons

Materials Development: *Self-Healing* Base Metals

Forming **conducting oxide scales: a) Doping** with cations, **b)** Inducing a **mixed valence state** in the base metal cations (electron/polaron hopping), **c)** Formation of a **mixed oxide scale** wherein oxide phase separation gives percolative conducting pathways through the insulating base metal oxide, **d)** Forming a **two-phase base metal alloy** where the second phase forms a inherently conductive native scale.



The Midas Touch: Turning Base Metals into "Gold" by Developing Alloys that Form Naturally Conductive Oxides

M. Aindow, S. P. Alpay, Y. Liu, J. V. Mantese and B. S. Senturk, "Base Metal Alloys with Self-Healing Native Conductive Oxides for Electrical Contact Materials," Appl. Phys. Lett. 97, 152103 (2010)

Figure 13. Materials Development: Self-Healing Base Metals

For example, Iron-Vanadium (Fe-V). Your base metal is iron. Iron rusts, right? But if you put a little bit of vanadium, you form a vanadium oxide passivating layer on top. The vanadium oxide has the balance of plus 2 to plus 5 charge vanadium and oxygen environment and it's a metallic conductor. So the conductivity of vanadium oxide, in a mixed oxide state of iron and vanadium, is as good as iron. That's a solution (Figure 14).

You put in a little bit of ruthenium; I mean, in this case, not a little bit, a lot of ruthenium. You get the same thing. Ruthenium oxide is a conductor. It's a metallic conductor as good as iron, nickel, and copper, especially under oxidizing conditions, because ruthenium oxide is already oxidized. So there are certain ways of achieving these kinds of self-healing capabilities in simple base metal oxides just looking by analyzing phase diagrams in the metallic and in the oxide level (Figure 15).

Waste Heat Recovery through Pyroelectric Energy Conversion

Another story. Going from metal and metal oxides, these are ceramic systems, and some of the speakers touched upon this. This is energy, heating/cooling. Starting off with funding from the U.S. Army, we've been receiving funding from United Technologies Research Center. They are the research arm of United Technology Cooperation, which produces air-conditioning units as one of their businesses (Figures 16 and 17).

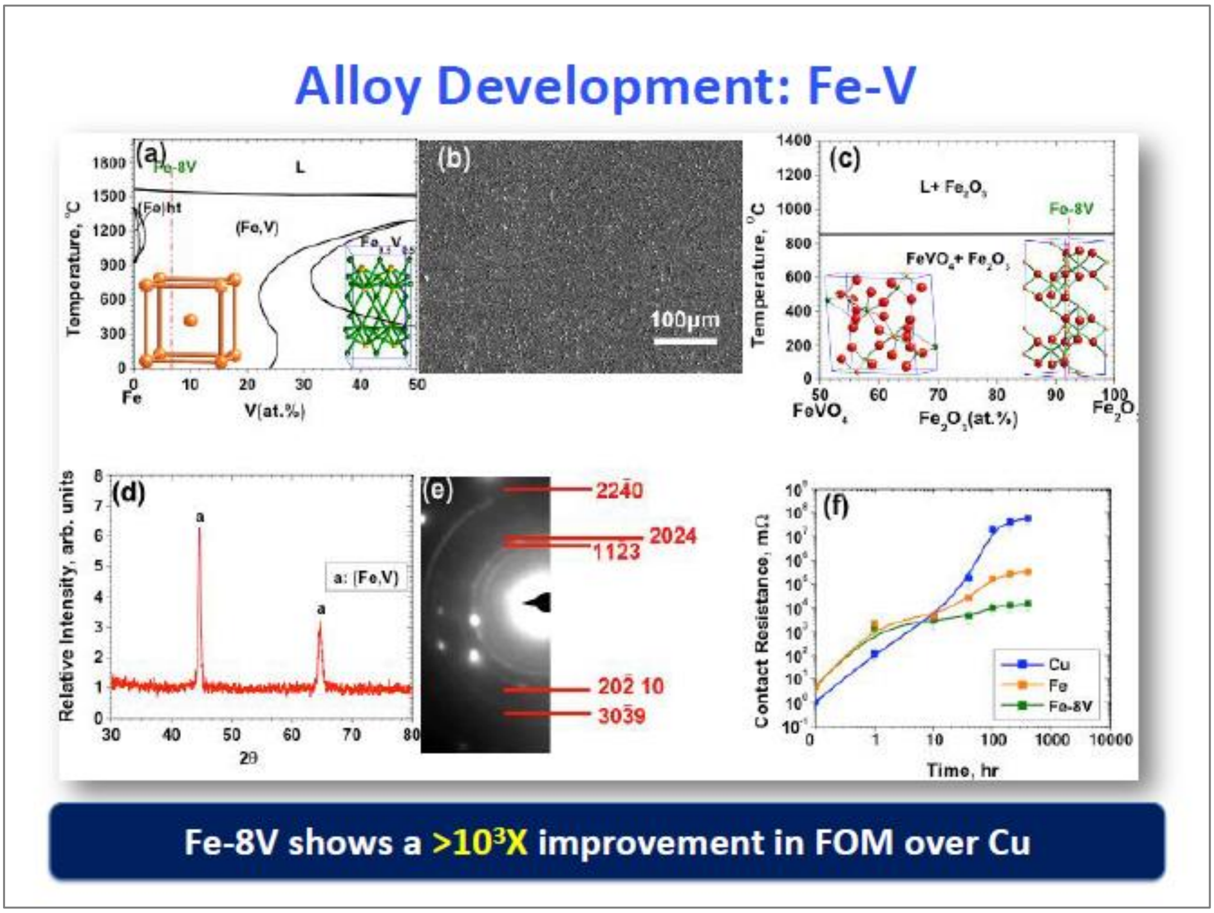


Figure 14. Alloy Development: Fe-V

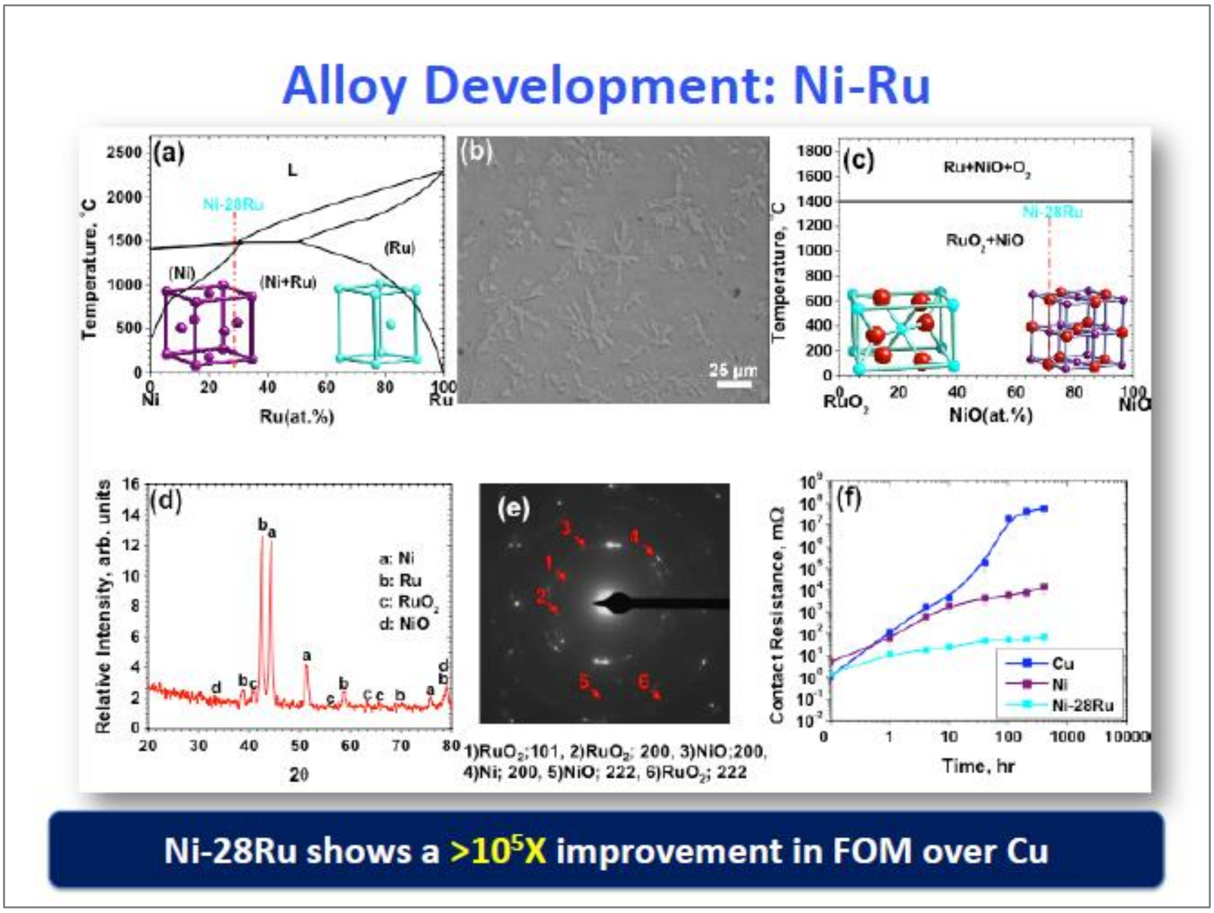


Figure 15. Alloy Development: Ni-Ru

Figure 16. Waste Heat Recovery through Pyroelectric Energy Conversion

My third generation of students is working on this. This has been going on since 2007. And we have enlisted the help of several other colleagues from Penn State and from Imperial College (Figures 18 and 19).

Figure 17. A Good Overview

Figure 18. People_2

The idea is trying to recover some of the base energy that is generated, for example, when you are running a car. A lot of that heat is wasted. If you could design a material to recover some of it to turn it into useful electricity as the car's operating, it would be beneficial (Figure 20).

Figure 19. People_3

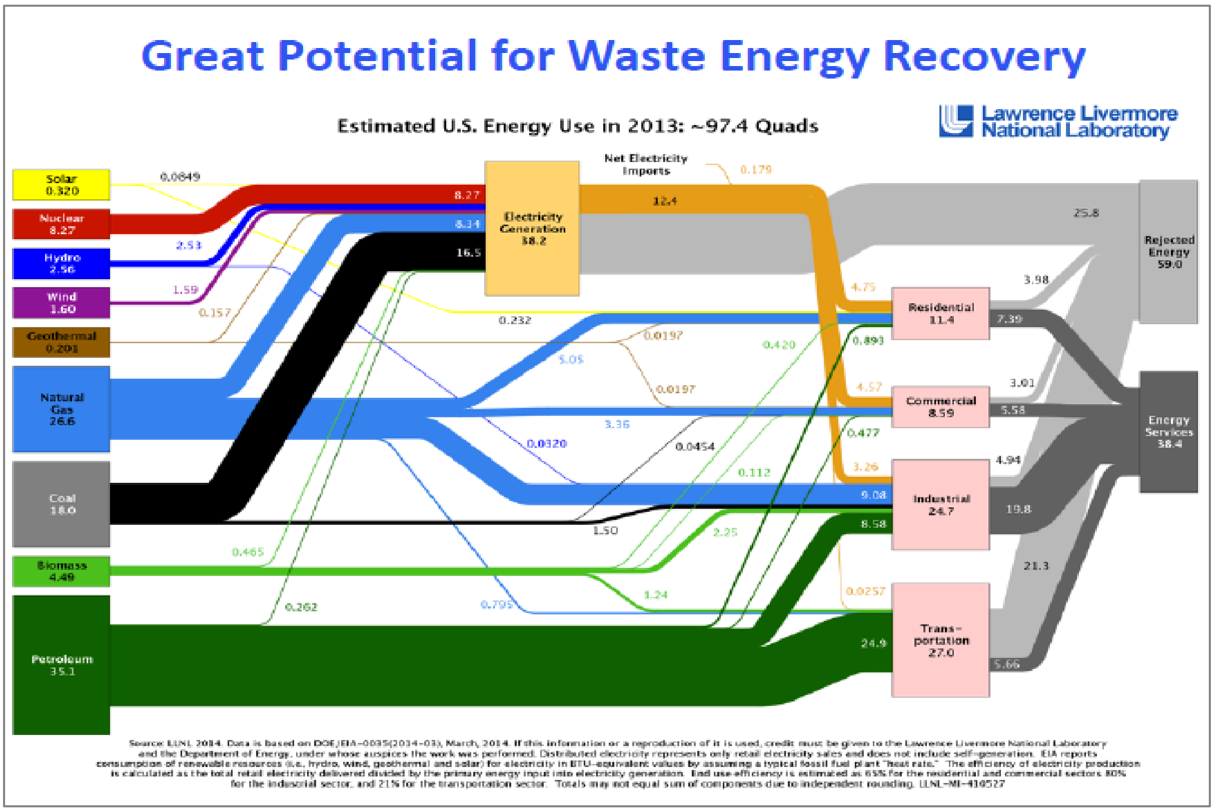


Figure 20. Great Potential for Waste Energy Recovery

There are also other applications. The concepts are the same: the effect is thermodynamically opposite of it. So you can use them for pyroelectric sensors, detectors, fire detection, in addition to energy harvesting (Figure 21).

This is the effect. Certain materials do that. Ferroelectric crystals do that very, very well. When you heat it up, you generate a current. This is the pyroelectric effects. It’s the change in the polarization that gives you this pyroelectric current (Figure 22).

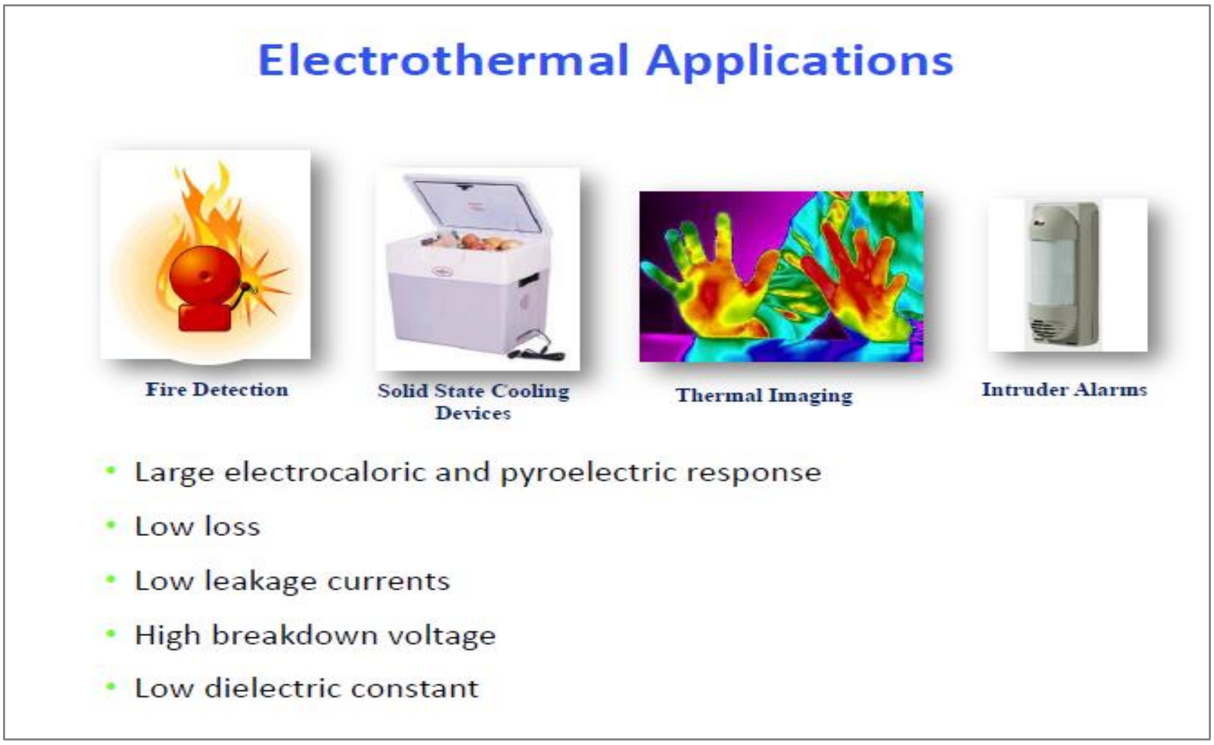


Figure 21. Electrothermal Applications

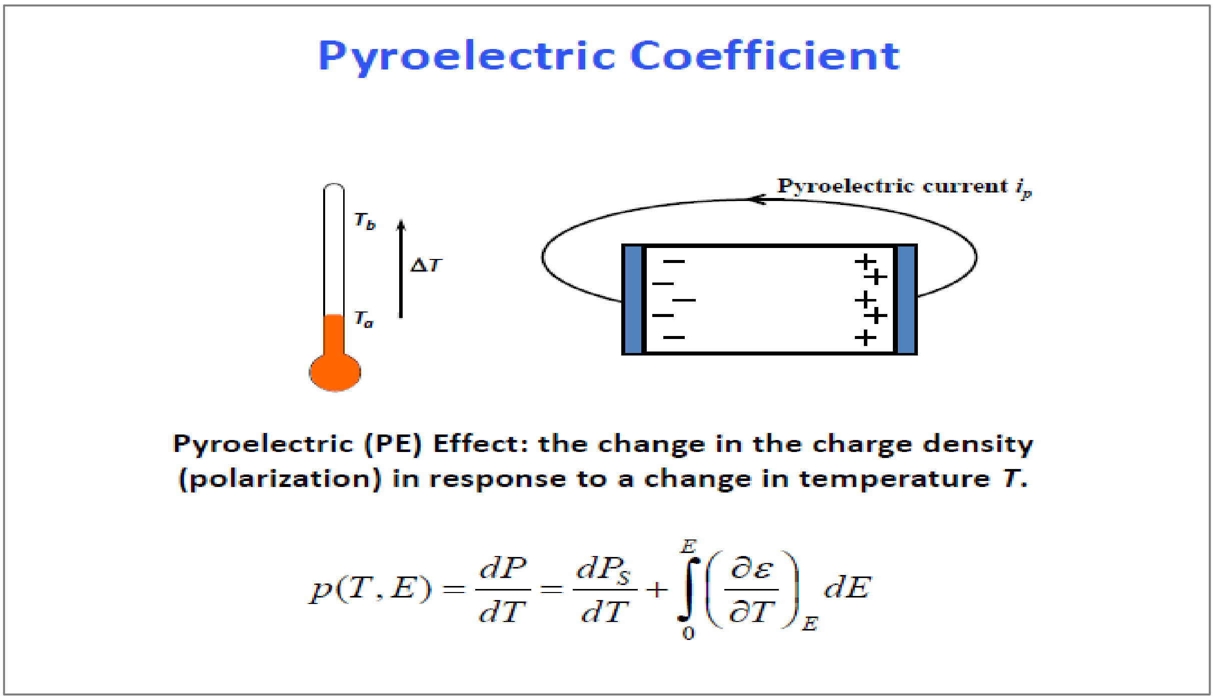


Figure 22. Pyroelectric Coefficient

The opposite effect is called electrocaloric effect. And this allows you to recover some of the lost energy. The temperature difference will generate a potential difference, which then can be converted into current (Figure 23).

These are the materials that do that. Very complex crystal chemistry. There are certain oxides that do that, these are ceramic materials, there are certain polymers that do that. And using theoretical tools, you can actually look into the properties of existing materials that have that (Figure 24).

And this is one of the landmarks where it was shown that if you can make thin films with these materials, you can actually generate temperature differences that are almost 10 degrees in C if you apply a large enough field. Since then, people have looked into different chemistries. Again, the concept here is playing with chemistry. Putting a little bit of, this and that and play with for example the chemistry of PVDF, and look at the properties. This is the trial and error approach (Figure 25).

These are models. These are the models that we have developed in understanding existing material systems. So you can change the temperature, you can change the electric field, and compute quantitatively what these properties should be before making these extremely expensive materials made by expensive technologies. You can try to understand how misfit strain changes properties. This is theoretical data that matches well with experimental result. So we know that our models are there. You can look into more complicated chemistries (Figures 26 and 27).

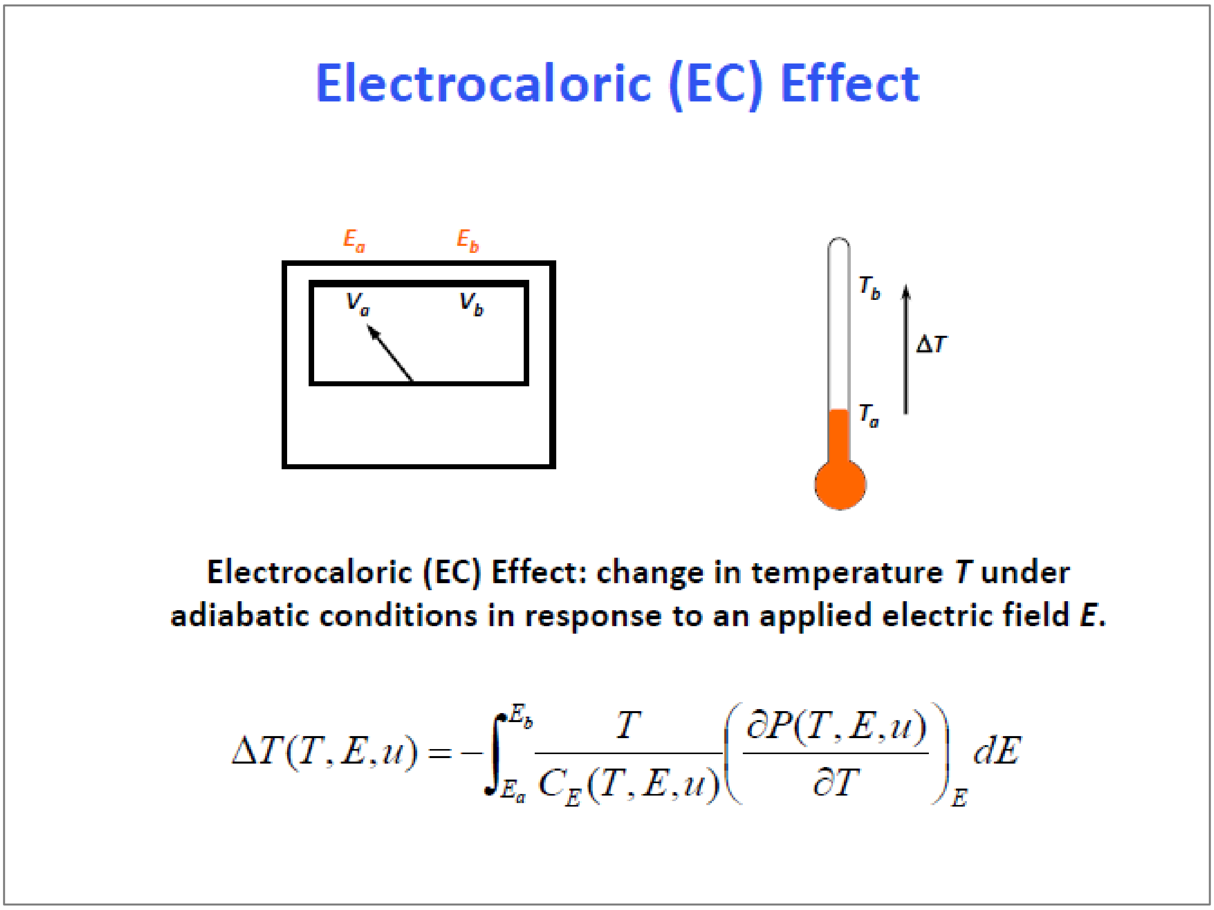


Figure 23. Electrocaloric (EC) Effect

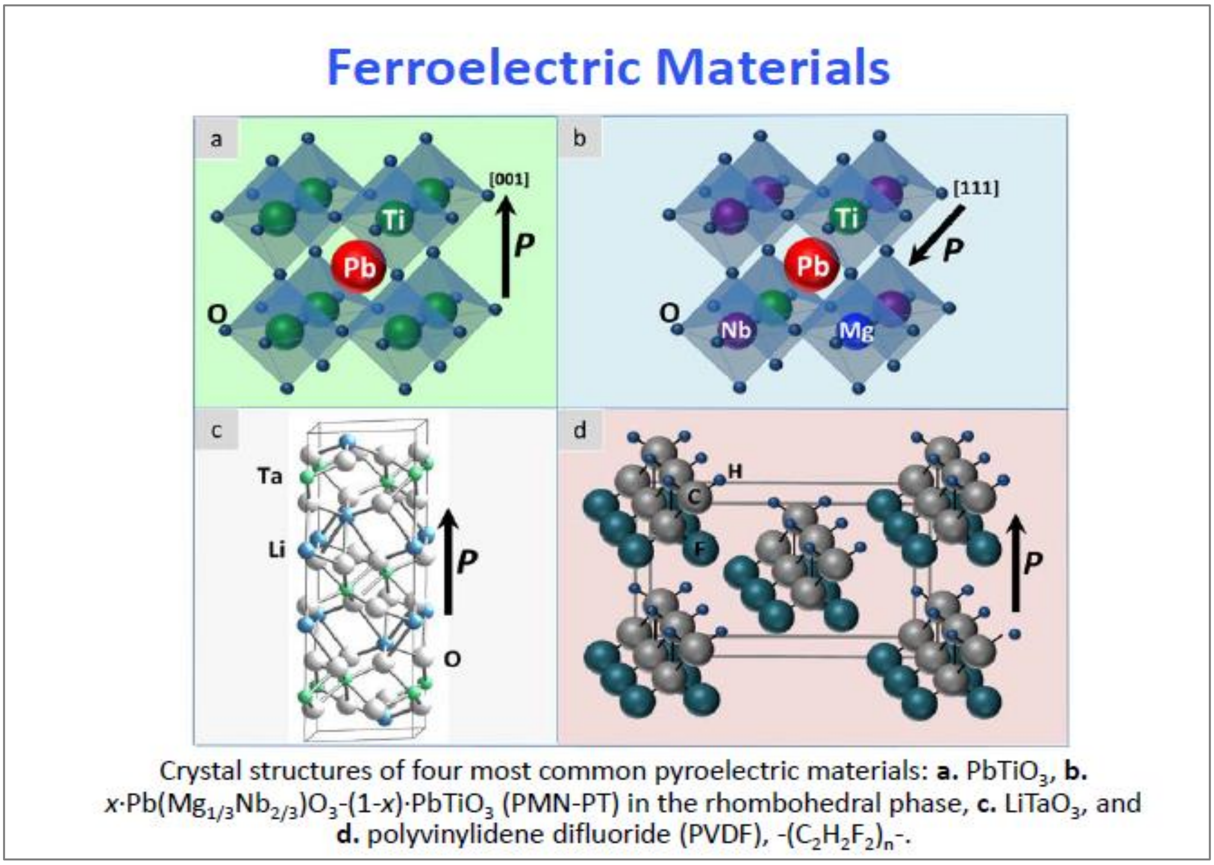


Figure 24. Ferroelectric Materials

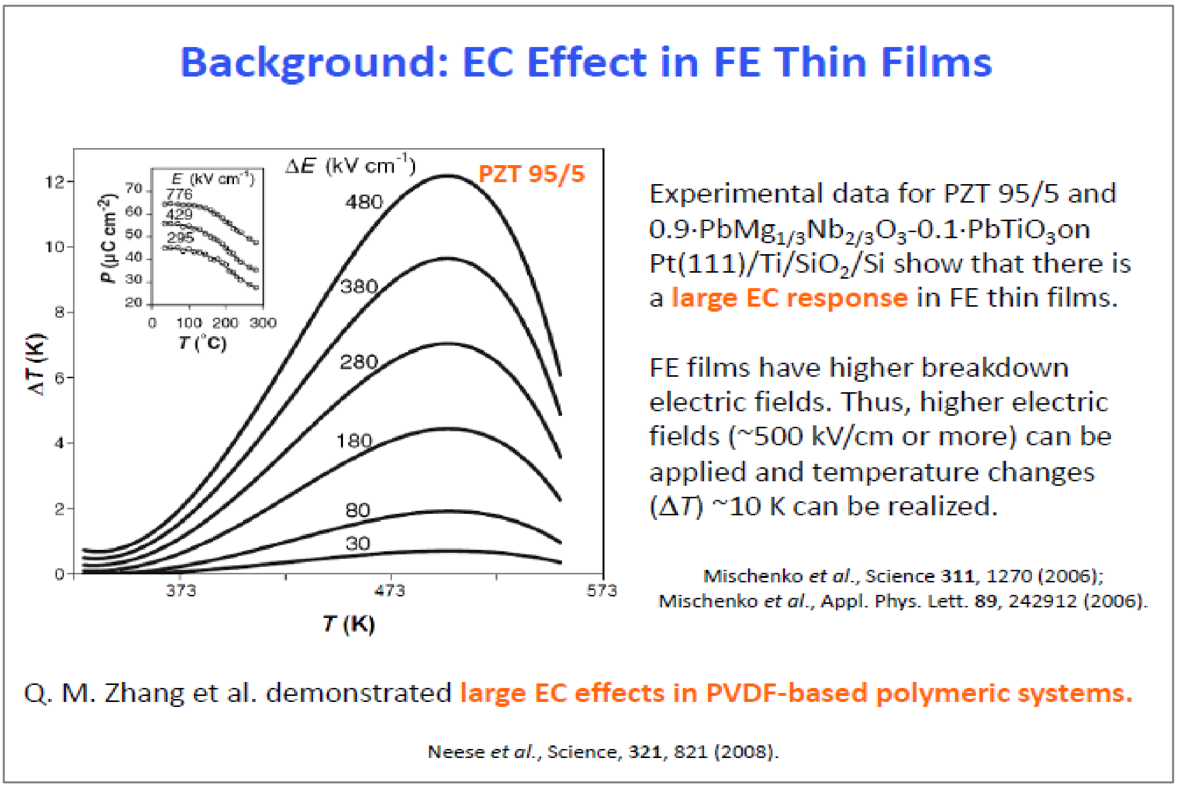


Figure 25. Background: EC Effect in FE Thin Films

Background: Since then…

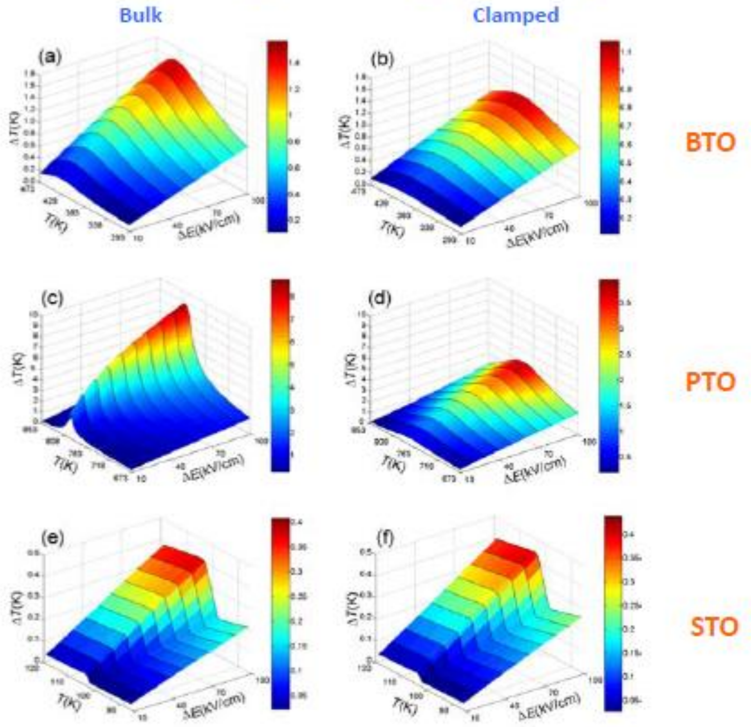
Table I. Properties of several pyroelectric materials when used for thermal energy harvesting in either a resistive (linear) or the Ericsson cycle.[a]

Material[b]	Type[c]	p (μCm^{-2}K^{-1})	ε	c' (MJm^{-3}K^{-1})	T (°C)	W_{cycle}[a] (kJm^{-3})	η_{Carnot}	η_{Res}/η_{Carnot}	Ref.
Linear Materials Employed in a Resistive Cycle									
$LiTaO_3$	X	230	54	3.2	100	8.7	2.6%	0.81%	8,24
0.72 PMN-0.28 PT	X (111)	1071	660	2.5	75	15.4	2.8%	1.85%	25
PZFNTU	C	380	290	2.5	100	4.4	2.6%	0.53%	26
PZT30/70-0.01Mn	F	300	380	2.5	100	2.1	2.6%	0.25%	27
PVDF	P	30	11	2.5	37	0.7	3.2%	0.09%	28
PVDF-TrFE 60/40	P	45	29	2.3	77	0.6	2.8%	0.08%	29
Non-Linear Materials Employed in Ericsson Cycle									
Material[b]	**Type[c]**	**Q_{ECE} (MJ m^{-3})**	**E_1 (MV m^{-1})**	**c' (MJ m^{-3}K^{-1})**	**T (°C)**	**W_{cycle}[a] (kJ m^{-3})**	**η_{Carnot}**	**$\eta_{Eric}/\eta_{Carnot}$**	**Ref.**
0.95PST-0.05PSS	C	4.2	2.5	2.5	−5	154	3.7%	14%	30
0.90PMN-0.1PT	C	1.4	3.5	2.5	30	45	3.2%	5%	23
0.75PMN-0.25PT	X (111)	3.2	2.5	2.5	75	91	2.8%	11%	31
0.75PMN-0.25PT	F	15	90	2.5	100	397	2.6%	38%	32
PZT95/05	F	31	78	2.5	220	631	2.0%	56%	33
PVDF-TrFE 55-45	P	38	200	2.3	37	1206	3.2%	62%	34,35
PVDF-TrFE-CFE	P	61	350	2.3	77	1718	2.8%	73%	35,36

[a] Computed parameters assume a temperature cycle of ±5°C about T.
[b] Material codes defined in text, with the following exceptions: PST = $PbSc_{1/2}Ta_{1/2}O_3$; PSS = $PbSc_{1/2}Sb_{1/2}O_3$; PZFNTU = $Pb(Zr_{0.58}Fe_{0.2}Nb_{0.2}Ti_{0.02})_{0.995}U_{0.005}O_3$; PZTx/1 − x = $PbZr_xTi_{1-x}O_3$, where 0.01 Mn means doped with 1% Mn.
[c] Types: C = ceramic; X = single crystal; F = thin oxide film; P = thin polymer film.

Figure 26. Background: Since then…

$BaTiO_3$, $PbTiO_3$, $SrTiO_3$ Films (Clamped)



J. Zhang, A. A. Heitmann, S. P. Alpay, and G. A. Rossetti, Jr., J. Mater. Sci. **44**, 5263 (2009).

Figure 27. BaTO3, PbTiO3, SrTiO3 Films (Clamped)

We also looked into relaxor-ferroelectics, and again, they match very well with experimental results. How about, how would we actually develop a material that has optimum electrocaloric properties? What if we could do this with on a computer? And that's the material that we have come up with. It resembles liquid crystal, but it's tethered along the Z axis of this crystal. Then you have in-plane rotational freedom. This kind of material, if it can be made, would have fantastic electrocaloric properties. This is the knowledge that was developed and transferred to our colleagues doing experimental material science and experimental physics or chemistry. So this is how an ideal material should look for an application that we are trying to harvest electricity, harvest heat, and convert this into electricity (Figures 28 and 29).

This is the paper that came out in *Nature Computation Materials* a couple of weeks ago (Figures 30 and 31).

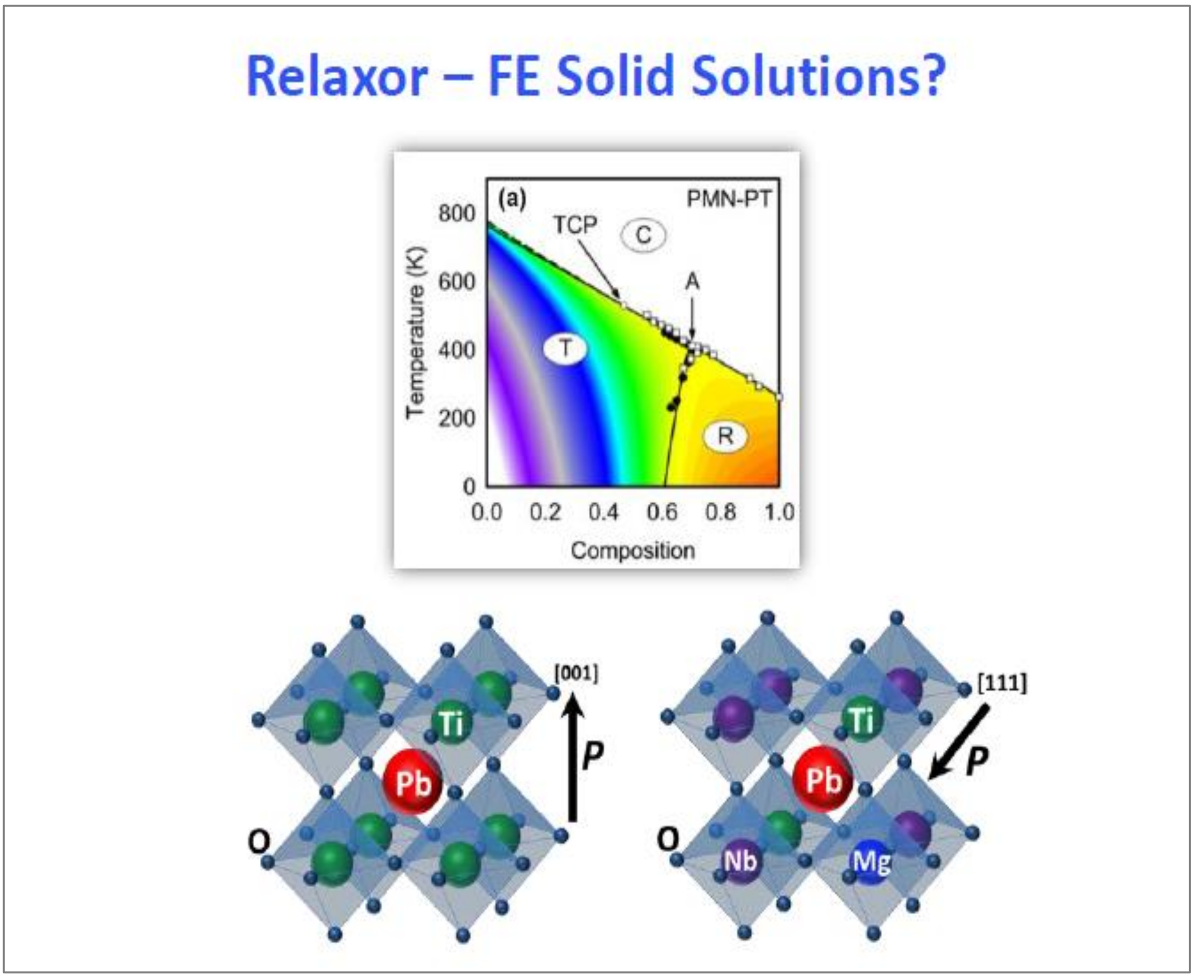


Figure 28. Relaxor - FE Solid Solutions?

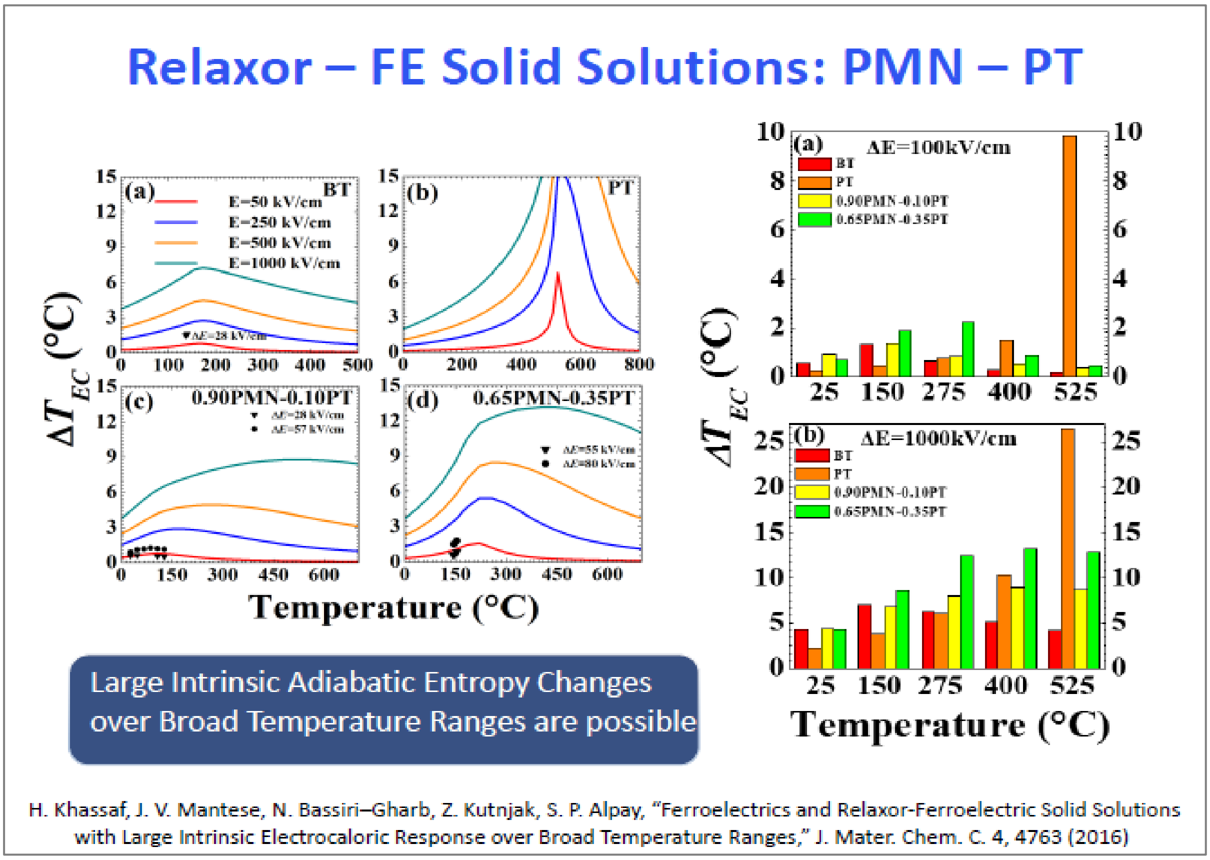


Figure 29. Relaxor - FE Solid Solutions: PMN-PT

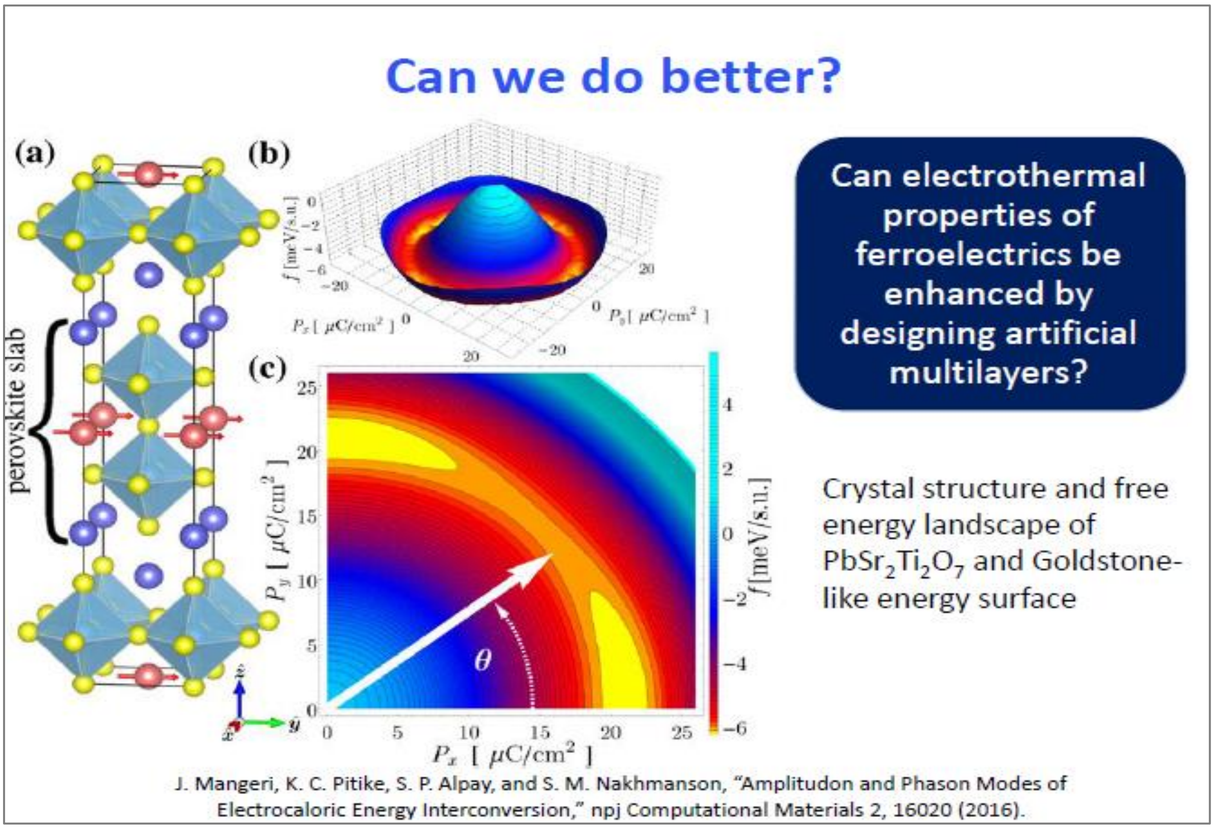


Figure 30. Can We Do Better?

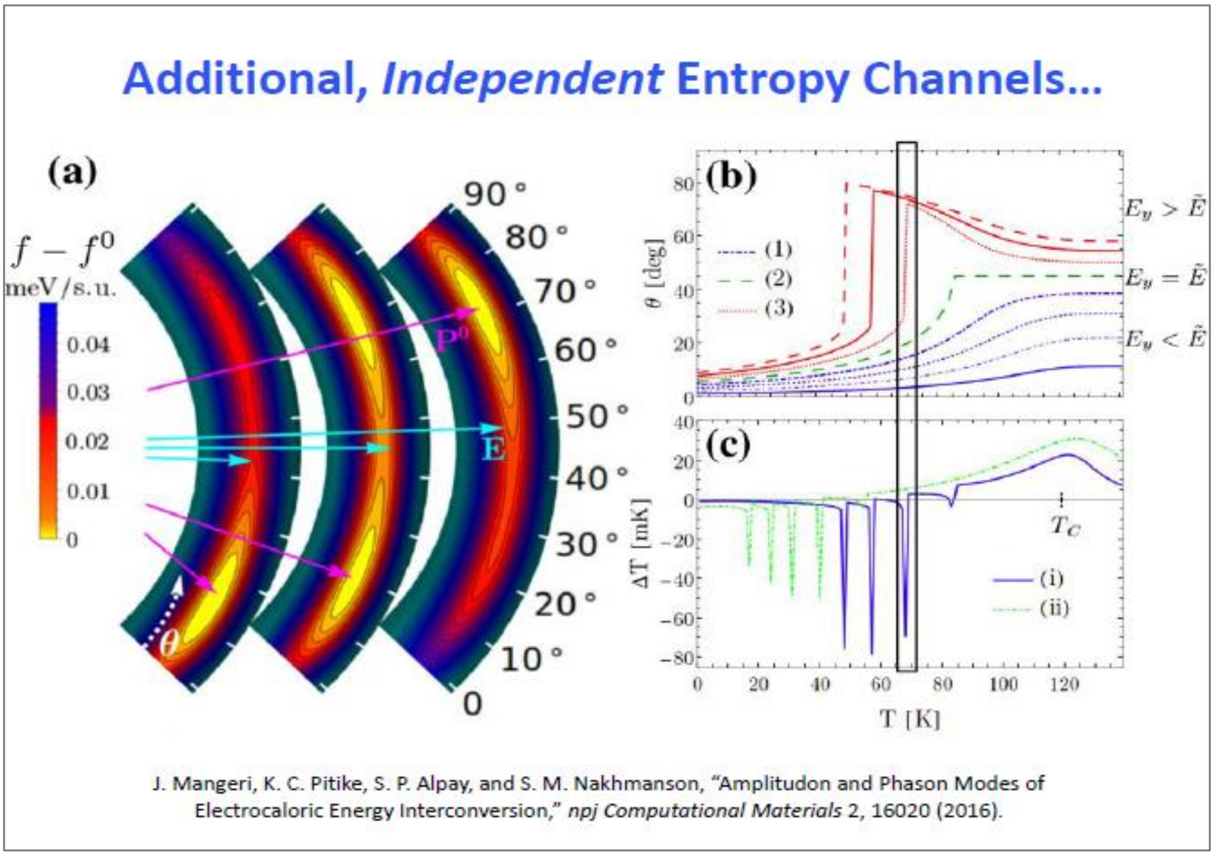


Figure 31. Additional, Independent Entropy Channels...

Design of Custom Aerospace Alloys for Additive Manufacturing

A third example. We are working with Pratt & Whitney. Pratt & Whitney is a company that makes turbine blades, turbine engines for aircrafts. Its sister company (these are both part of the United Technologies Group), United Technology Aerospace Systems does not make engines; they make everything else for the airplane, so the fuselage and the electronics and what goes on into an aircraft. The problem here is, "How do we describe the additive manufacturing process?" We had one speaker talking about laser processing of materials. We know a lot of things about the laser; we know a lot of materials that are being used because, as I said, those are the materials that have been used for the last 70 years. We know these concepts very well, but we don't know much what happens then the laser touches with titanium powder. We don't know what happens when that laser touches in Inconel powder. You are taking this for granted when looking into this kind of new processing metals (Figure 32).

This is the team that's working on that. This is the effort led by Rainer Hebert. Again, with industrial colleagues, we work together as a team. We are not doing research for them. We are doing research together. And there are physicists involved in this process, and we have very, very bright graduate students who work on that. One of them is sitting in the back. Ms. Tulsi Patel spent her summer here working at KIMM on looking into the powder methodology process adapted for additive manufacturing (Figure 33).

And the idea is, this is the basic premise of additive manufacturing really, right? So you are not just manufacturing things subtractively. So you are not getting rid of materials. You are not shaping it from a block of metal. You are essentially building this from the bottom up using laser or electron beam processes. In the case of polymeric 3D, it's almost a material technology. In the case of metals,

metals have micro structural complications. The idea is very neat but adapting this to something as critical as aircraft alloys takes a lot of research.

So, these are the basic concepts that tell you all about the advantages. These are all kinds of things you can do. You can actually get rid of a lot of these valves, these seams, these parts that you have to put together. If you carefully design your part from the bottom up, this is a fantastic process. So, you can design molds for golf balls; you can do all sorts of things. Actually, your imagination is a limit.

Figure 32. Design of Custom Aerospace Alloys for Additive Manufacturing

Figure 33. People_4

Now the issue here is, metals that you make out through additive manufacturing are not the same metals. Composition-wise they are the same. But microstructure-wise, they are completely different. So, how do we actually develop materials that are now adapted to the additive manufacturing process instead of forcing existing materials into this brand new, fantastic method of processing? So that's the question that we asked with our partners at Pratt & Whitney as well as UTC Aerospace Systems. And we have put this team together two years ago (Figures 34 and 35).

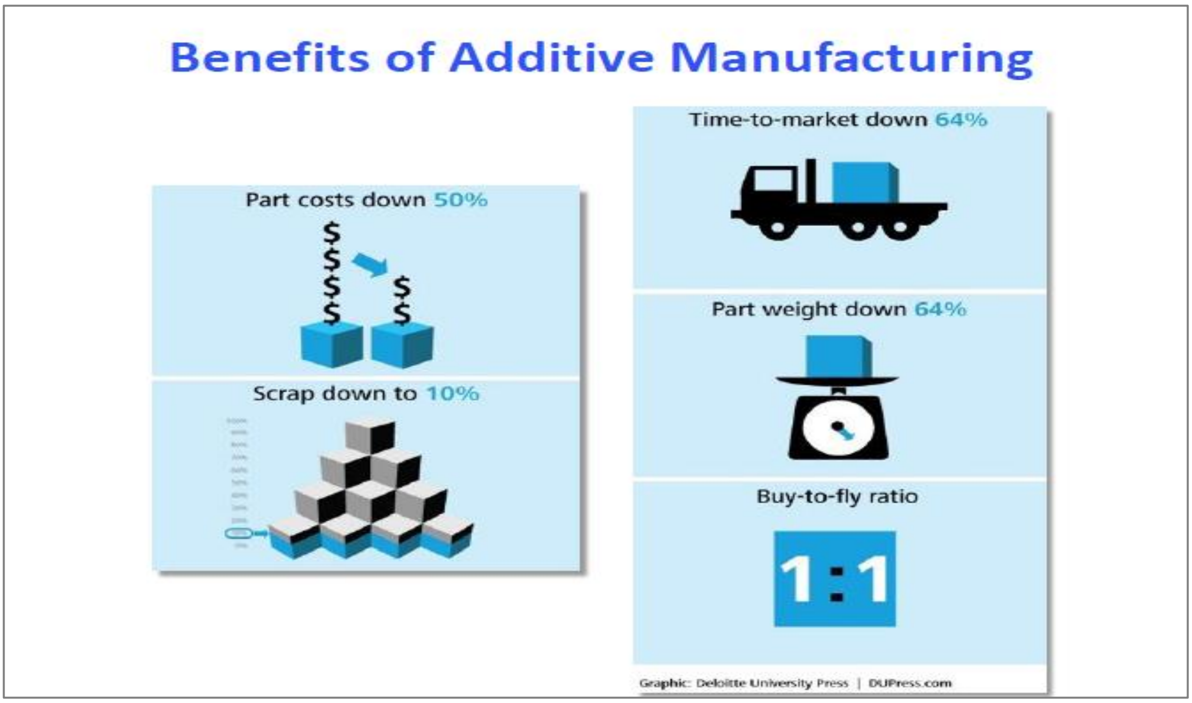


Figure 34. Benefits of Additive Manufacturing

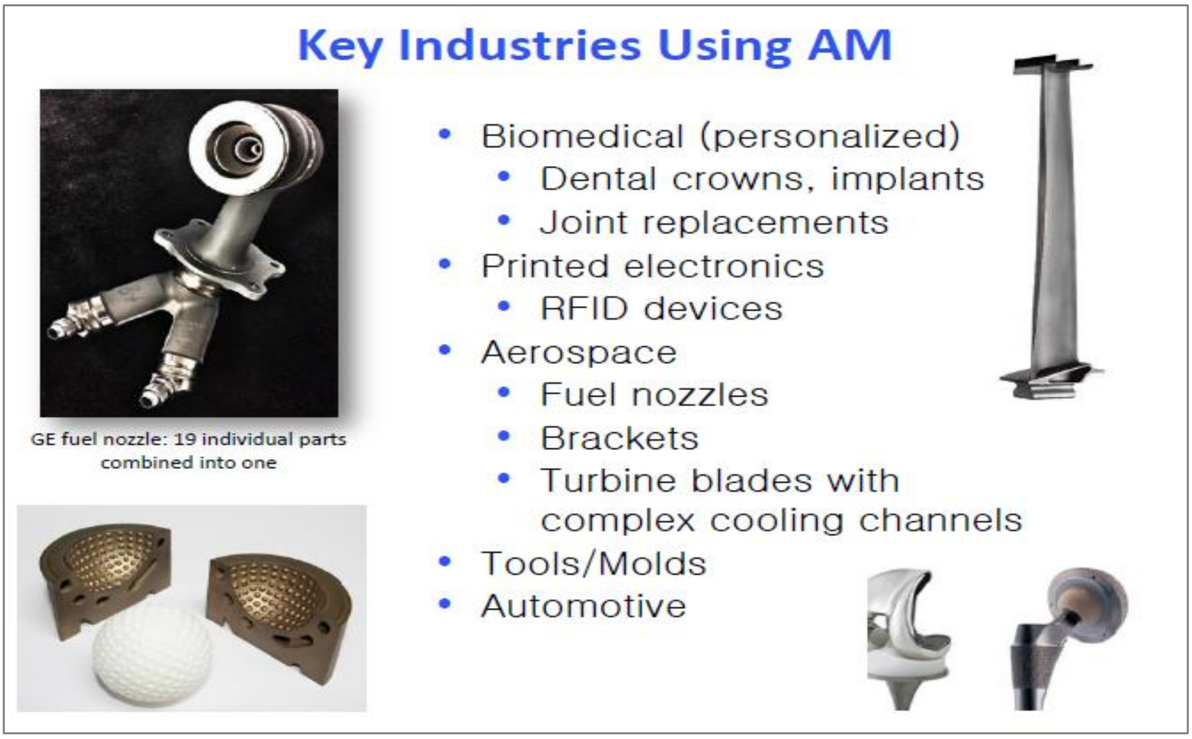


Figure 35. Key Industries Using AM

Now, we have a center at UCONN, and that center is jointly funded with Pratt & Whitney and UCONN. We have several 3D printers. These are the 3D printers for nickel alloys, titanium alloys, aluminum alloys. We have four of these. We are developing the fifth one. This is open box UCONN based additive manufacturing equipment so that we can keep every little control of that machine. This is the so-called Phoenix system. This is for stainless steel and aluminum alloys (Figures 36 and 37).

Figure 36. P&W Additive Manufacturing Innovative Center_1

Figure 37. P&W Additive Manufacturing Innovation Center_2

When you look at the additive manufacturing process, it seems very simple. But it's a very, very complicated process. A lot of things are happening when you start hitting a metal with a laser. You form plasma. You have partial melting. You have air bubbles escaping. You have spattering. You have melt pool convection, melting. And melting is processing rapid solidification. These are not easy issues, and none of them—although all of them solvable individually—have been solved as a one process (Figure 38).

We started asking some very basic questions. If we have titanium powder, if I have some impurities in the built chamber, how would these react with a laser beam? What would happen in the chamber as soon as we start hitting that titanium powder with a laser? How would impurities change the melting behavior?

We started looking into where these impurities would go. These are the kind of questions that we are working on right now (Figure 39).

The same thing with aluminum alloys. You would like to use aluminum alloys for almost everything that requires metal type, or the strength of metals. But these don't fit the additive manufacturing mold. How do we come up with better aluminum alloys that land themselves to additive manufacturing? What do we need to describe, theoretically, to make that happen? We have a good team in place, and we are looking into understanding modeling high strength, looking into understanding the precipitate method to measure its interaction, and looking to understand the solubility limits computationally. We are looking into thermodynamic stability. Individually, all of these problems have been solved. But when you put them together and to come up with a comprehensive theoretical model, it hasn't been done (Figure 40).

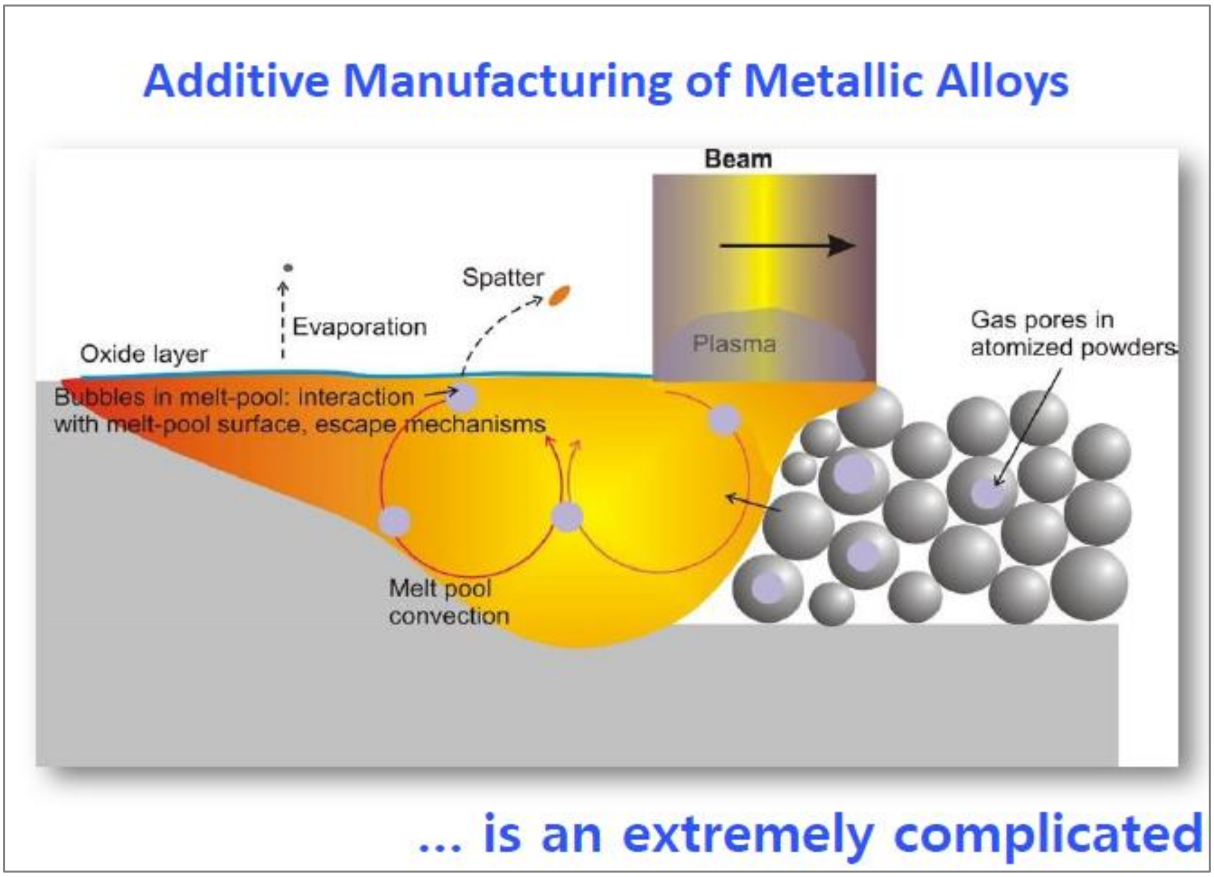
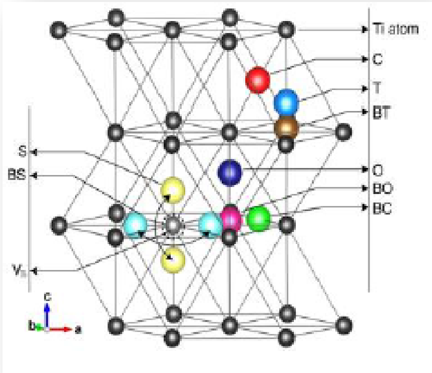


Figure 38. Additive Manufacturing of Metallic Alloys

Modeling Impurity Effects in Additive Manufacturing

Defect chemistry of Ti



Impurities impact the surface tension/gradient and melting behavior, formation of voids

First-principles computations are used to probe chemical effects on interactions in Ti and select alloys

Surface tension of Ti-6Al-4V particles as a function of temperature, impurity content in atmosphere and the particle

Surface chemistry of Ti

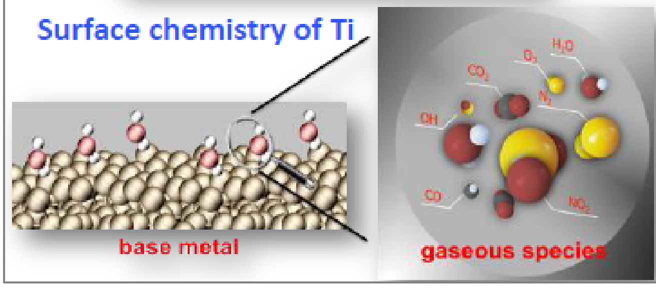
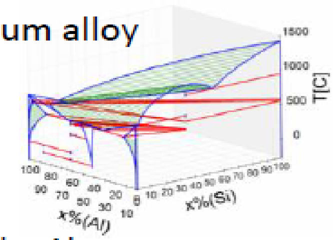


Figure 39. Modeling Impurity Effects in Additive Manufacturing

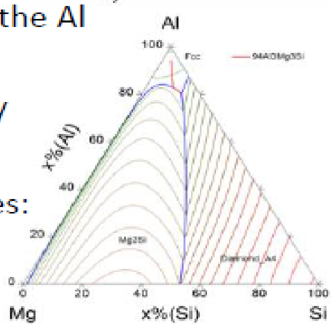
Searching for descriptors for strengthening Al alloys

- Theory assisted design of high strength aluminum alloy
- Density functional electronic structure theory



Potential descriptors

- High strength: Large bulk modulus
- Must form coherent/semicoherent interface with the Al matrix: Lattice mismatch
- Immiscible in Al matrix: Solubility, interface energy
- Temperature stability: Ab initio thermodynamics
- Constructing large database of materials properties: Materials genomics



Al 6061 powder, average powder size 10 microns

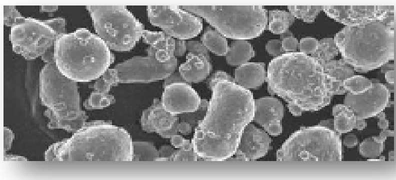


Figure 40. Searching for Descriptors for Strengthening Al Alloys

Conclusion

We are not stuck with alloys developed 70 years ago (Figure 41).

What we can do is, as theoretical physicists, experimentalists in solid state physics, physical chemistry and material science; we can come up with rapid methods that allow you to develop better materials for specific applications in a short time frame. This is essentially the basis of the so-called the Material Genomics Initiative. And they all use everything that's under your fingertips in terms of theoretical tools. But we also have to be mindful of what exists in the literature over the course of the last 100 years. We have to think about data mining techniques, about developing databases, and machine learning. This then leads to materials properties that can be used in systems-level computations for coefficients of performance or figure of merit to check the feasibility of these materials for specific applications (Figure 42).

So with this, I would like to finish my talk. Thank you very much for your attention, and thank you once again for the invitation. I am honored to be here. Thank you very much.

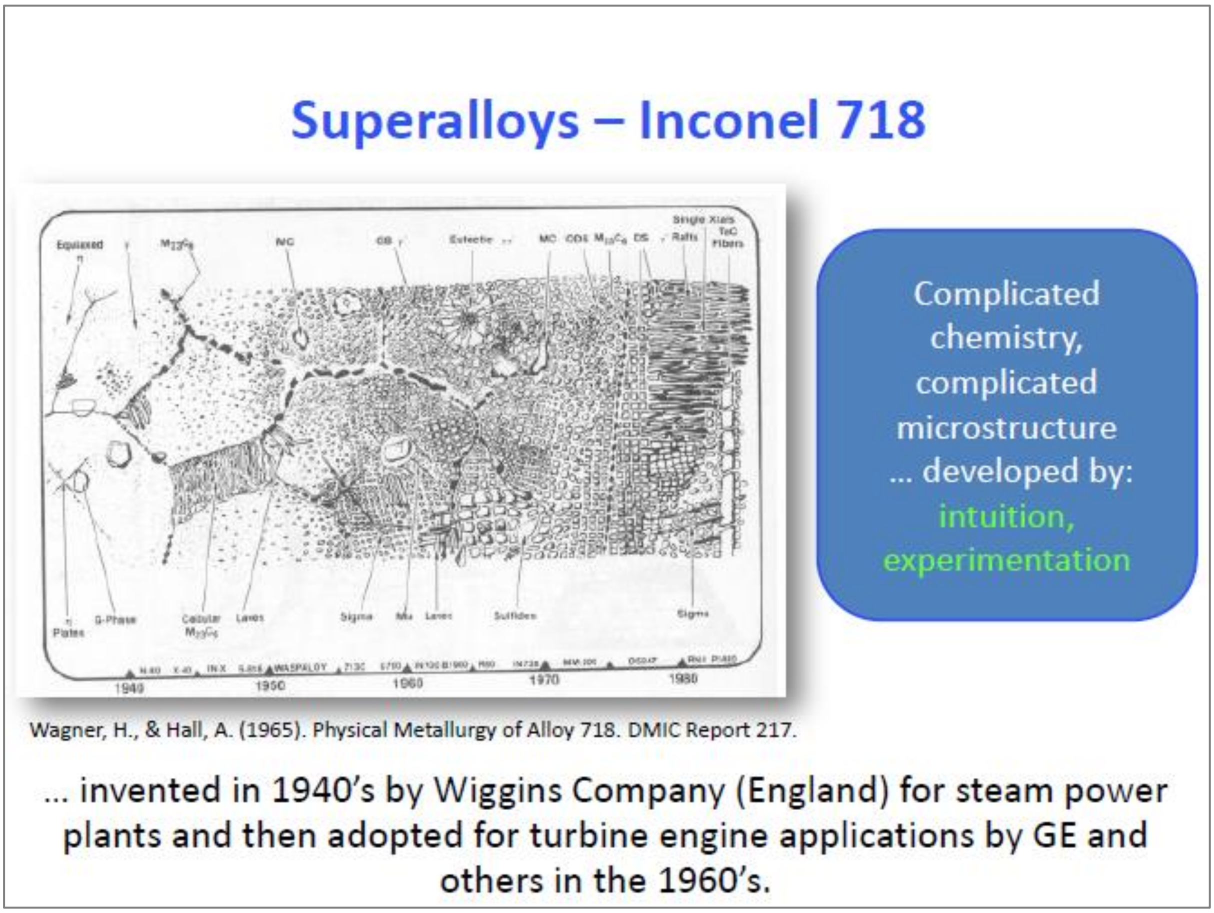


Figure 41. Superalloys - Inconel 718

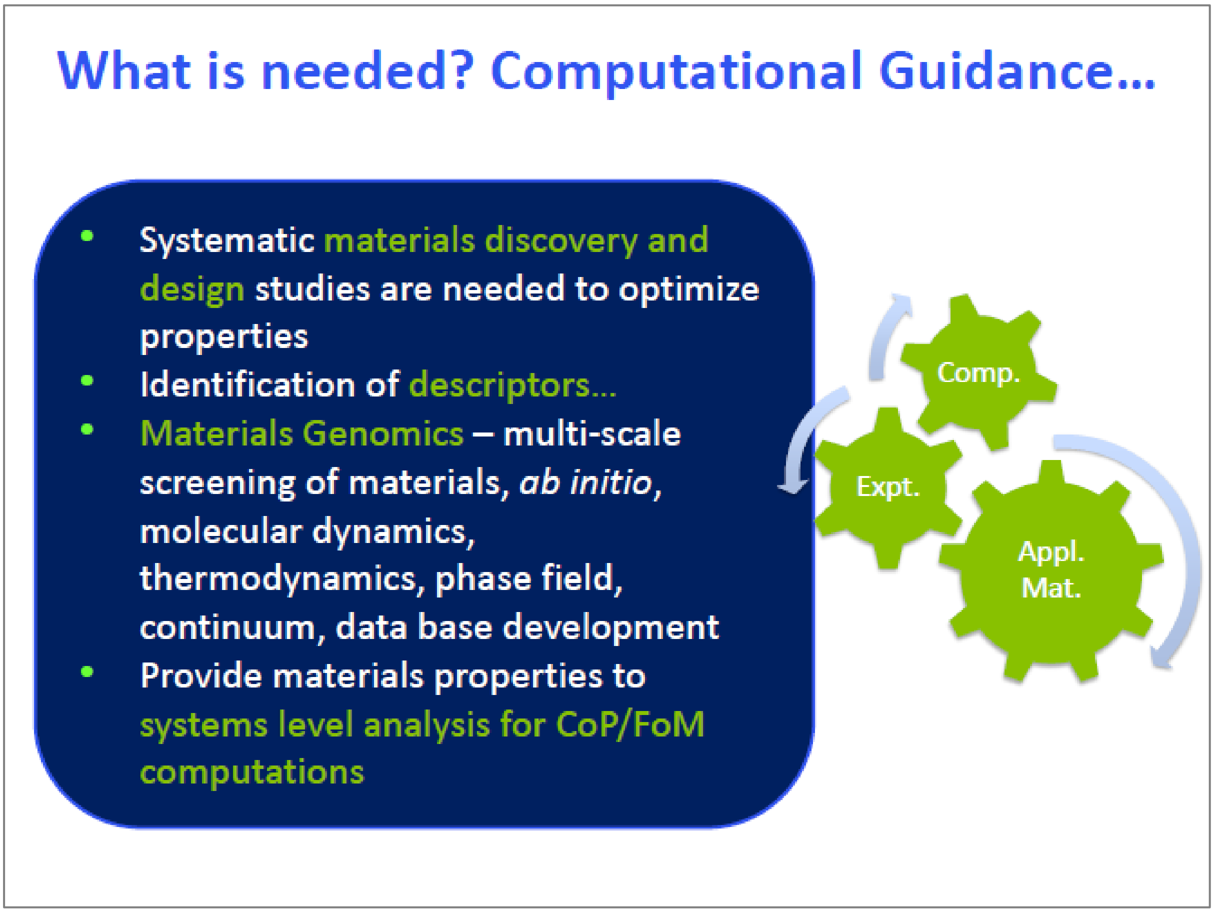


Figure 42. What is Needed? Computational Guidance

Q&A

Q1: You showed a lot of possibilities. So if I understand that correctly, you can design properties within the materials, and mixing of materials is not an art anymore, it's science to a certain extent?

A1: That's a very good question. If you are doing it experimentally, there is a lot of art element to it, too. If you're doing this theoretically, it's a science but you are missing the intuition of a chemist essentially.

Q1': Please let me continue. All the materials which you mentioned are not fully designed to the full capability? Let's put it this way. Nevertheless, a lot of these materials have been substituted by plastic materials. Would you think and extrapolate from what you know now that this design process is applicable in some sort of other plastic materials?

A1': There is a group in my institution who are looking into developing better dielectric polymeric materials using the very same principles. So the same principles apply. The tools are slightly different.

Hyundai Steel's Challenge toward "Automotive Steel Specialized Steelworks"

Dr. Man-Been Moon

Vice President

R&D Center of Hyundai Steel

Thank you for your kind introduction. Good afternoon, ladies and gentlemen. My name is Man-been Moon, who is in charge of the process technology division in the R&D center of Hyundai Steel. It is a great honor for me to have this opportunity to talk about our steel business in front of you, and thank you, KIMM, for inviting me. Today's topic is Hyundai Steel's challenge toward "automotive steel specialized steelworks."

Introduction

What I will talk about today includes an overview of Hyundai Steel, the history of challenge for a new steel business, and Hyundai Steel's efforts and achievement toward "automotive steel specialized steelworks," and finally the vision of Hyundai Steel (Figure 1).

Hyundai Steel Overview

Figure 1. Hyundai Steel Overview – Introduction

As you know well, Hyundai Steel is a member of Hyundai Motor Group. In the group, approximately 50 affiliates are lined up in the field of automotive, steel, construction, parts, logistics, finance, and others. Particularly, Hyundai Steel, the company specialized in steel material, playing a key role for the competitiveness of Hyundai Motor Group by producing and supplying a competitive steel material (Figure 2).

I would like to introduce the growth history of Hyundai Steel. Hyundai Steel was established as the first steel company in Korea with the name of Korean Heavy Industry Corporation in 1953. And it joined Hyundai Group in 1978. And later on, it was incorporated into Hyundai Motor Group, which was created in 2001. And then in 2004, we took over Dangjin Plant of Hanbo Steel to build the basic framework of integrated steelworks. And then in 2005, we founded the R&D center to start the development of automotive steel in advance. And from the ground-breaking ceremony for integrated steel in 2006 to operation of the blast furnace #3 in 2013, Hyundai Steel had completed the integrated steel works project successfully. And from now on, we are trying to become a global top level steel maker (Figure 3).

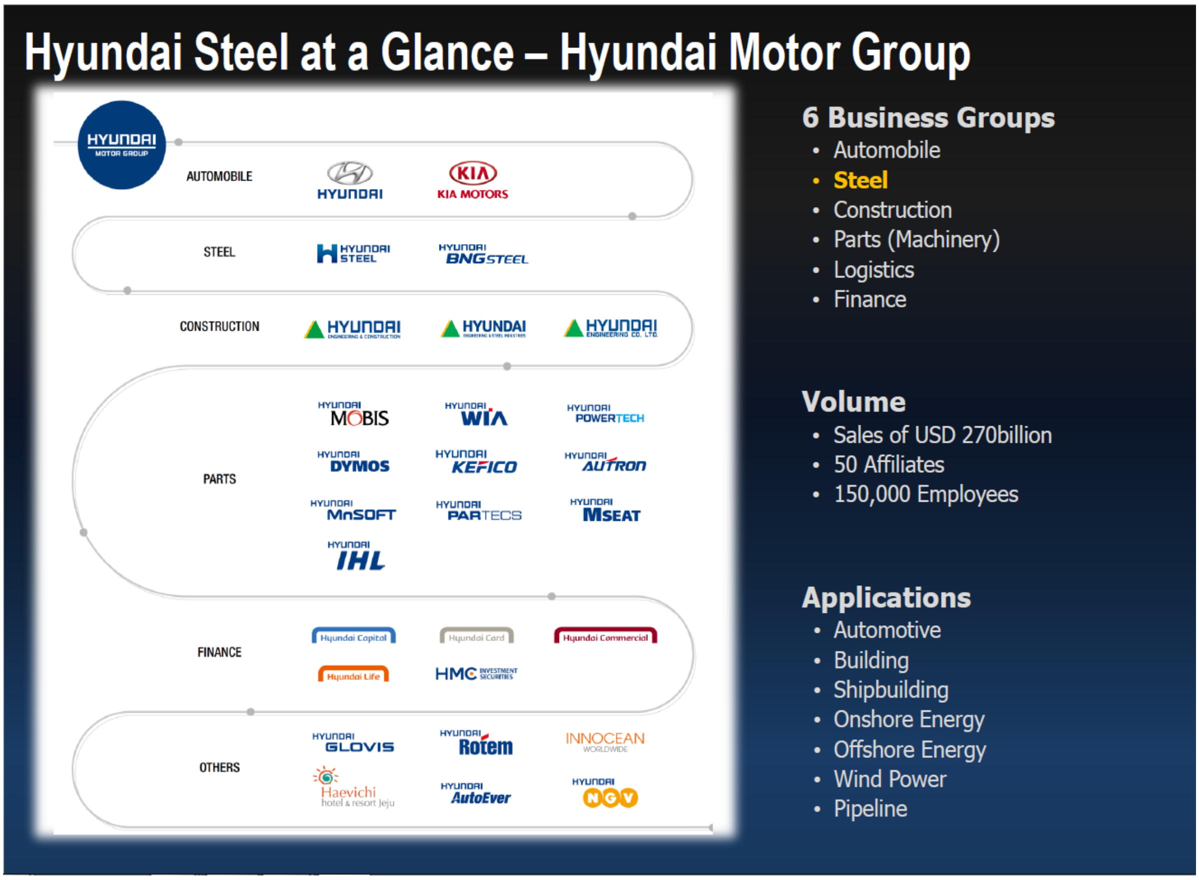


Figure 2. Hyundai Steel at a Glance – Hyundai Motor Group

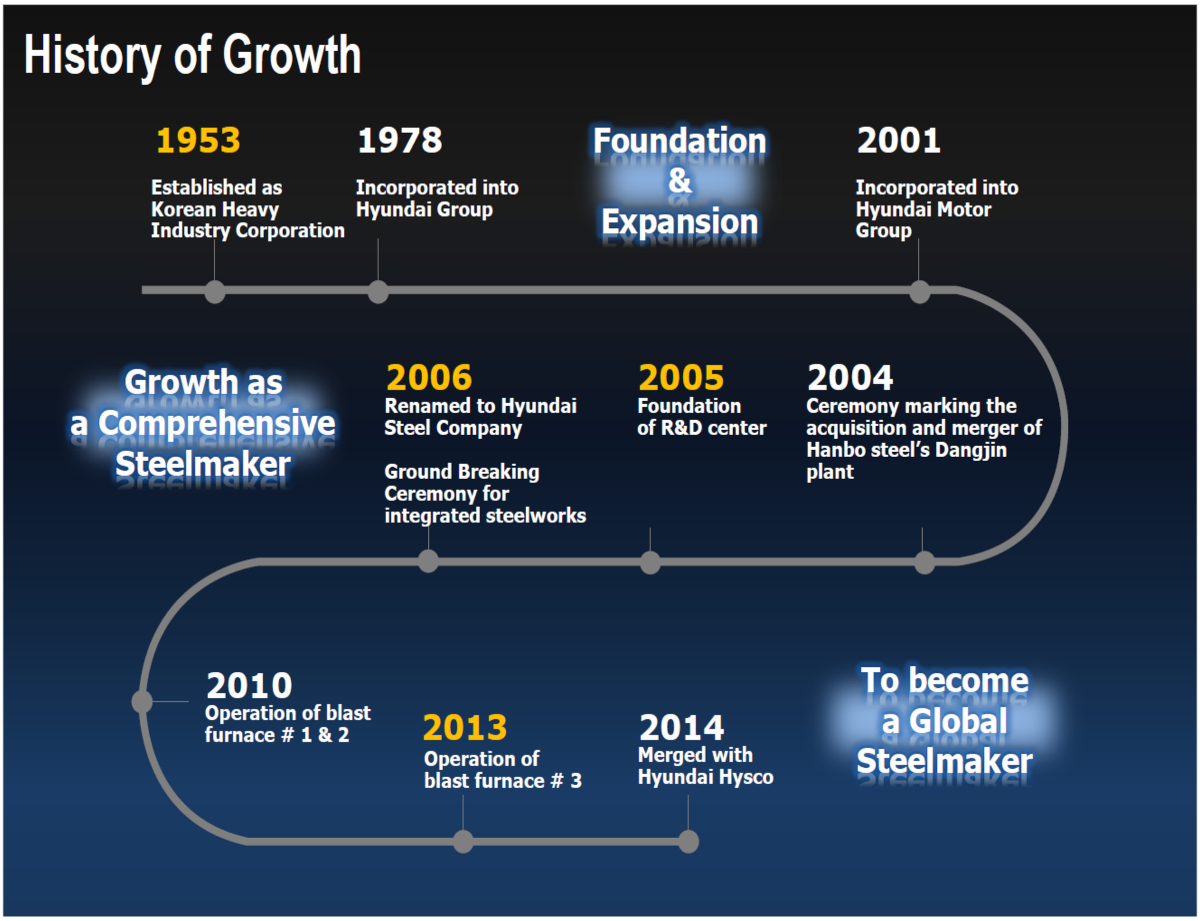


Figure 3. History of Growth

This slide shows the business structure of Hyundai Steel. As we finished the integrated steel project and obtained the total manufacturing capacity of 24 million tons, including 12 million tons from blast furnaces and 12 million tons from electric arc furnaces, we have made an extremely well balanced portfolio system that cannot be seen anywhere else in the world. Normally, the products from the blast furnaces are used for automobile, ships, offshore structure, and others. The products from the electric arc furnaces are for construction, railway, and so on.

Our well balanced production system makes it possible for us to cope well with the rapidly changing market situation through a flexible control of product mix. And it is also another big benefit having strong captive market, such as automotive, construction, railway, and so on in the group (Figure 4).

This slide shows the current status of domestic production sites and facilities of Hyundai Steel. There are a total of six locations for our production, including Dangjin Works as the main production base. And the specialized products are manufactured in different locations, and the hot/cold rolled coils, heavy plates, and rebar from Dangjin Works of which capacity is 15.6 million tons per year. And the H-beam and stainless steel in Incheon Works of which capacity is 4.7 million tons. And the H-beams, rebars, and rails from Pohang Works of which capacity is 3.4 million tons, and the cold rolled steel from Suncheon Works which has the capacity of more than 2 million tons (Figure 5).

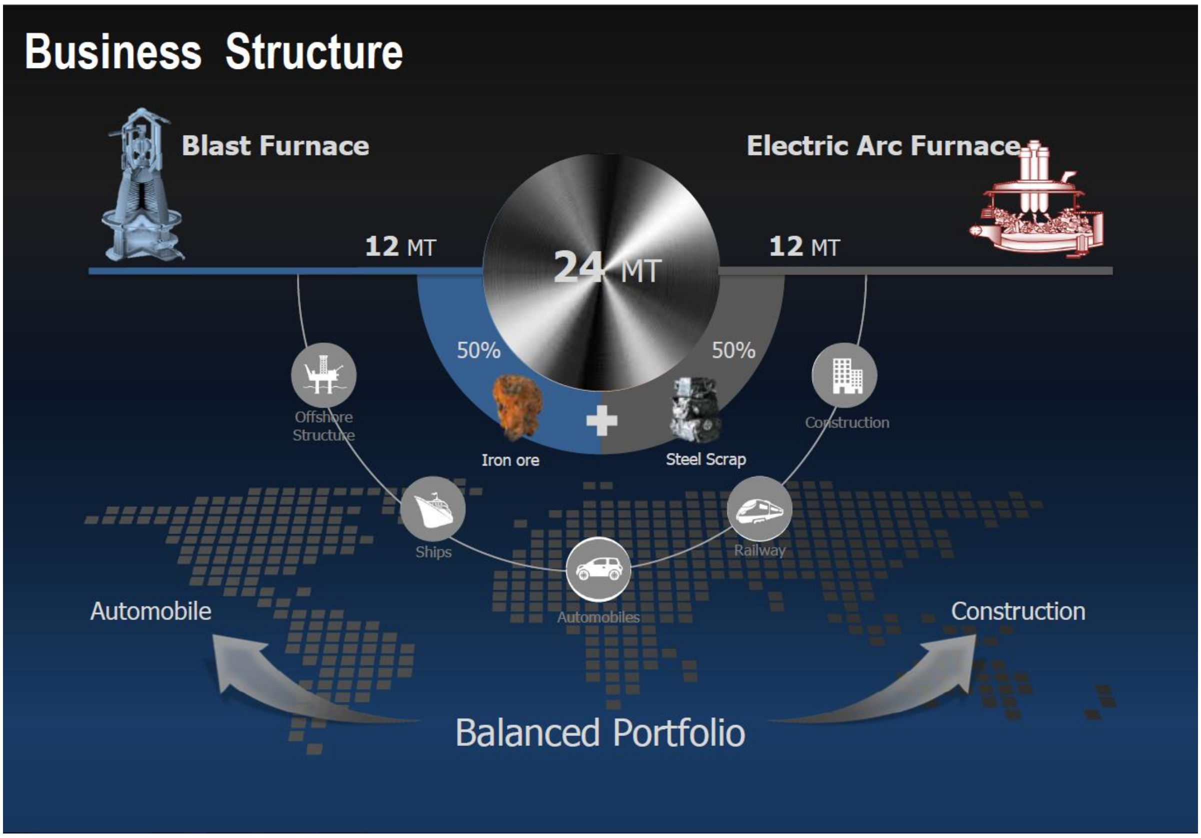


Figure 4. Business Structure

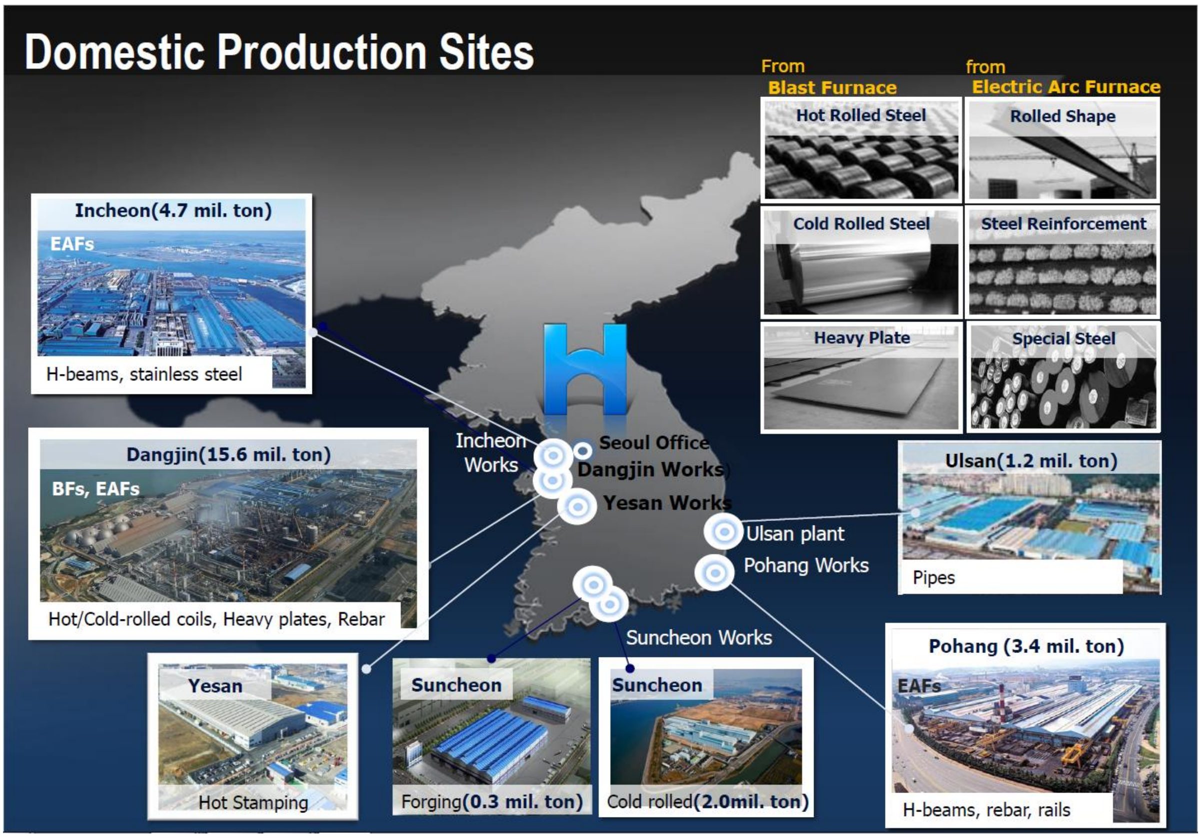


Figure 5. Domestic Production Sites

Figure 6. Global Operations

This slide shows the current status of global operations. We are branched out from 11 steel service centers along with Hyundai Kia Motor's global production bases for a stable supply of steel products. And we have two manufacturing plants in Qingdao in China and Chennai in India. Here we produce pipes and railways (Figure 6).

History of Challenge

On the next slide, I will talk about the history of challenge for the new steel business. One of the main points of this talk is to share how Hyundai Steel has become an automotive steel specialized steelworks. So in advance, I would like to talk about the background (Figure 7).

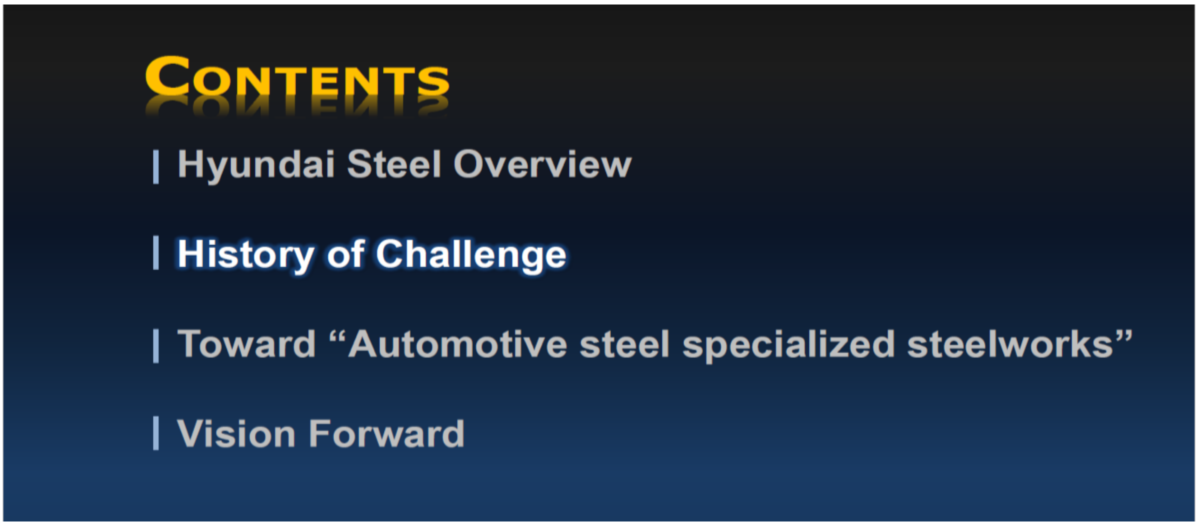


Figure 7. History of Challenge - Introduction

As you know well, Korea, following China, the US, Japan, and Germany, is the fifth largest country in automotive production. Last year, we produced 4.6 million vehicles. And out of those, 3.5 million vehicles were produced by Hyundai Kia Motor Company, which is approximately 80% of the total domestic market share. And also, the global amount of vehicles produced by Hyundai Kia Motor Company was about more than 8 million vehicles last year. It's also the fifth largest in the world (Figure 8).

In addition, I would like to talk about the effects of the steel industry on the national economy. The steel industry contributed to the competitiveness of our country by stable supply of high quality steel materials to main downstream industries such as automotive, shipbuilding, and construction.

Based on the report of Korea Iron and Steel Association, the steel consumption per capita was reported to be 1082 kg. It's the first rank in the world. In addition, steel industry is one of main plant industry which needs a huge capital investment, so it possesses 12.5% share of the total Korean capital investment, in 2012, when our company was under construction. The employment volume is about 100,000 people, which cover 2.7% of the total employment in Korea (Figure 9).

Recently, it is difficult for an automotive company to have competitiveness without the support of a steel maker. The typical properties needed for automobile such as fuel efficiency, flexibility in design, durability, and safety. Such features can be embodied by the support of the steel side through lightweight, high strength technology, formability, corrosion resistance, and so on. So it can be said that steel supports the automotive industry in the technological side (Figure 10).

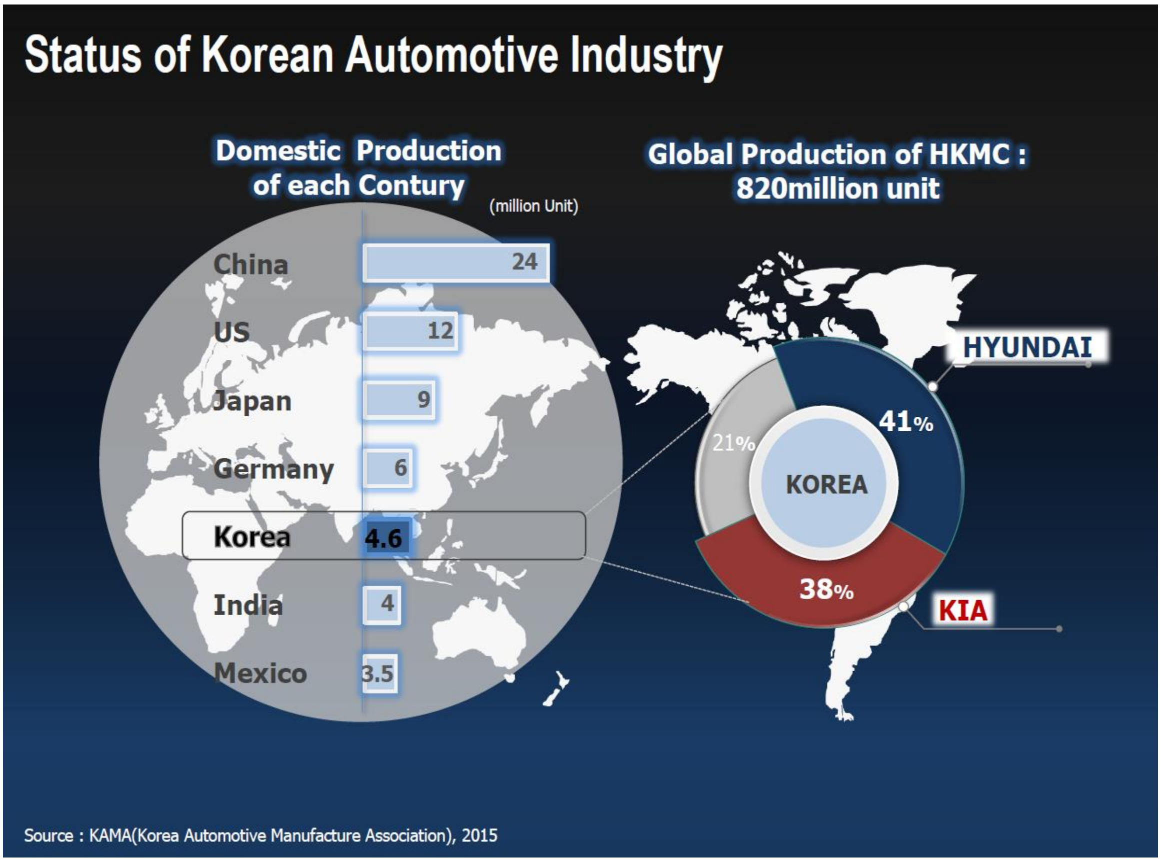


Figure 8. Status of Korean Automotive Industry

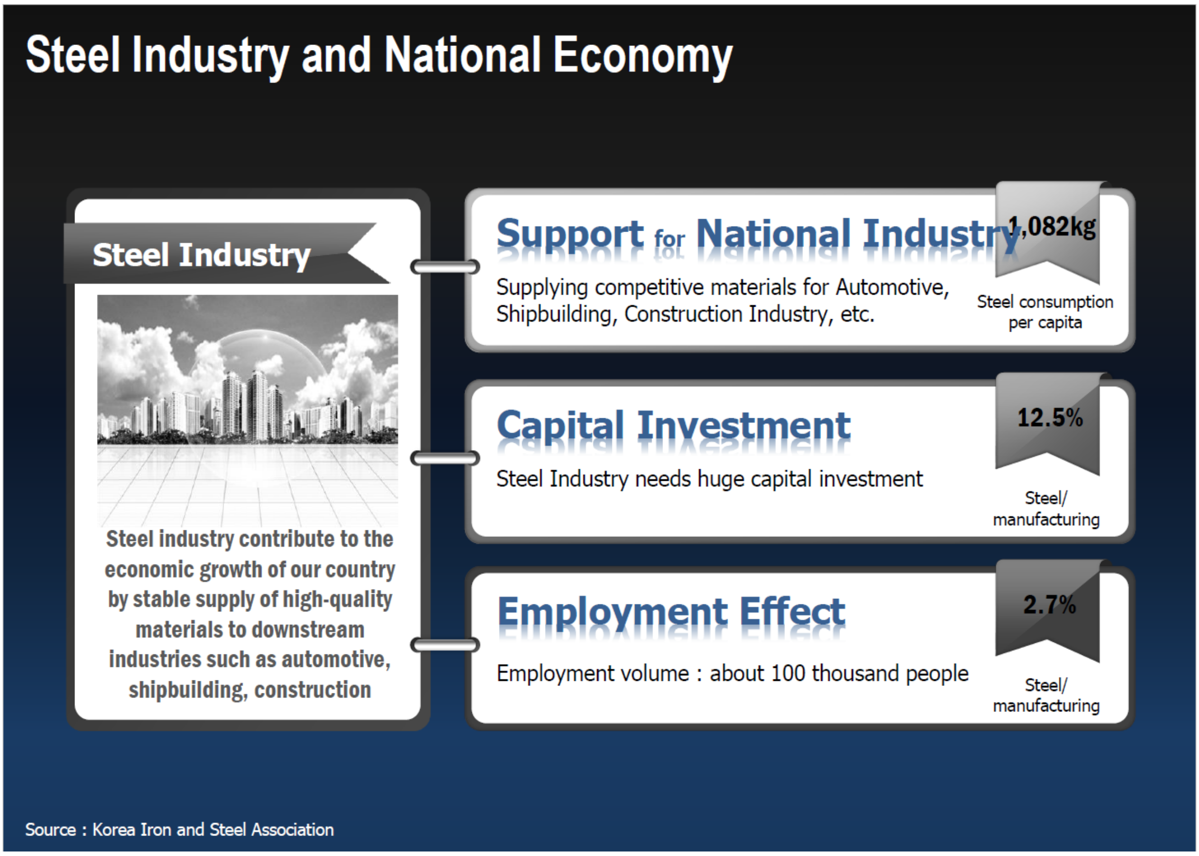


Figure 9. Steel Industry and National Economy

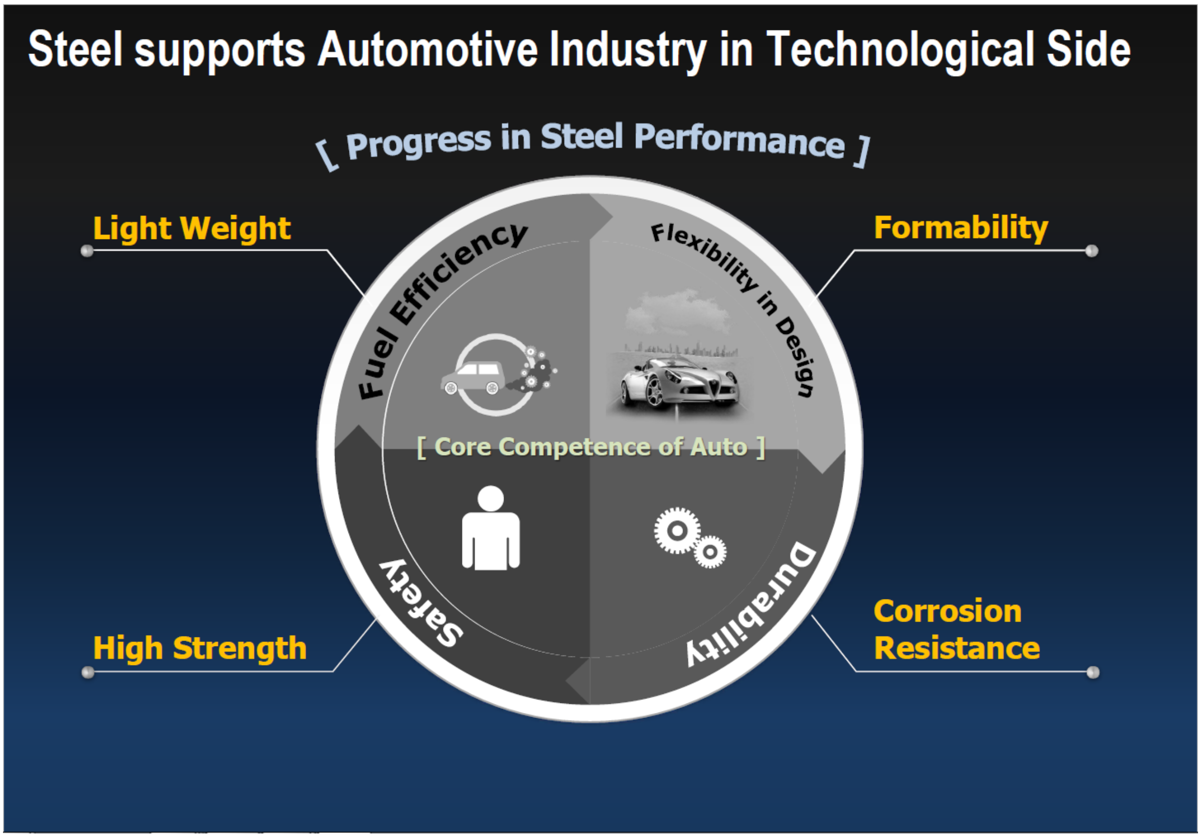


Figure 10. Steel Supports Automotive Industry in Technological Side

Automotive steel is called as the “flower of steel” because it is technology-intensive, and there are a few makers capable of producing automotive steel. In fact, the market share of the global top seven in automotive steel is about 65% over the world. The first steel maker, Arcelor Mittal holds 15% of the market share, and the other six companies, including Hyundai Steel, hold around or below 10% of the market share. As the technological entry barrier is high, automotive steel is one of a very profitable business area. Based on the data from Korea Automotive Research Institute (KARI), the average operating profit of Asian steel makers was reported to be approximately 12% on automotive steel yielding robust profit compared to other products. So the steel companies with high technology are focusing their business on automotive steel. In the case of Korean steel makers, 20% of the total profit is actually from automotive steel and 32% for Japanese steel makers (Figure 11).

So, Hyundai Steel launched an integrated steel mill project to be automotive steel specialized work. And the location of Dangjin Steel Works is optimal for automotive steel specialized work because it is near our major customers of Hyundai Kia production bases in Asan and Hwaseong. And it is also near West Coast Express Way, being advantageous for both land and marine transportation (Figure 12).

Hyundai Steel took over Dangjin Plant of Hanbo Steel in 2004. And later on, with the reclamation of the foreshore, we were able to create a large site area, with a total of 8.82 million square meters. As you can see, the regions that were once either sea or farmland turned into a large scale mill area like this. And from the ground-breaking ceremony in 2006 to the #3 blast furnace blow-in 2013, it took seven years to accomplish the project (Figure 13).

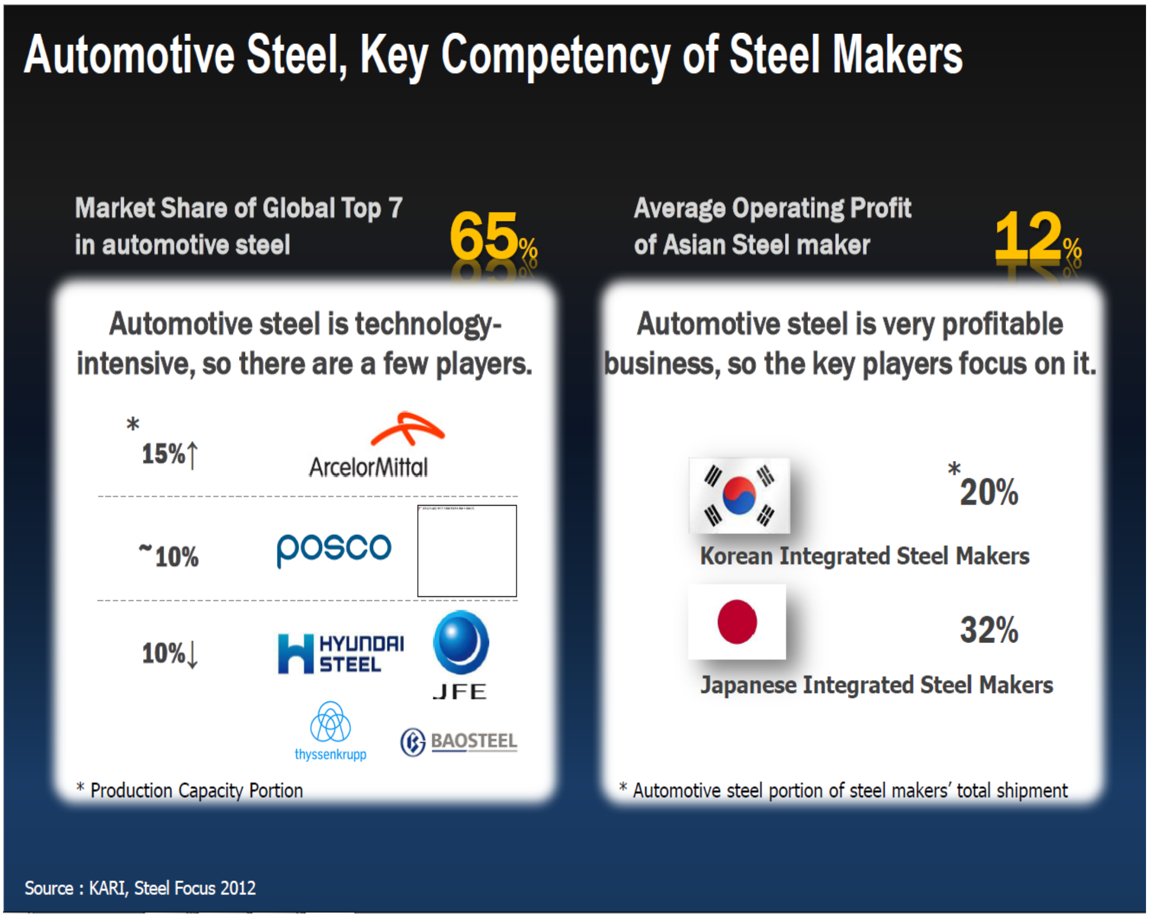


Figure 11. Automotive Steel, Key Competency of Steel Makers

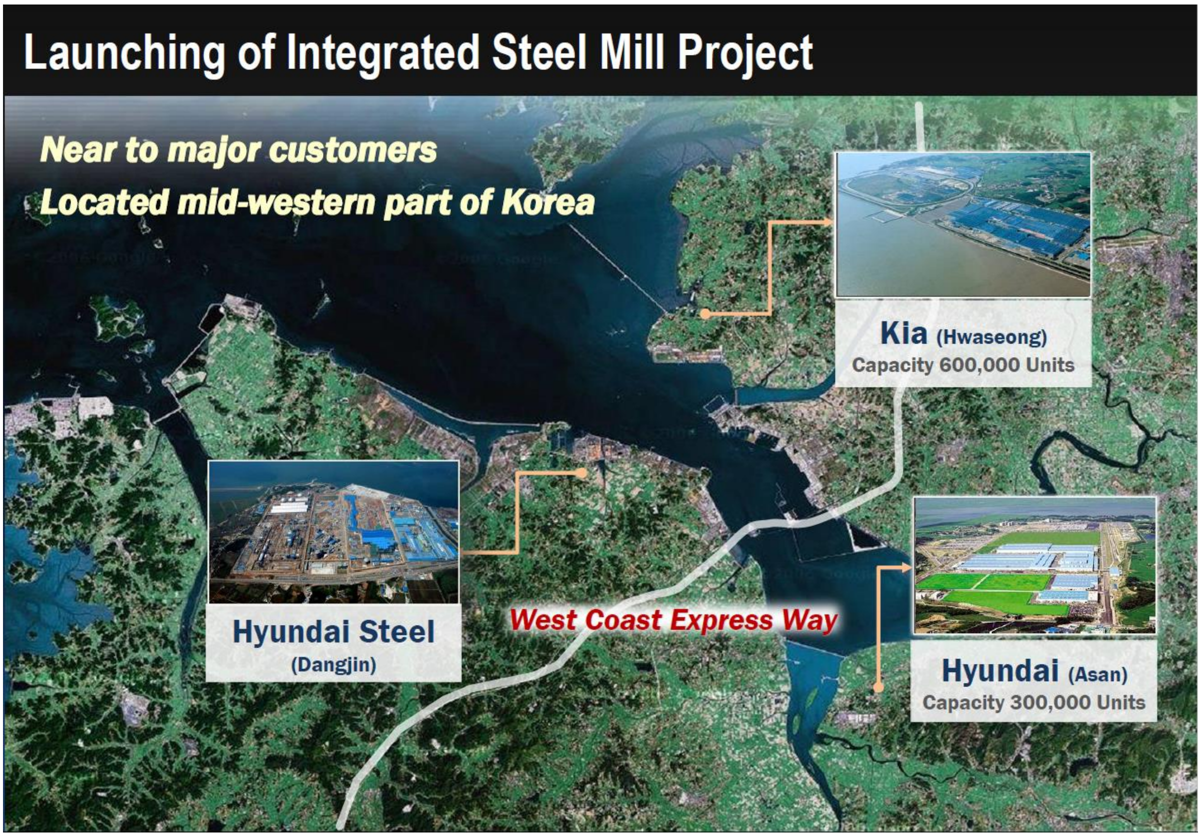


Figure 12. Launching of Integrated Steel Mill Project

Figure 13. Completion of the Project

This slide shows the economic effects of the project. This project contributed to a job creation for 201,000 people, an investment of 18.2 billion US dollars on construction, and the value added inducement of 9.34 billion dollars (Figure 14).

Toward “Automotive Steel Specialized Steelworks”

Next, I would like to talk about the efforts and achievements for being automotive steel specialized steel works. It includes trends of automotive steel, development of related automotive steel, and lightweight and application technologies. First, I would like to introduce the trends of automotive steel (Figure 15).

This slide shows an overview of the needs of the automotive market and the counter measurement of car makers and steel makers. The given environment has required low cost, reduction of carbon dioxide, global environment protection, safety enhancement, and so on. To meet these requirements, automotive companies strengthened the unification of parts and improved fuel efficiency through car lightening and enhancing the car design for passenger’s safety and durability. Meanwhile, Korean steel makers are concentrating on developing high formability steel, high strength steel, car body lightening technology, eco-friendly anticorrosive coated steel (Figure 16).

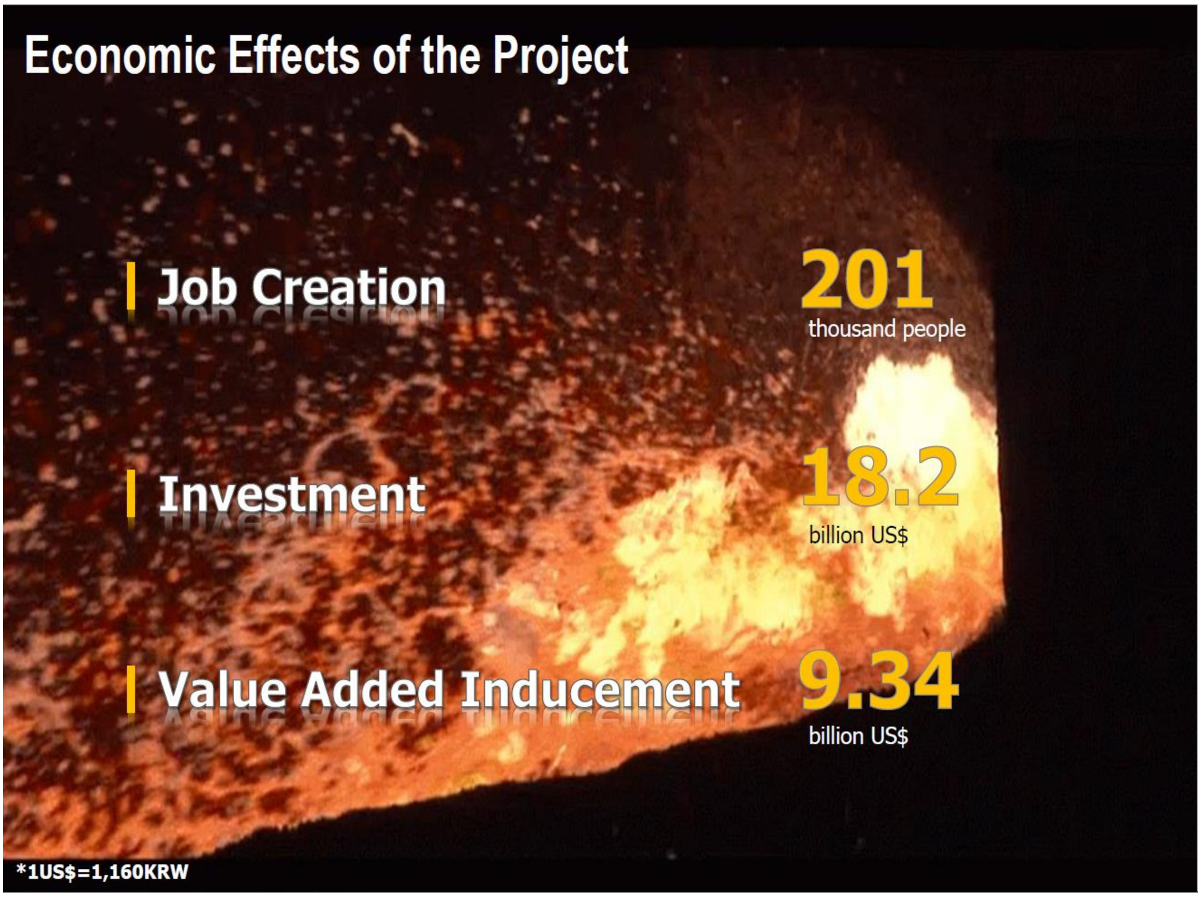


Figure 14. Economic Effects of the Project

Figure 15. Toward "Automotive Steel Specialized Steelworks" – Trend of Automotive Steel

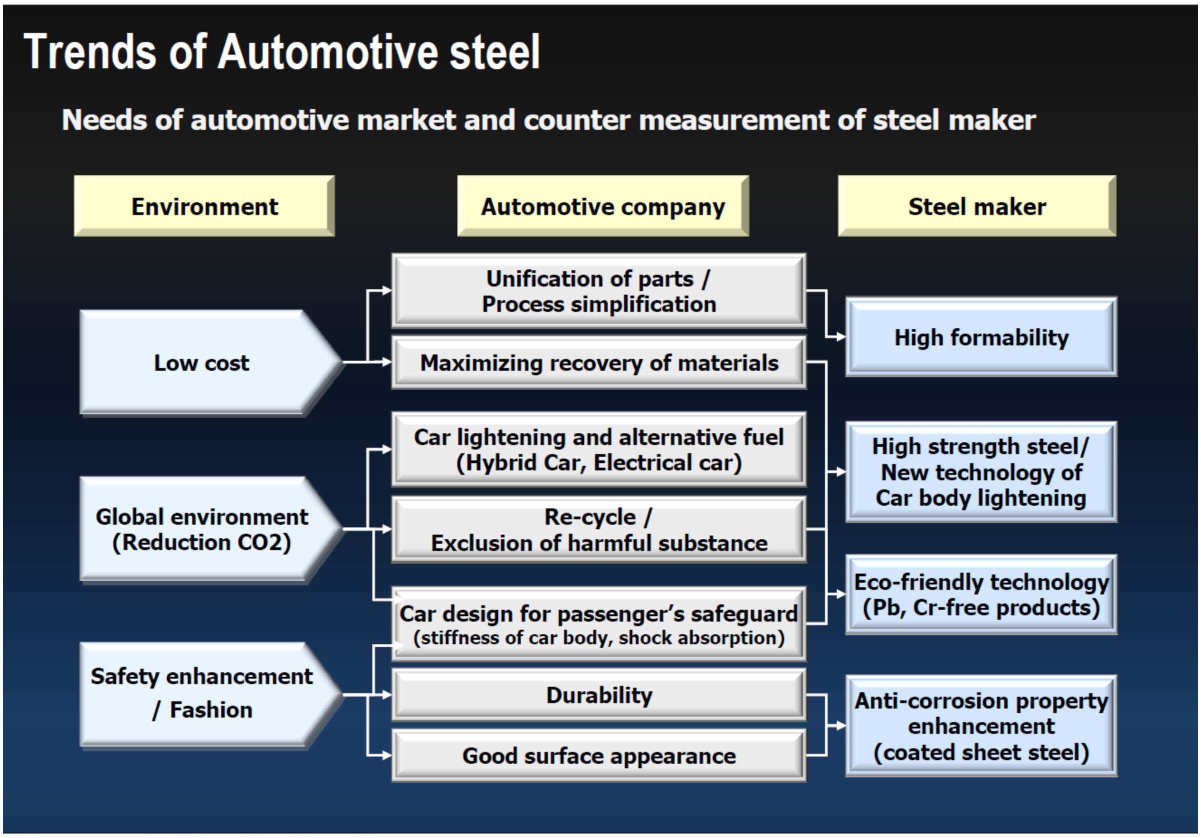


Figure 16. Trends of Automotive Steel

Among these requirements, I would like to talk about high strengthened steel in more detail because its usage is increasing because of its big effectiveness. This is a well-known banana graph representing the categorization of different steel grades by their characteristics. As common sense, if strength increases, then formability decreases. Nevertheless the requirements for both high formability and high strength of steel are growing. So there were only six steel grades of automotive steel in 1993, but nowadays over 100 steel grades with higher formability and higher strength steels have been developed to meet the needs. And further study and development are going on for the next generation new steels (Figure 17).

This slide shows the material application trends of car bodies with a lightweight concept. Hyundai Kia Motor Company is drastically extending the application of ultra-high strength steel. And in the case of Sonata 2014 model, it had a 53% adoption rate of high-strength steel. And for your interest, other automotive companies have a lower adoption rate of ultra-high strength steel than HKMC. Also, the adoption rate of hot stamping is also increased. I will talk in detail about hot stamping afterward. Meanwhile, the adoption rate of nonferrous metal and non-metallic materials such as aluminum also tends to increase. Aluminum has widely been adopted by Tesla Model S car and Ford F150 pick-up truck and CFRP by BMW I3 and I8, like this, which is becoming a big challenge for Hyundai Steel as a competing material to steel along with strengthening fuel efficiency regulation, as you know well (Figure 18).

Next, I would like to talk about the development of automotive steel (Figure 19).

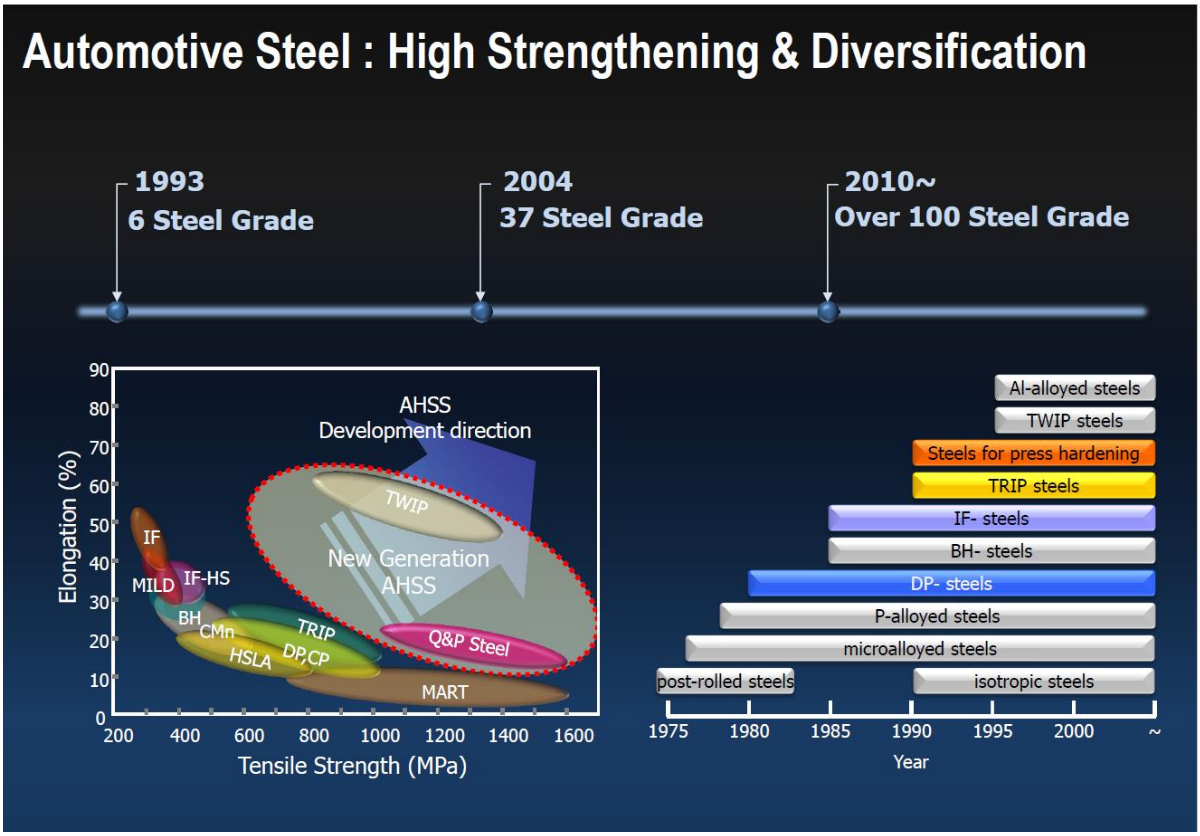


Figure 17. Automotive Steel: High Strengthening & Diversification

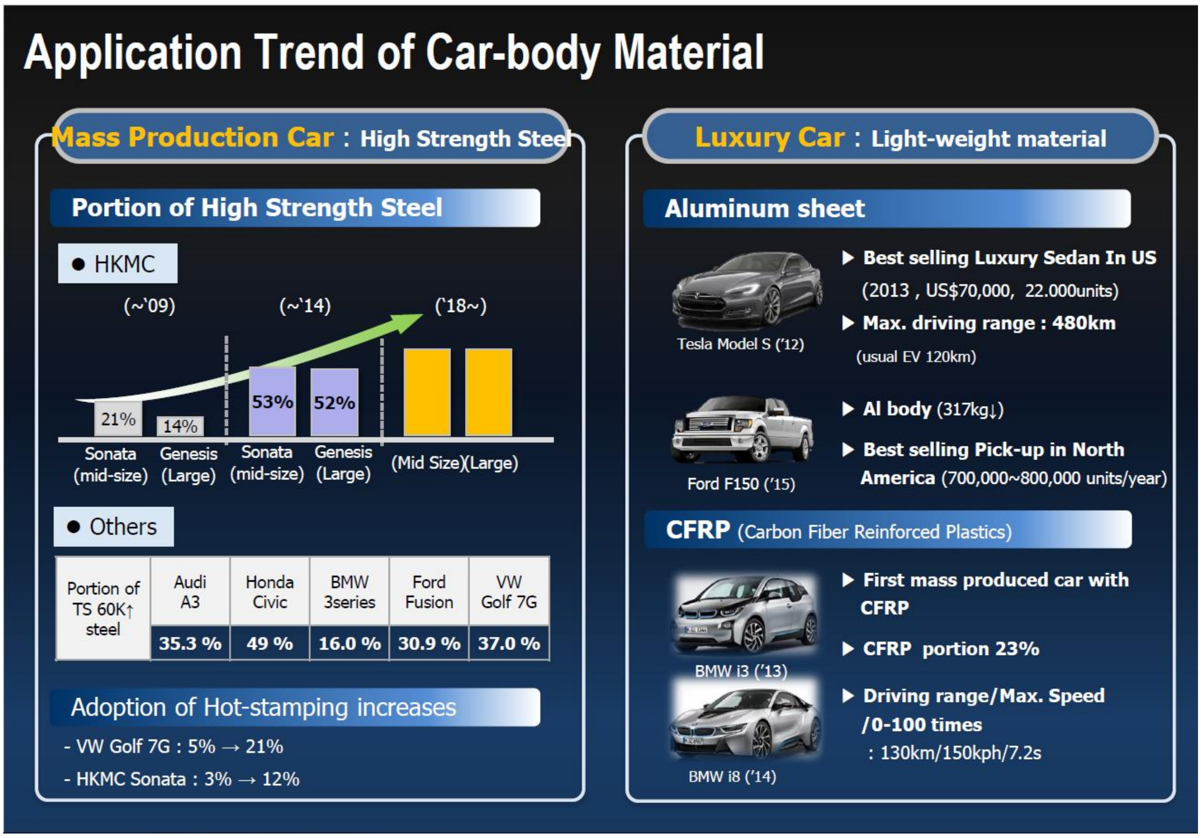


Figure 18. Application Trend of Car body Material

Figure 19. Toward "Automotive Steel Specialized Steelworks"
– Development of Automotive Steel

We started operating blast furnaces and initiated developing automotive steel in 2010. And after five years, in 2014, we finished developing 99.6% of automotive steel used by Hyundai Kia Motor Company. In 2010, 49 steel grades of inner panels were developed. And in 2011, 22 steel grades, including outer panels (which are known as the most difficult parts to produce) were developed. From 2012 to 2014, 17 grades of high strength steel including 100 and 120kg TS grade were developed. And in total, 88 steel grades were developed in a short period of time which was exclusively unique cases in the world. And since 2015, we have been developing new steel grades for the next-generation automotive steel, catching up with the future needs of a car body (Figure 20).

This shows the manufacturing process and the production mix, followed by the development results. The manufacturing capacity of three blast furnaces is 12 million tons in terms of molten iron. And that much of the molten iron is produced by 19 million tons of iron ores, 8.7 million tons of cokes, and 3.6 million tons of supplementary materials including lime. Through composition adjustment, followed by continuous casting, slabs are produced. By using that, 8.85 million tons of hot rolled coil are obtained, and 2.5 million tons of heavy plates are produced. 6.03 million tons, out of the hot rolled products, are manufactured as cold rolled steel. Five million tons of cold rolled steel are produced as automotive steel which is about 44% of the total steel products (Figure 21).

The reason why it is possible to finish the development process so quickly is that the R&D center has optimized the manufacturing conditions in advance and applied them in a real practical line through advanced research by all possible simulators, such as vacuum induction melting, hot rolling, cold rolling, continuous annealing and coating, and their precise analysis equipment for each process (Figure 22).

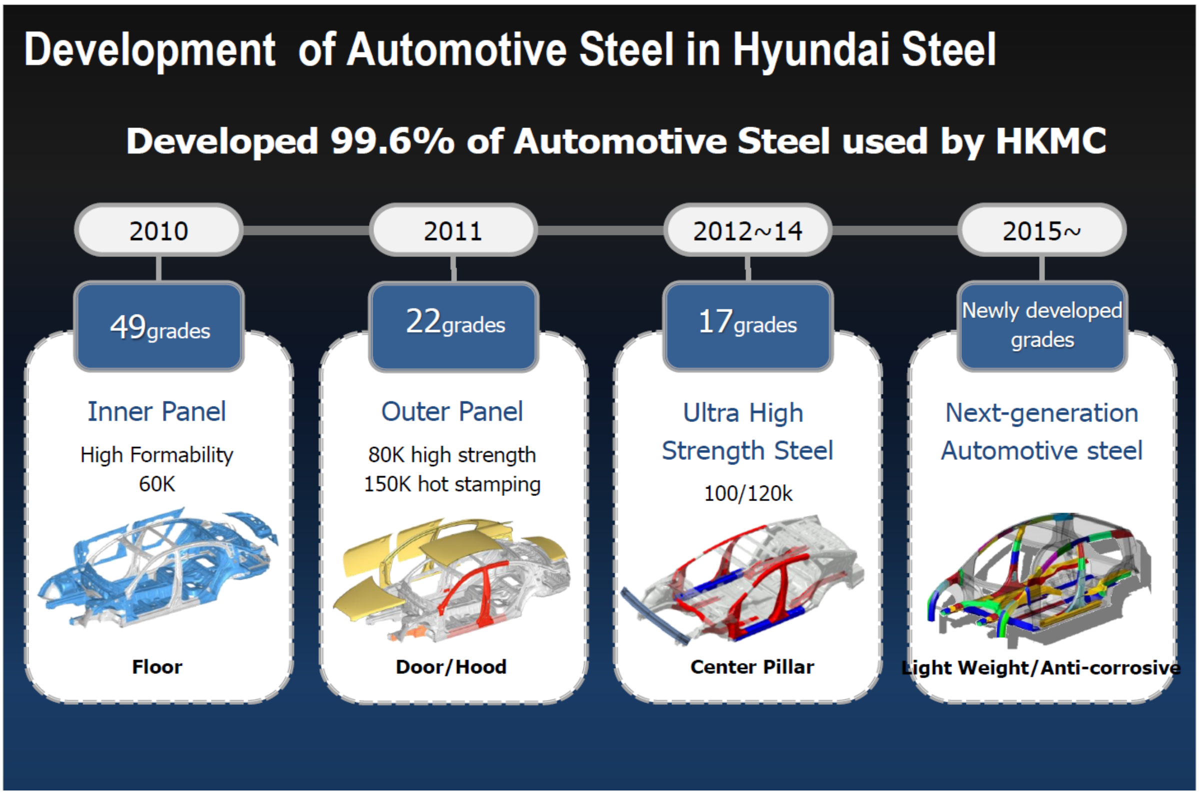


Figure 20. Development of Automotive Steel in Hyundai Steel

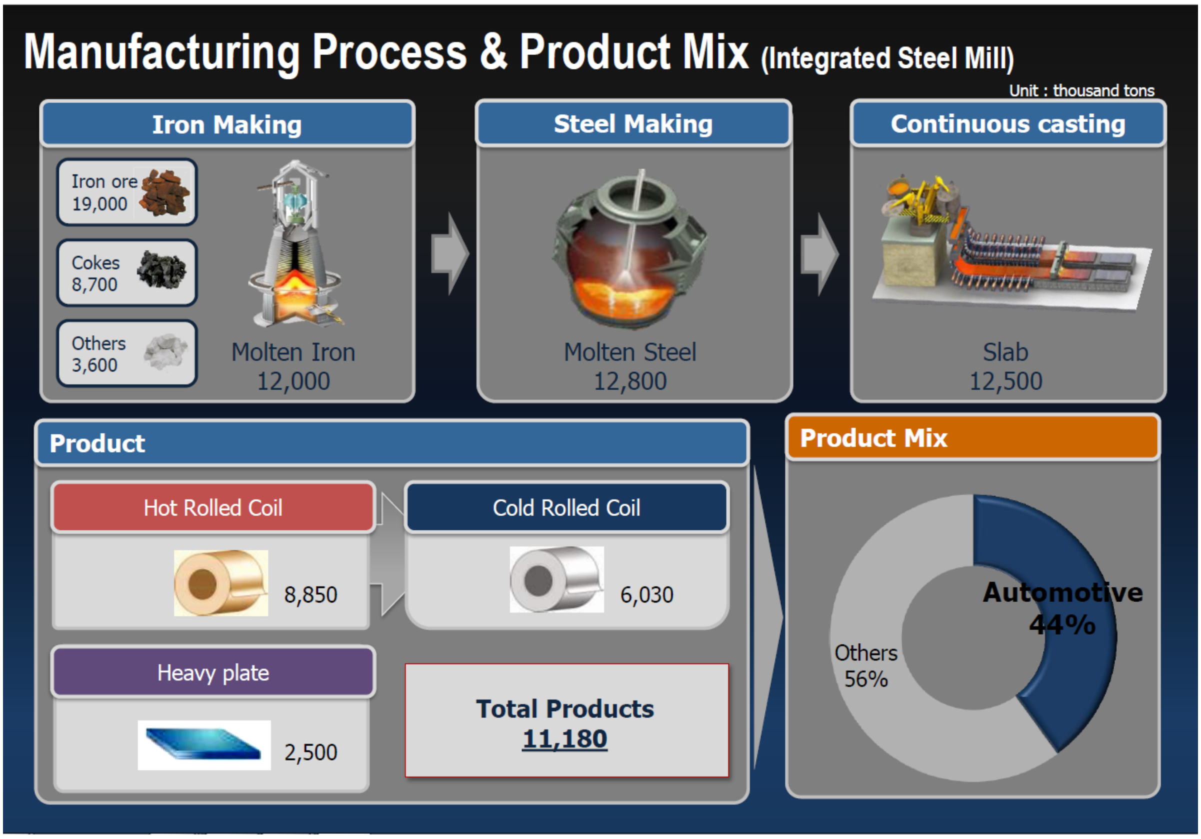


Figure 21. Manufacturing Process & Product Mix (Integrated Steel Mill)

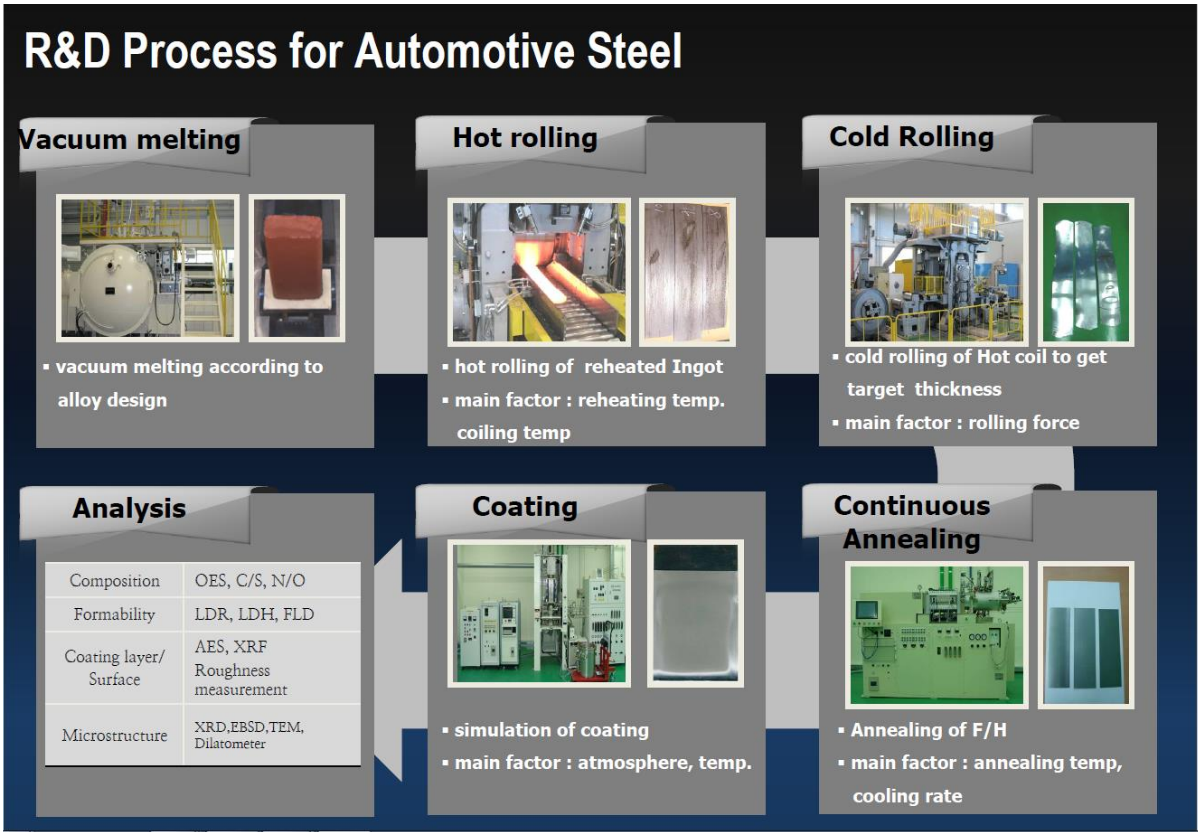


Figure 22. R&D Process for Automotive Steel

This slide shows the development direction for automotive steel in Hyundai Steel. We are developing more strengthened steel grades to improve the dent resistance of an outer panel and to enhance car-body lightening and safety performance for frame structures. And we are also developing hot rolled galvanized steel with high strength to reinforce anti-corrosiveness for chassis (Figure 23).

Next, I would like to introduce lightweight technologies for part manufacturing (Figure 24).

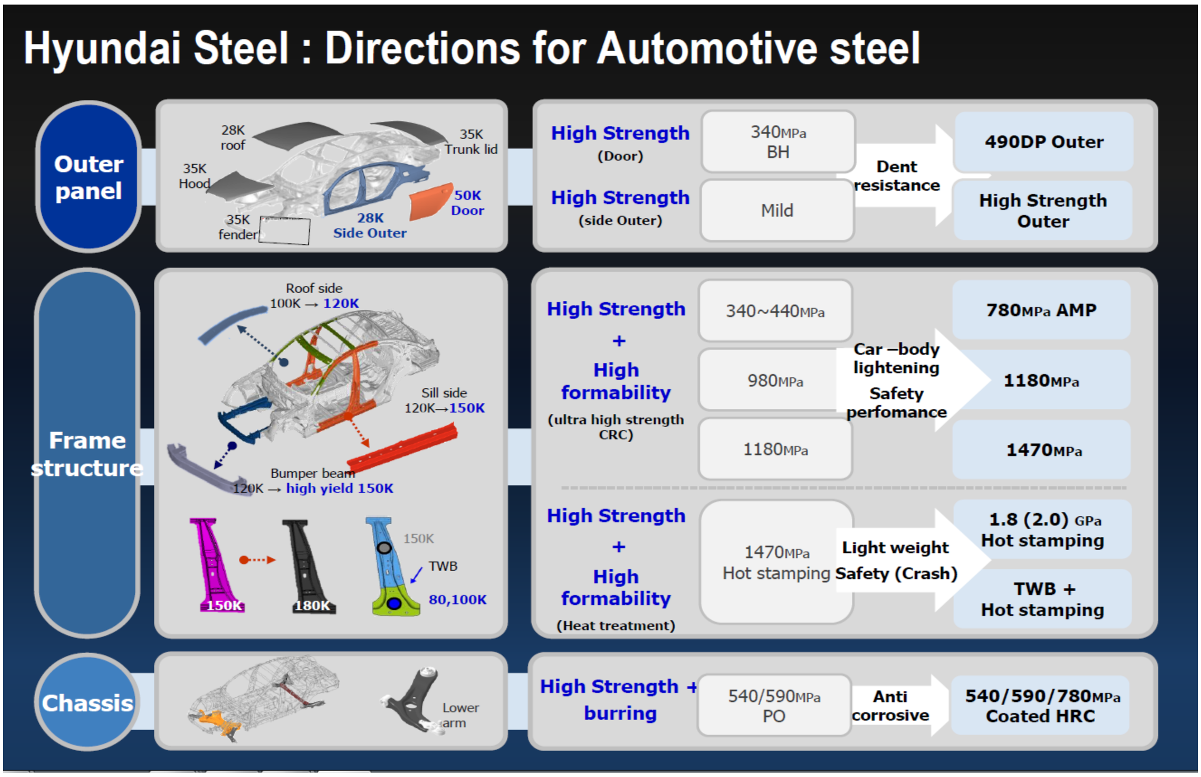


Figure 23. Hyundai Steel: Directions for Automotive Steel

Figure 24. Toward "Automotive Steel Specialized Steelworks"
– Lightweight technologies (for part manufacturing)

There are mainly three technologies including hot stamping, hydro forming, and tailor welded blanks. Here, I would like to talk about hot stamping in more detail because its effectiveness is very big and it is increasing steeply. Hot stamping technology is used for framework, frame structure parts, such like center pillar, light rail, and so on. And the manufacturing capacity is 38 million units per year in 17 lines including 5 overseas lines.

This figure shows the manufacturing process of hot stamping. First, TS 50 kilo grade sheet is heated up above 900°C. At this temperature, the sheet becomes ductile enough to form easily. At the high temperature, the sheet is formed and quenched by mold cooling in order to change the microstructure to high-strength martensite. And finally, we obtain 150 kilo degree grade high strength parts.

Because of its advantages, its adoption rate is steeply increasing. In the case of HKMC, the adoption rate has been increasing from 3% for YF Sonata in 2009 to approximately 50% for Avante in 2015. And it will also increase for more than 20% in the near future (Figure 25).

Next, application technologies (Figure 26).

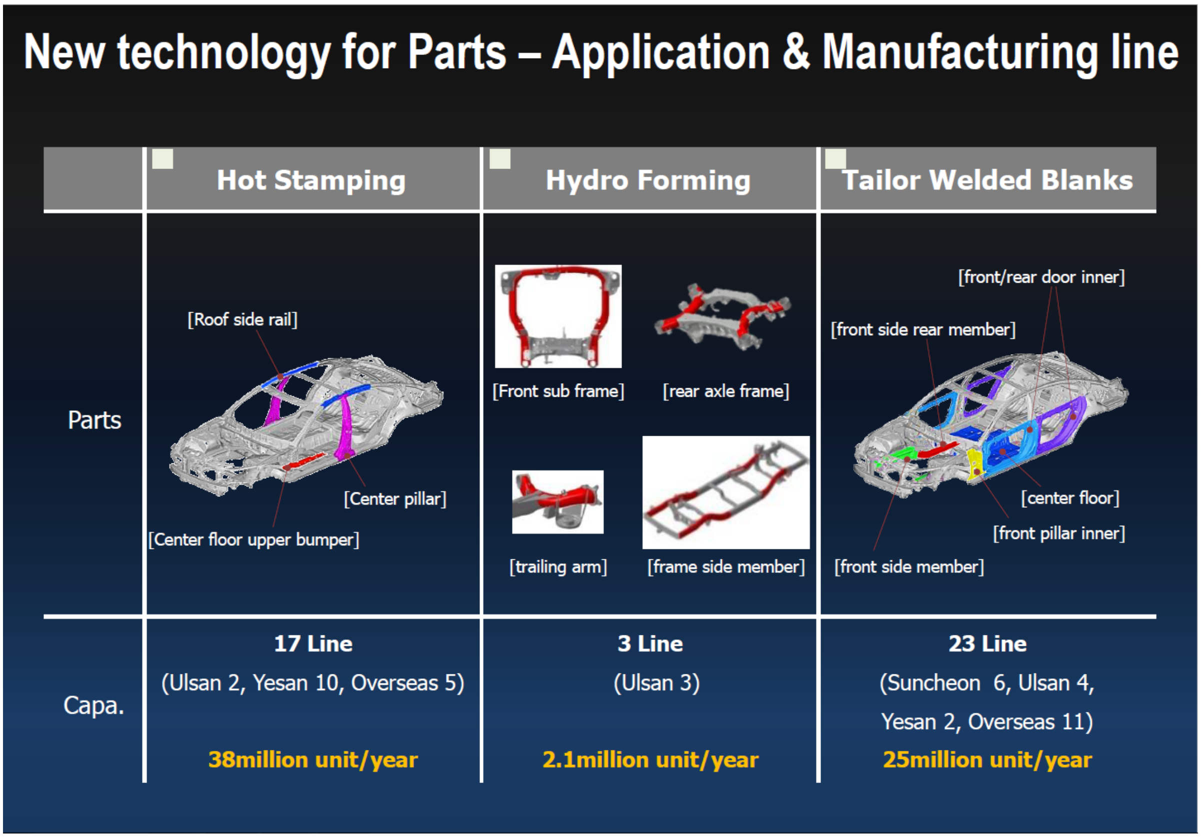


Figure 25. New Technology for Parts – Application & Manufacturing Line

Figure 26. Toward "Automotive Steel Specialized Steelworks" – Application Technologies

To apply newly-developed automotive steel, appropriate material with cost and quality competitiveness and efficient part design proper to the part manufacturing process, related to automotive processes, such as forming, welding, anti-corrosiveness, and coating. Furthermore, an optimized total solution should be provided to avoid a potential problem in the automotive steel process (Figure 27).

So in order to apply new steel grades to a new car body, Steel Makers including Hyundai Steel is closely cooperating with Hyundai Kia Motor Company from the early stage of car development by strengthening EVI: Early Vendor Involvement. Through EVI we proposed optimized material and design and structure drawn through stamping and crash analysis with the aid of CAE. Eventually, we provide steel based total solution for a lightweight car body (Figures 28 and 29).

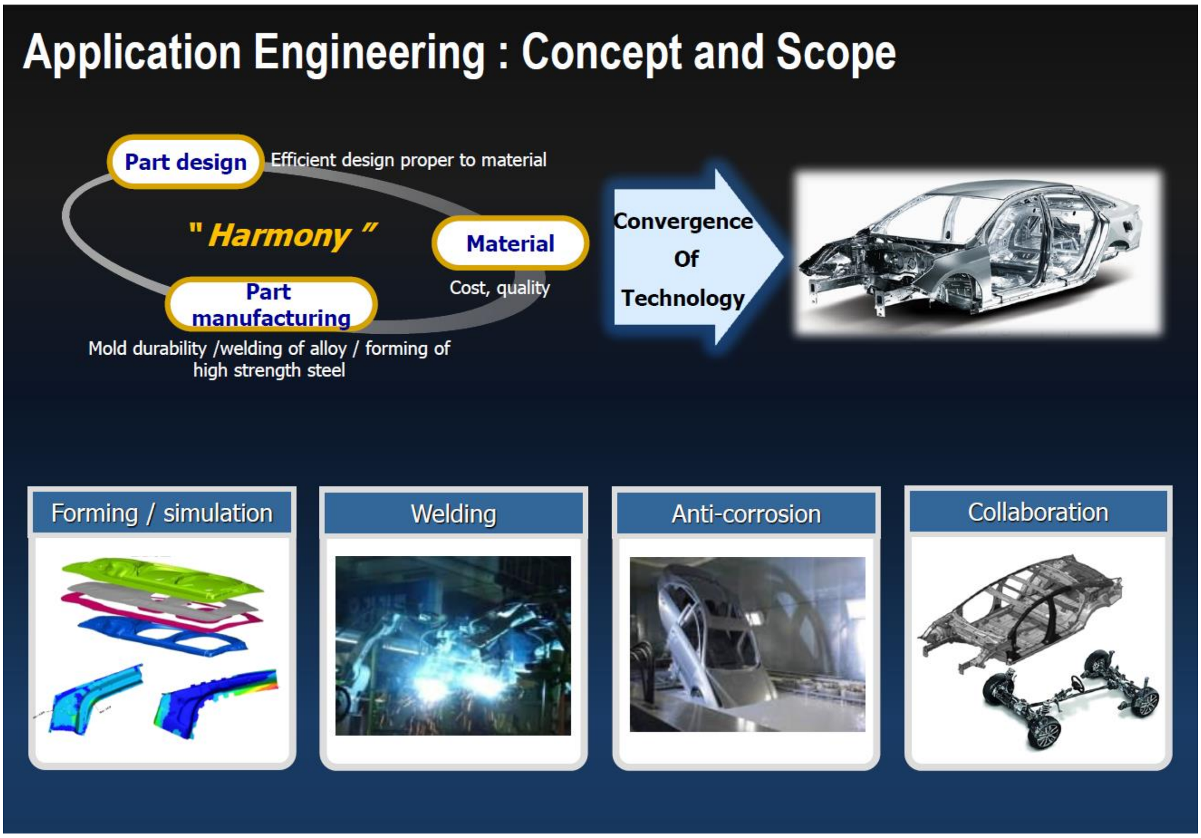


Figure 27. Application Engineering: Concept and Scope

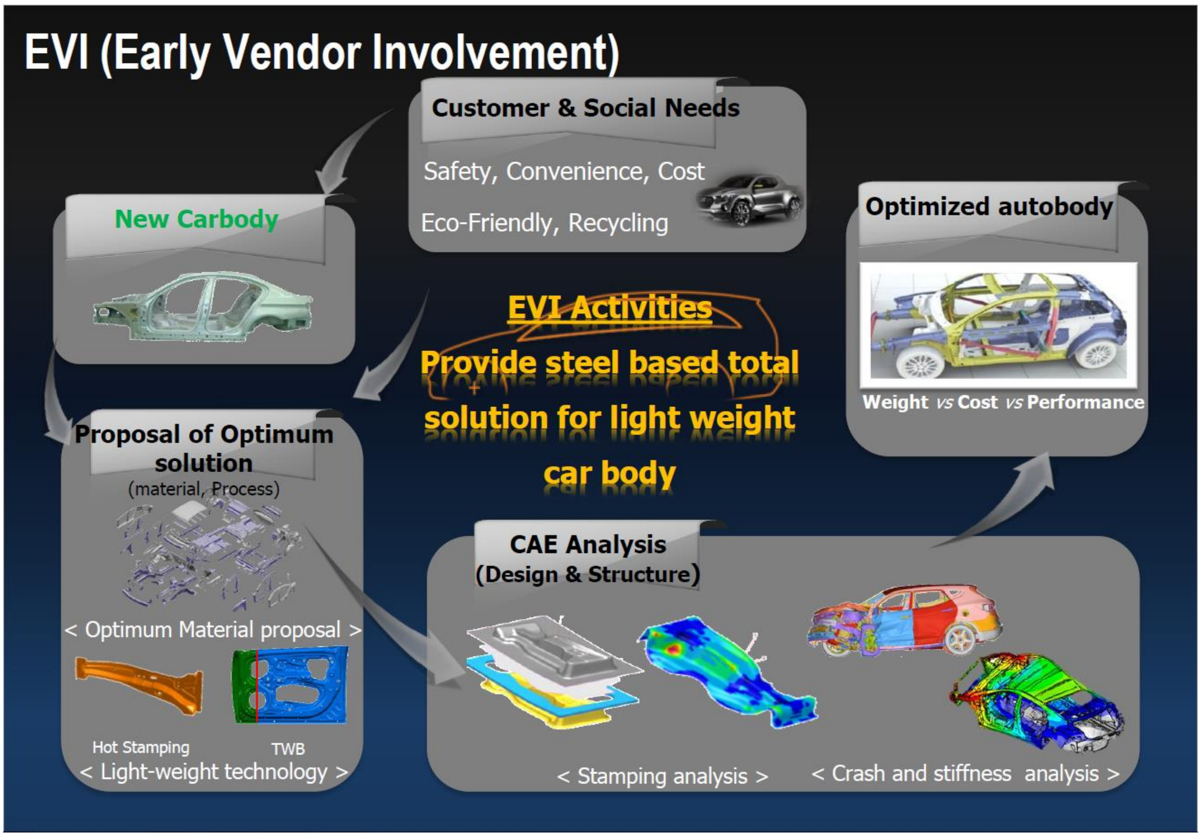


Figure 28. EVI (Early Vendor Involvement)

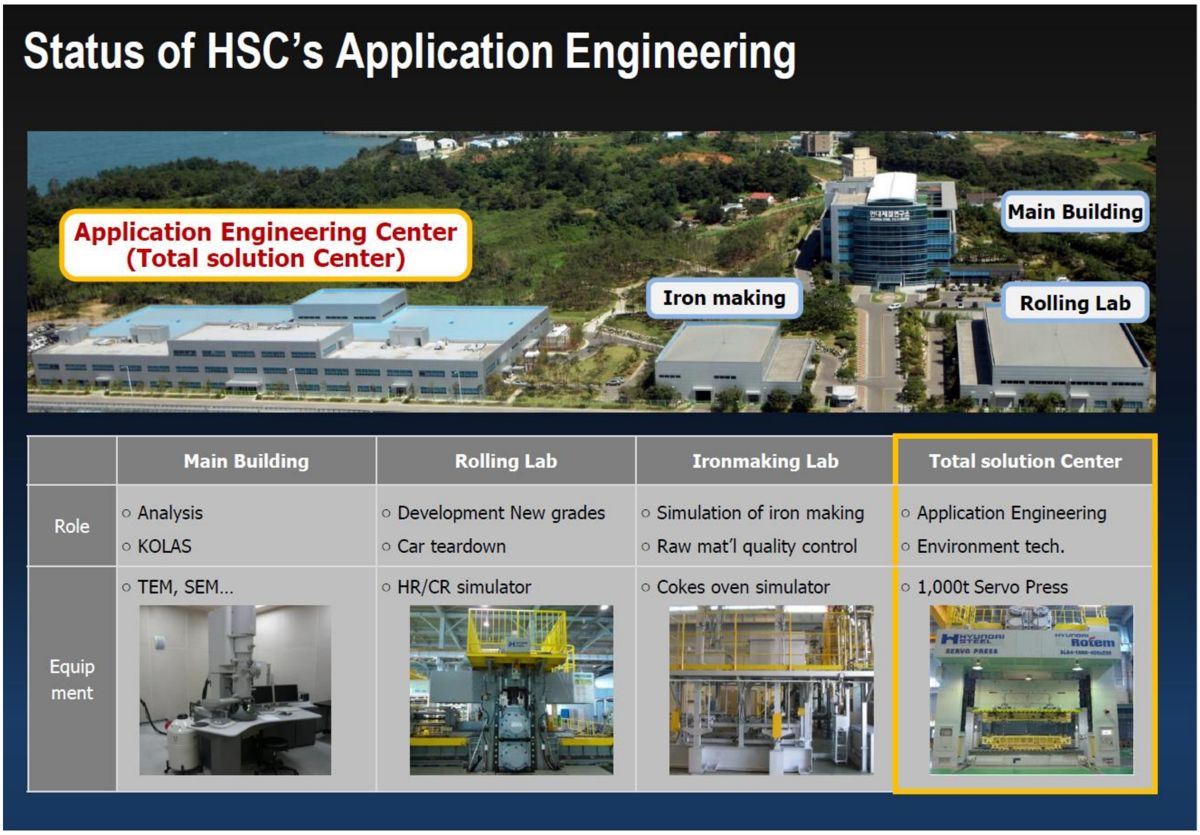


Figure 29. Status of HSC's Application Engineering

Figure 30. Vision Forward - Introduction

Vision Forward

At last, I would like to share the vision of Hyundai Steel (Figure 30).

Hyundai Steel has been focusing on catching up as a fast follower of the automotive and process technology, but Hyundai Steel is no longer the fast follower but rather turning to a new first mover to lead the world's steel industry. Our company announced a new vision last year: "Engineering Future beyond Steel." The new vision comprehends a meaning of which we, Hyundai Steel, provides not only steel but also a new value beyond steel to customers through optimization of various materials and convergence of application technology on newly-developed automotive steel (Figure 31).

OK, thank you for your attention.

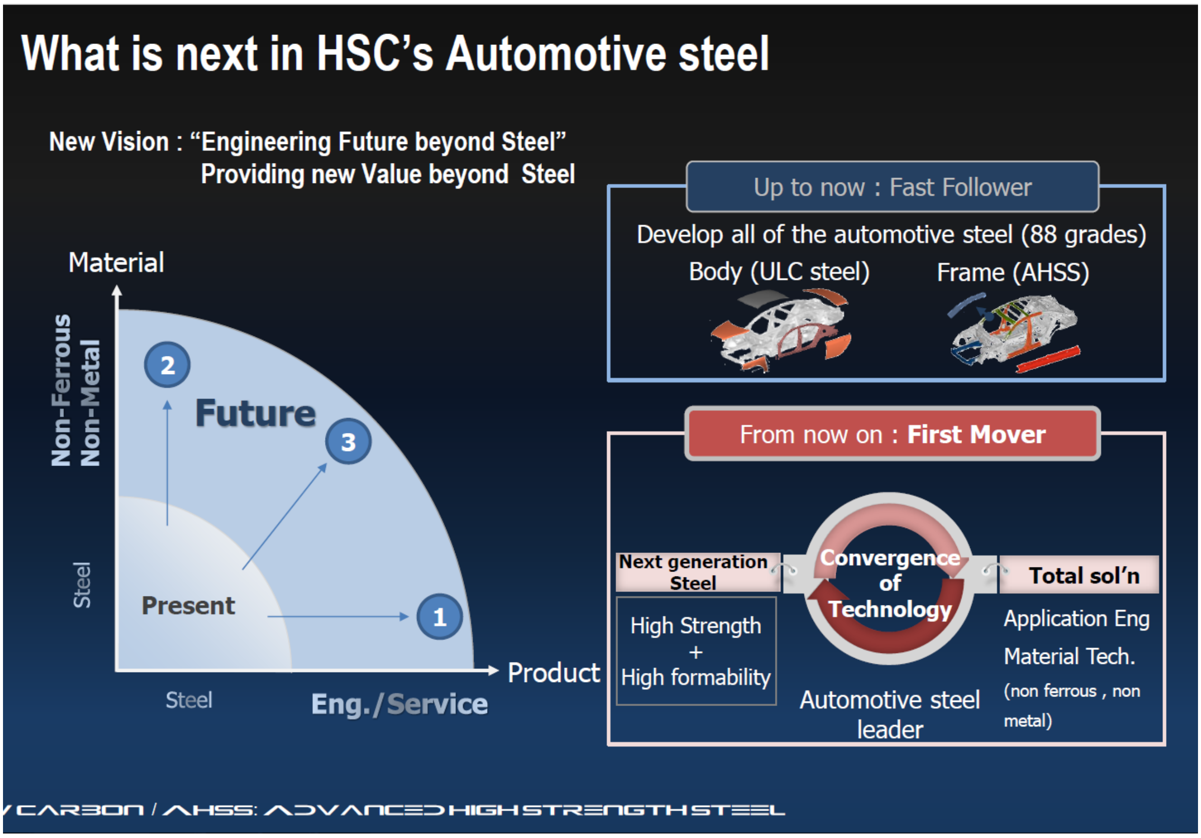


Figure 31. What is next in HSC's automotive steel

The R&D Prospects of Additive Manufacturing (AM) Technology at MIRDC

Chun-Chieh (Jack) Wang
Director of Metal Processing R&D Department
Metal Industries Research and Development Centre

Many thanks for your introduction, Prof. Kim. I want to express my sincere thanks to KIMM and President Im first for inviting me to show the R&D prospect of Additive Manufacturing at MIRDC. I am Jack Wang from MIRDC in Taiwan.

Introduction

In my talk, I want to make a brief introduction of our center to you first. Then, I'll be talking about what our AM technology focuses on, following the strategy and prospect of our AM technology development and application (Figures 1).

Figure 1. Outline of the Presentation

Metal Industries Research and Development Centre

The headquarter of our center is located in Kaohsiung, south of Taiwan (in south of Taiwan here), and we have nine branches in six cities over Taiwan from north to south. Our center was established in 1963. Until now, we have more than 850 employees. And we conduct more than 700 industry service projects per year and also conduct more than 17,000 training services and more than 18,000 verification and certification cases.

In the past 50 plus years, we have always focused on the metal related industry core technology: for example, the primary processing technology (alloy design for the lead-free copper, nitinol…etc.) and the secondary process and technology. We also have established some core technologies: rapid production intelligent manufacturing, micro and meso manufacturing, and also the lightweight technologies like tube hydroforming and hot stamping (Figure 2).

The vision of our center is to upgrade the capabilities of our industry and our R&D missions are to develop some advanced technologies, key components, modules, the process design and to establish some core laboratories. Our industrial strategy is to cooperate with industrial, academic, and research centers. We also have international cooperation, facilitate some industrial clusters, and conduct technology transfer (Figure 3).

This is our organization chart. You can see the board of directors, chairman of the board, and president. The Planning and Promotion Department report to our president. We have three vice presidents in charge of eight departments, such as Medical Devices and Opto-electronics Equipment Department, Regional R&D Service Department, Industrial Upgrading Service Department and Micro/Meso Mechanical Manufacturing R&D Department. And this is my department, Metal Processing R&D Department, and the other ones are Energy and Agile Systems Department and the two logistic small departments (Figure 4).

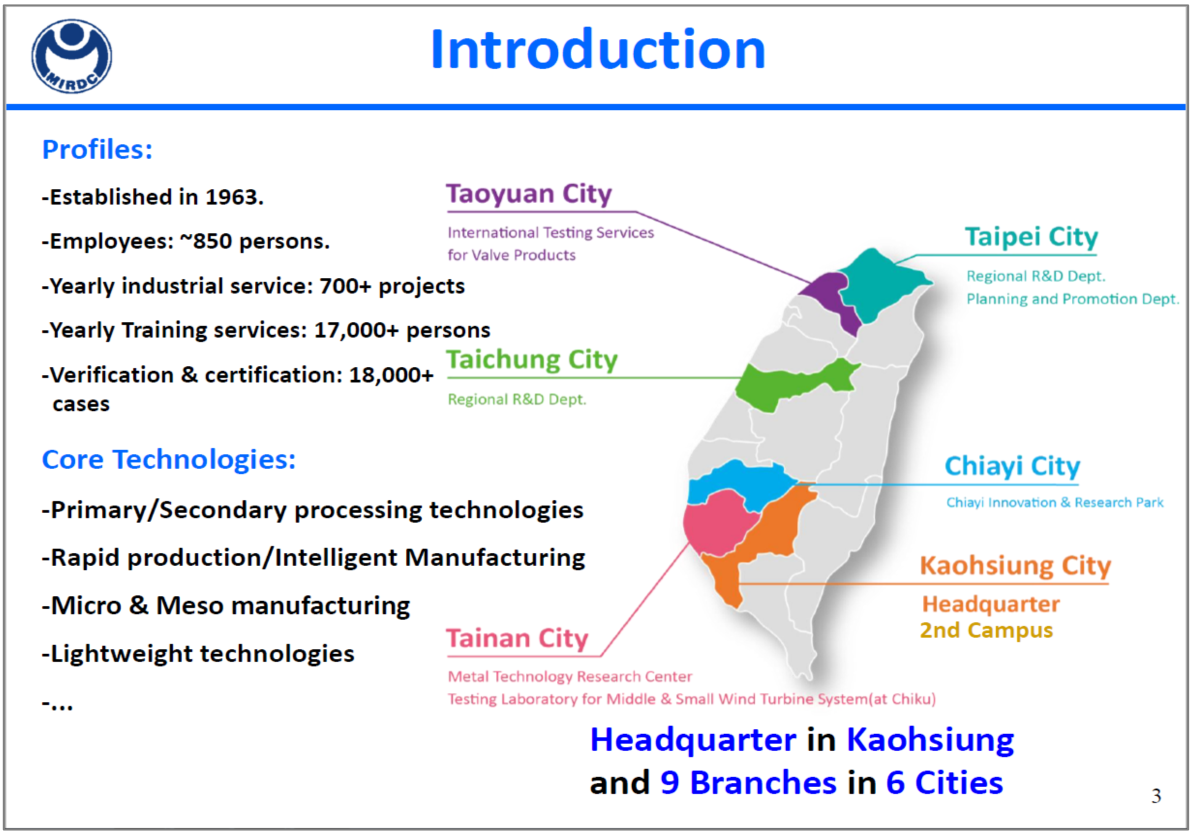


Figure 2. Introduction to the Metal Industries Research and Development Center

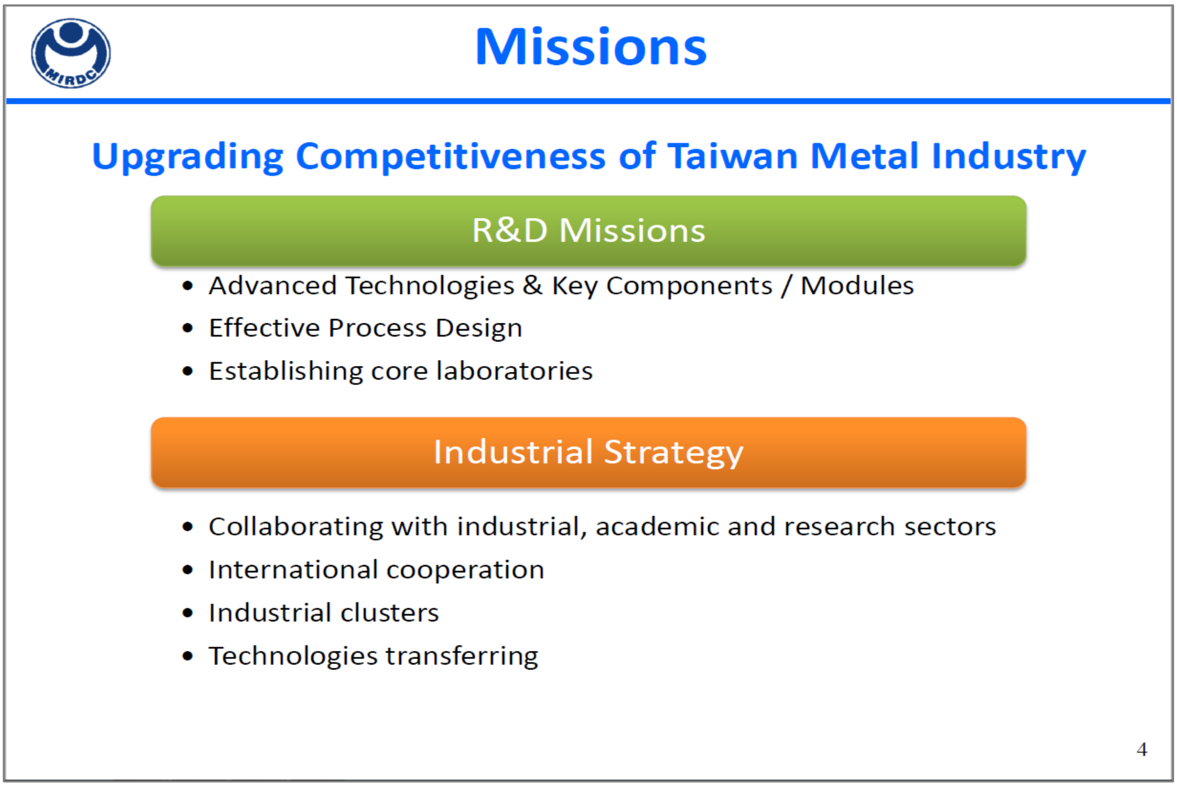


Figure 3. Missions of the Metal Industries Research and Development Center

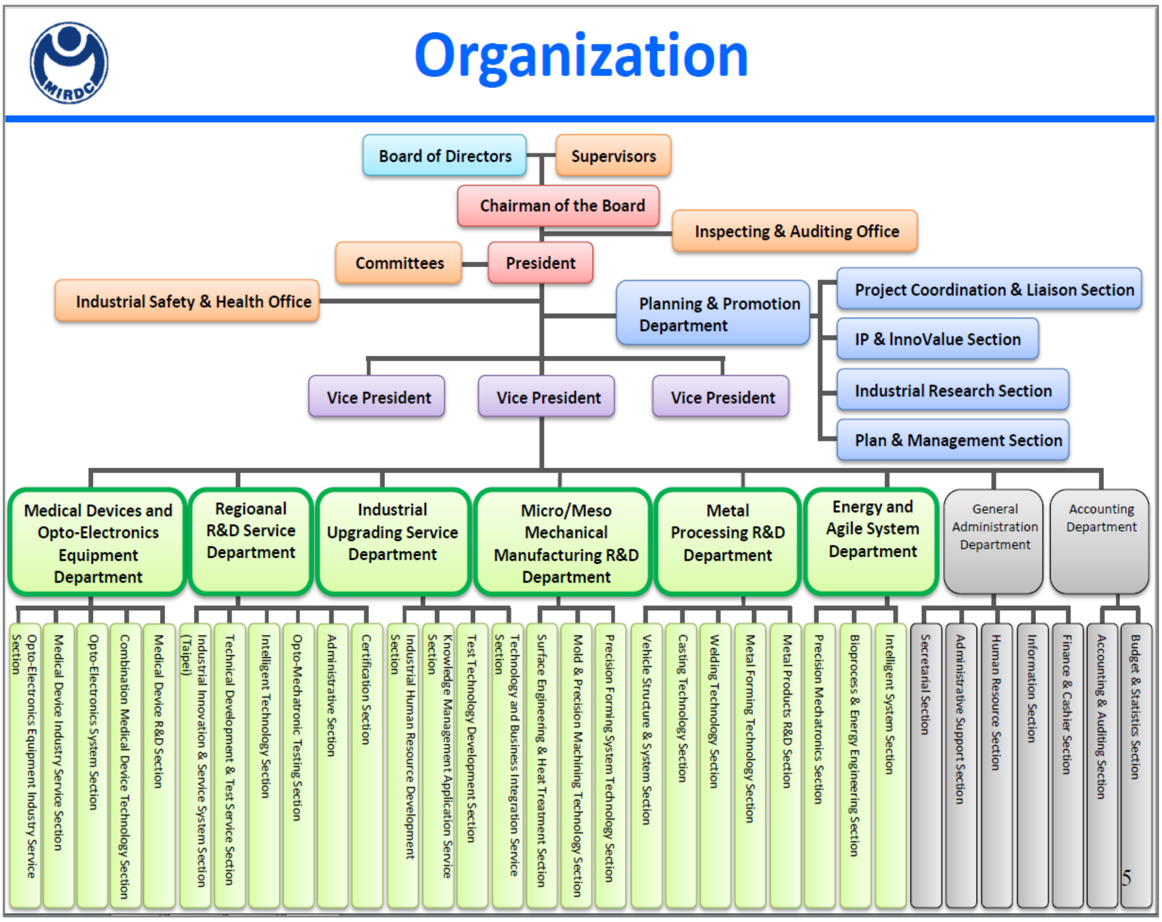


Figure 4. Organization of the Metal Industries Research & Development Center

The industrial application of our center has focused on six fields recently. The first one is metal-based products regarding the core technology like alloy design and high value-added metal products. The second one focuses on mold & die/micro machining for precision molds and components and advanced micro processing technology. The third one is medical devices and health care. We focus on dental and orthopedic implants and minimally invasive surgery systems. The fourth one focuses on the automotive vehicle industry, including the light materials and some kind of lightweight process design (also including the chassis design and certification). The fifth one focuses on high value-added equipment: for example, the testing and certification of equipment for the wind power or auto manufacturing industry. The last one, we call it integration platform like eco-friendly processing technology (Figure 5).

Additive Manufacturing (AM) Technology

In the following, I will talk about what the AM technology development and application focus on. As we know, the AM technology is a digital manufacturing process, and it is very suitable for the small amount of diversity and cost minimization parts. Concerning the government policy, for example, productivity 4.0, it’s very like Industry 4.0. And the other project is to promote our industry productions to increase the added value. And industrial needs wish to upgrade the productivity and increase flexibility in manufacturing. So we think the AM technology is an opportunity, maybe one of the appropriate ways to meet the government policy and industry needs (Figure 6).

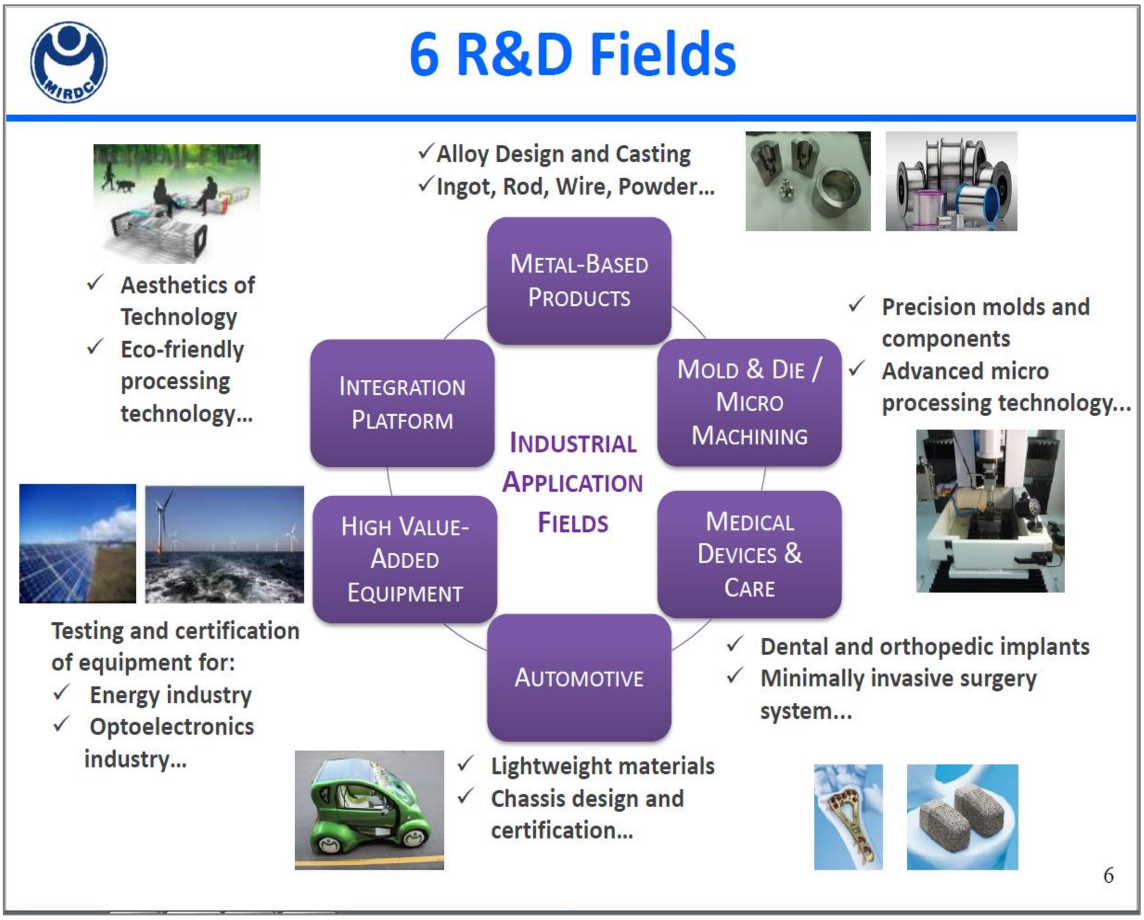


Figure 5. Research and Development Fields

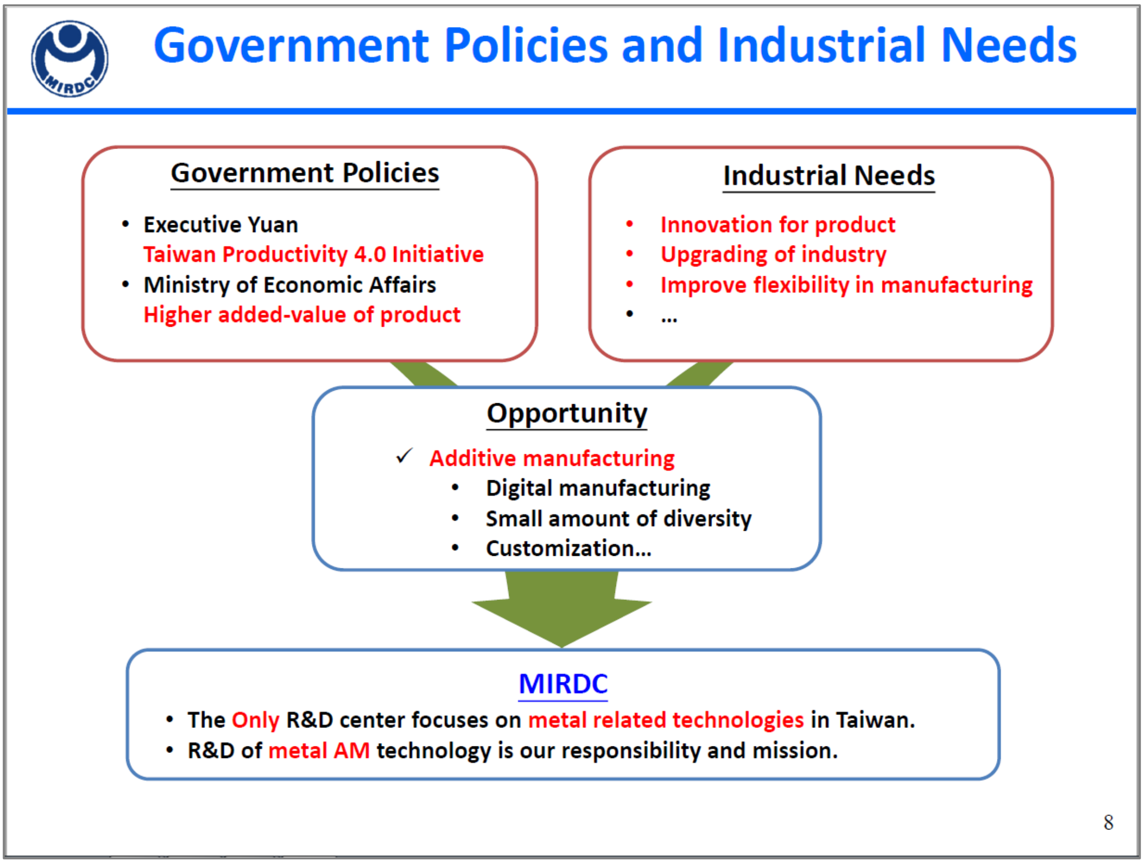


Figure 6. Government Policies and Industrial Needs

Our center is the only one research center focused on metal-related technology in Taiwan. So we thought out to conduct the R&D of metal AM technology. It's our responsibility and mission. So I'll show you the two cases of AM application. The first one is in the medical industry. You can see the figure on the left side: the market trends of our medical industry. Even though the value of the market has increased recently by the growth rate of 5%, the unit price of the imported parts is higher than that of our domestic manufactured parts. The ratio maybe reaches about 9 times. So the status of our medical industry is highly dependent on imports, and many of our home manufactured parts still now maybe are low value products or maybe medium value products. The AM technology can provide porous and gradient property of parts, so it's suitable for the customized and complex structure of the medical devices like hip cup, cage and shoulder joints. So we think that maybe the AM technology development and application have helped out our industry to increase the export value and decrease the import dependence (Figure 7).

In this case here, we have cooperation with some hospitals for quick customization of mandible implants. The traditional process for mandible implant used (as you can see here) raw materials. And then we used 5-axis machining directly and surface treatment for surface roughness. This process, as you can see here…the material loss rate is very high, about 80%. And the other problem is it's very hard to machine such kind of implants. It has a very complex shape, so commercially; it is very difficult to machine it. So the traditional manufacturing process technology takes a very long time. It's very hard to fit the hospital needs. We cooperated with the local hospital. We used the EBAM process to produce and develop this part. Regarding the process to manufacture this part, we have some improvement or advantage shown here. The material loss rate decreased from 80% to 10%. And we also used this EBAM process to lower the cost from 1500~2500 US dollars to maybe 500 US dollars per piece. We can also shorten the delivery time from four days to one working day (Figure 8).

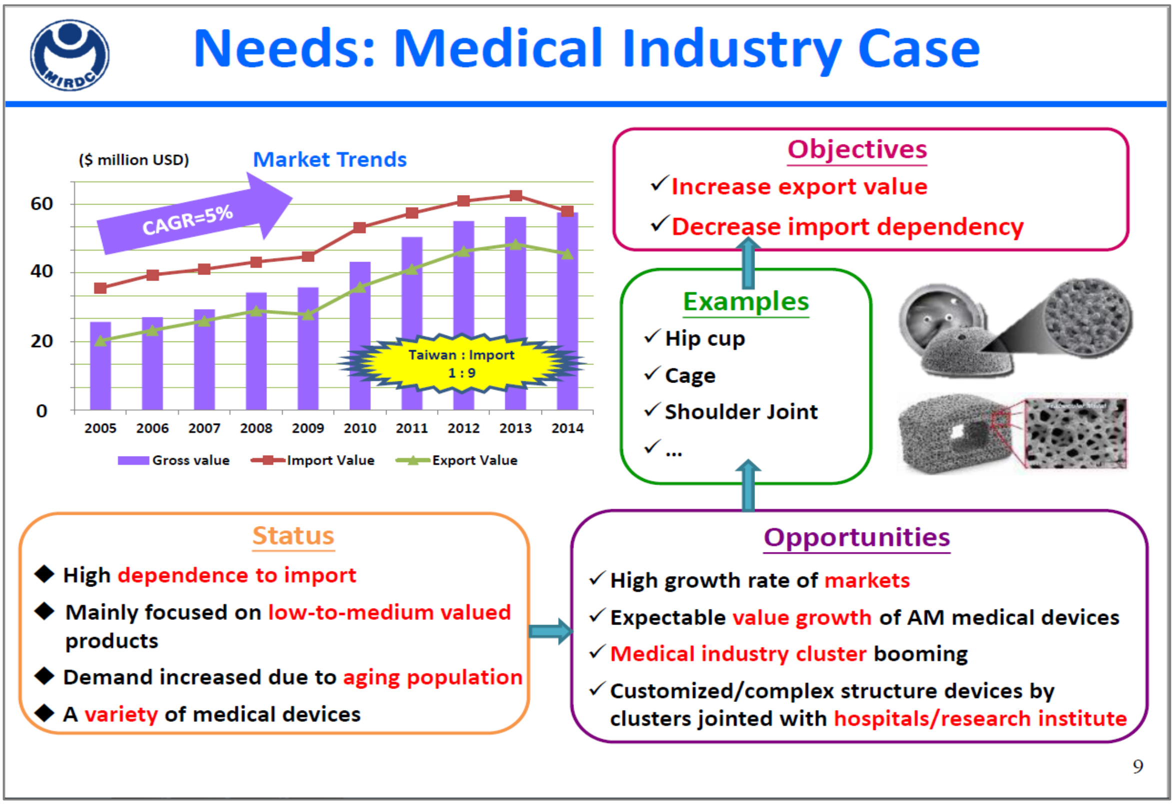


Figure 7. Needs: Case of Medical Industry

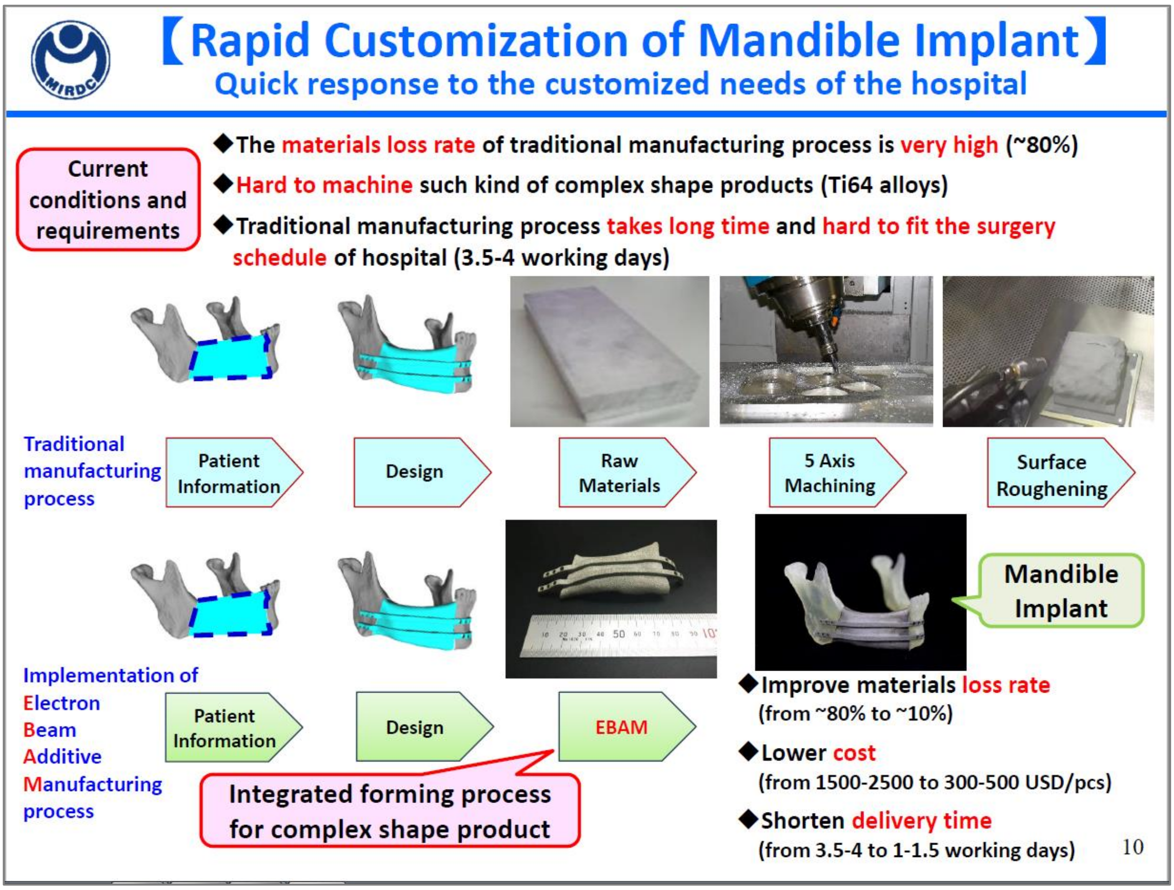


Figure 8. Rapid Customization of Mandible Implant

And the second case is the application case for the foundry industry in Taiwan. You can see the figure on the left side. Our foundry industry is focused on the domestic market, but over maybe 90% is SME. The number of employees of most of foundry companies is less than 70. By the way, the foundry industry is a 3K style industry, in Japanese are kiken (very dangerous), kitanai (very dirty), and kitsui (very difficult). Our government is concerned about this, and gives us some financial support, which asks us to help the industry change their 3K style to 4C casting industry style. The four Cs are cleanness, career, competitiveness, and creativity. This project includes the environment improvement, automation, intelligent manufacturing, and the AM technology (Figure 9).

This case is our first application that uses the binder jetting process in Taiwan. For the maintenance and replacement of an impeller, the original process for this impeller is lost wax precision casting. So some companies wish to lower the cost through sand casting. But sand casting has some problems as the curved blades of the enclosed impeller will generate airback pressure. It causes a defect of the metal filling. And the traditional impeller should also require combinative sand core molds. That means it has a high cost process and a poor combination/precision. So we cooperated with this company to redesign the conformal air escape channel of sand casting mold. This sand mold is the hollow sand core design, and it reduces vapor generation from heating of resin in the sand core. So the process has some benefits. It can reduce the processing cost by 20% and improve the product yield ratio by more than 10% (Figure 10).

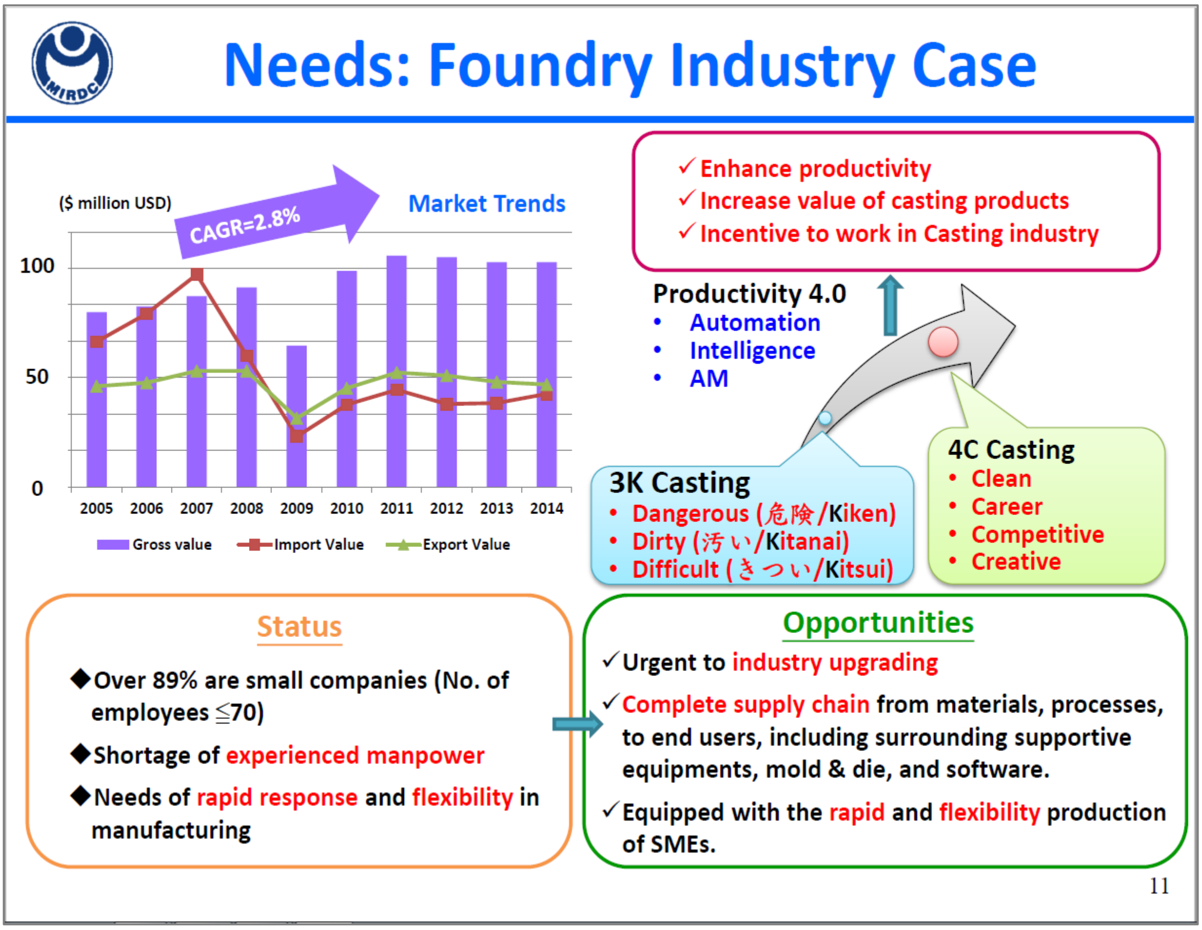


Figure 9. Needs: Case of Foundry Industry

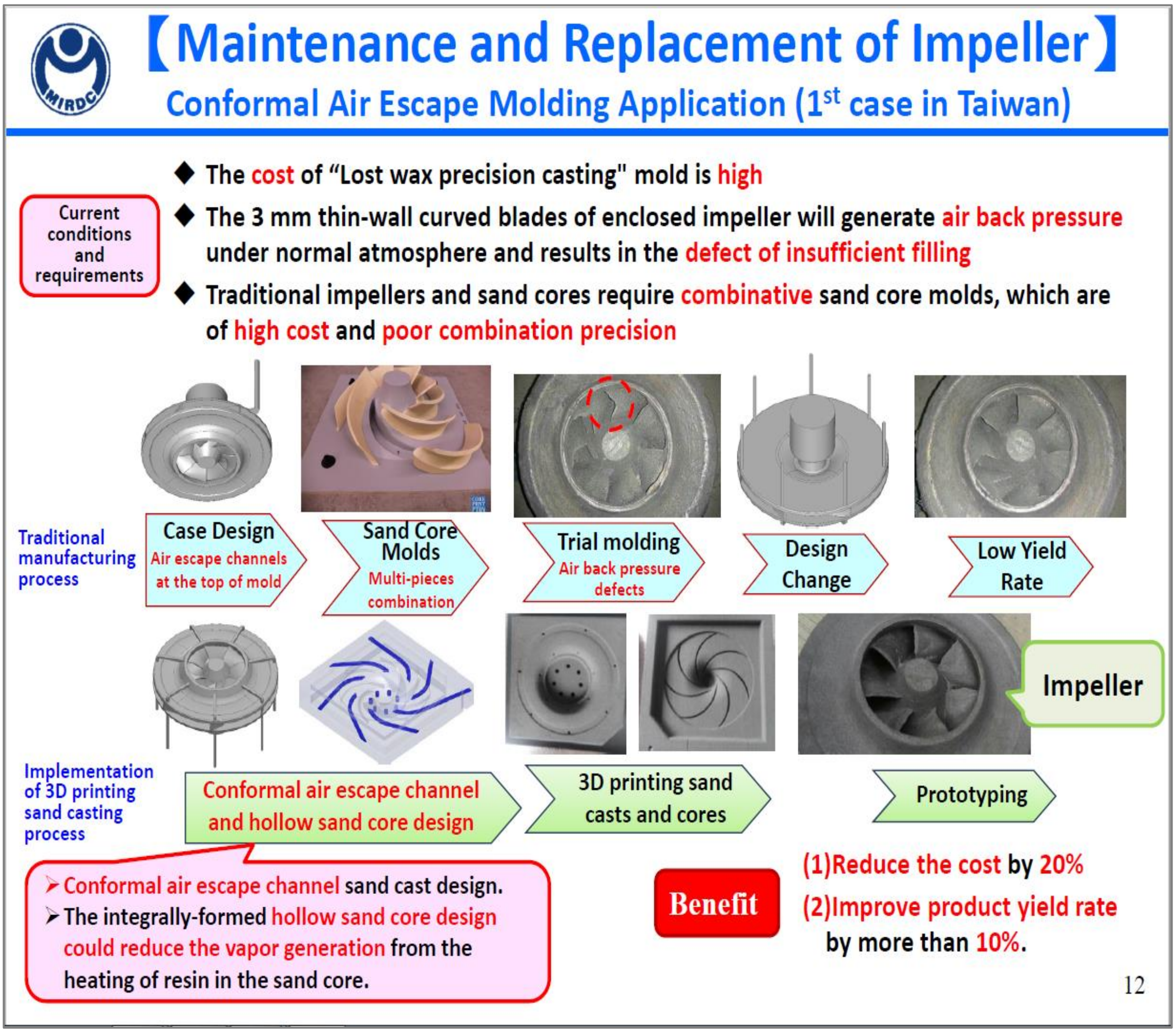


Figure 10. Maintenance and Replacement of Impeller

There are some universities, research institutes, and industrial companies involved with the AM technology, development, and application for the material, AM powder, and also equipment and process design. Concerning the resource and location, our center came up with a competitive strategy. Our center focuses on the high value-added or high-purity AM powder. And regarding the AM process, we focus on the EBM process, the binder jetting and also the hybrid SLM. Our center also conducts some post-treatment for the AM part, including the AFM and electrical and chemical machining (Figure 11).

This shows our recent research results. In the AM powder, we developed some very unique or niche alloy materials like the shape memory nitinol from the melting, rod, to wire and powder. This material can meet the ASTM biomaterials requirements. By the way, we also have cooperation with our local company to develop some hip cups. We used the EBM process for the medical industry, and also we used hybrid SLM to produce the conformal cooling channel for the plastic injection mold for the biochip testing. The other one used the binder jetting process to develop the sand mold for the clutch housing for the vehicle industry application (Figure 12).

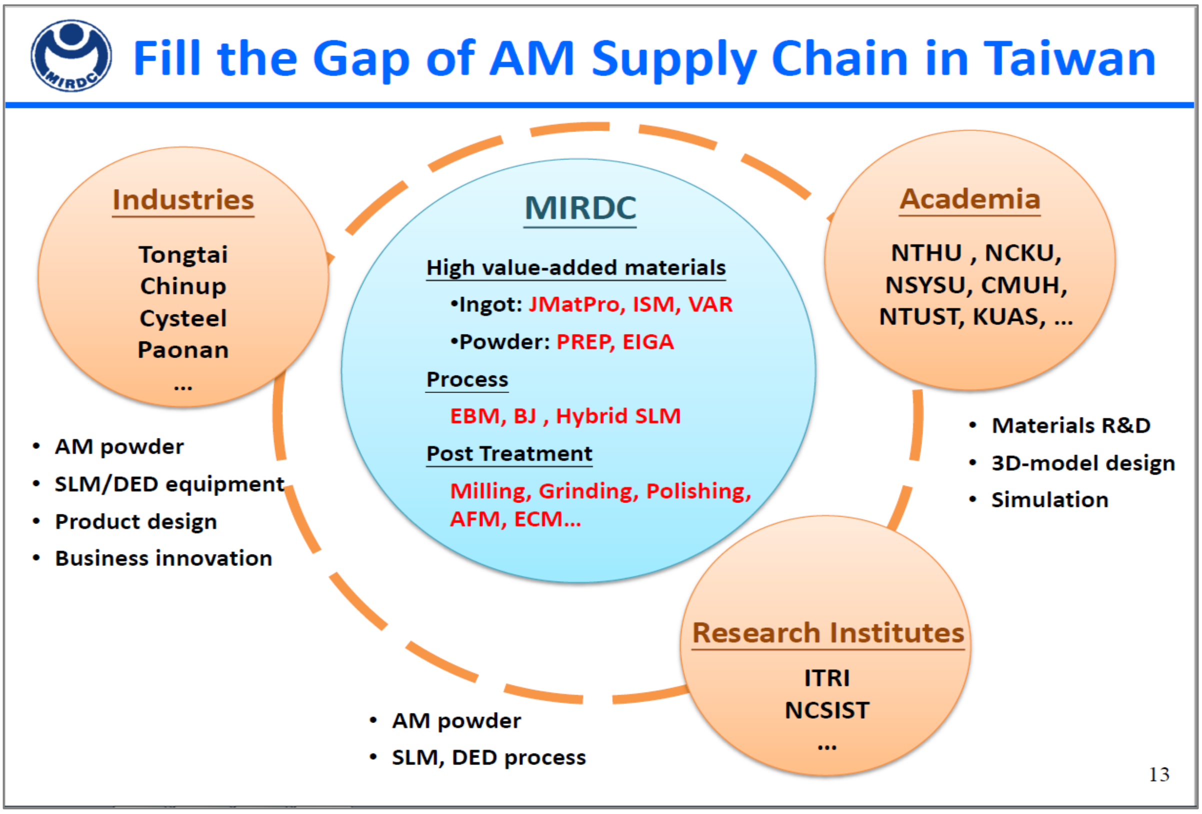


Figure 11. Fill the Gap of AM Supply Chain in Taiwan

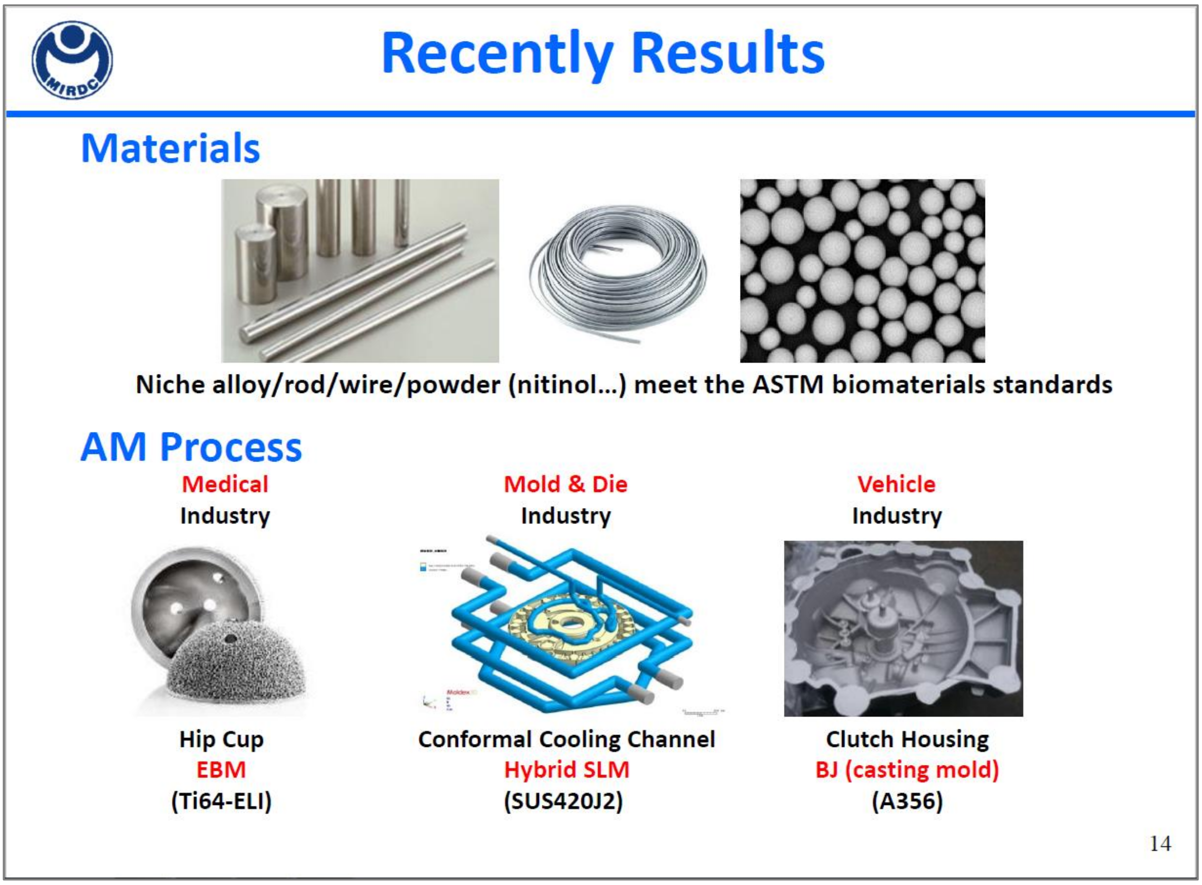


Figure 12. Recent Results

MIRDC's Strategy

In the following, I will discuss our strategy of AM technology development and application.

This shows facilities related to the AM process in our center. Regarding the material or AM powder, we used simulation software like JMetPro to develop some titanium, nitinol and also some kinds of special materials. And we also have the VAR and VIM to develop some materials. Regarding the powder, we use special equipment like...we call the PREP (plasma rotating electrode process) and EIGA (Electrode Induction Gas Atomization) (Figure 13).

For the AM process equipment, we established an EBM, the binder jetting from a German company, and the hybrid SLM for the cooperation with the Japanese company Sodick. And we also have developed a wire arc DED and powder DED.

We also have developed some post treatment technologies and the inspection and certification of the AM parts like the ultrasonic machining, milling, AMF and so on. In the meanwhile, we also enhanced international cooperation in the AM technology development. For example, in Japan, we have in cooperation with Tohoku University and Sodick. We have exchanged researchers with ENISE, France. And Norway's SINTEF, we have joined together to apply some European Project Horizon 2020. And Sweden, Stockholm University came to work with us, and Georgia Tech and Michigan University, as well (Figure 14).

This is an example of the international cooperation. We have cooperation with Tohoku University by the joint laboratory and joint project and exchanged researcher. We designed alloy and melting, and Tohoku University used these materials to produce powder (Figure 15).

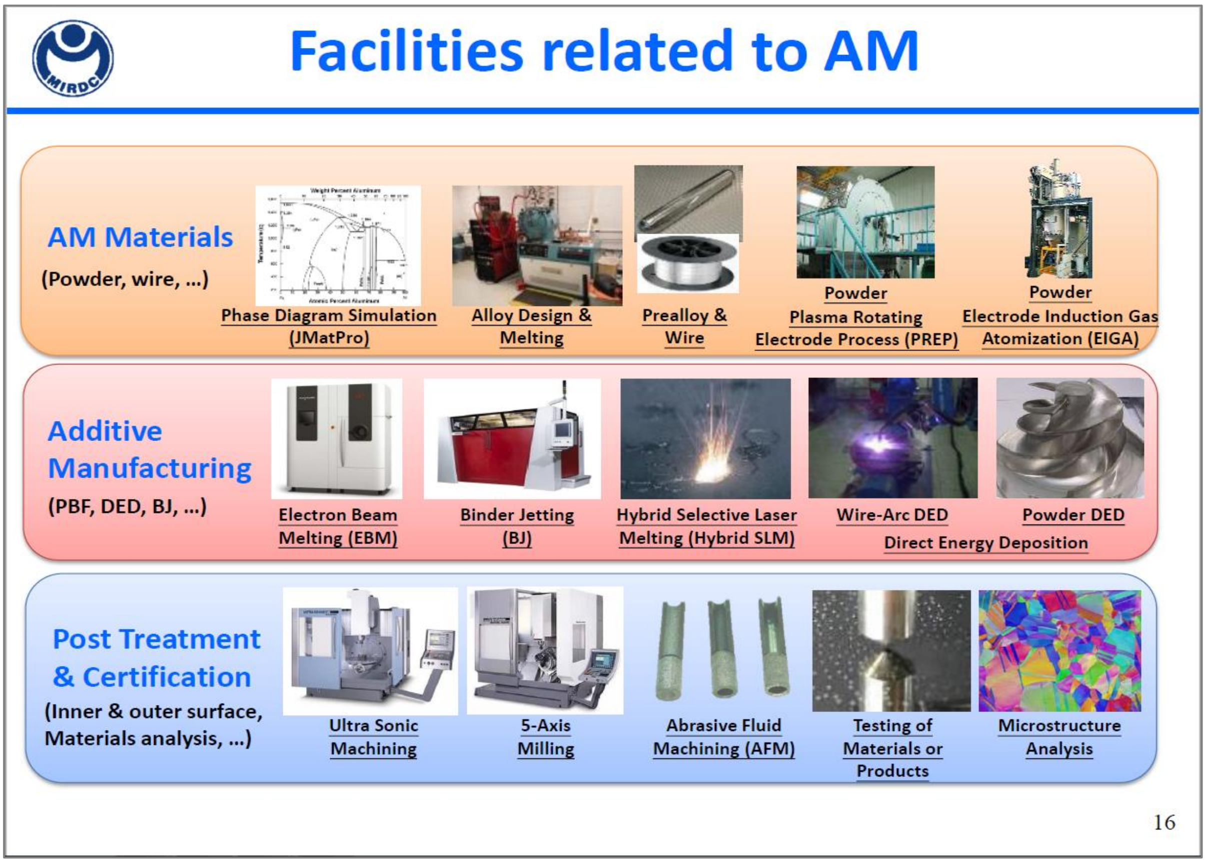


Figure 13. Facilities related to AM

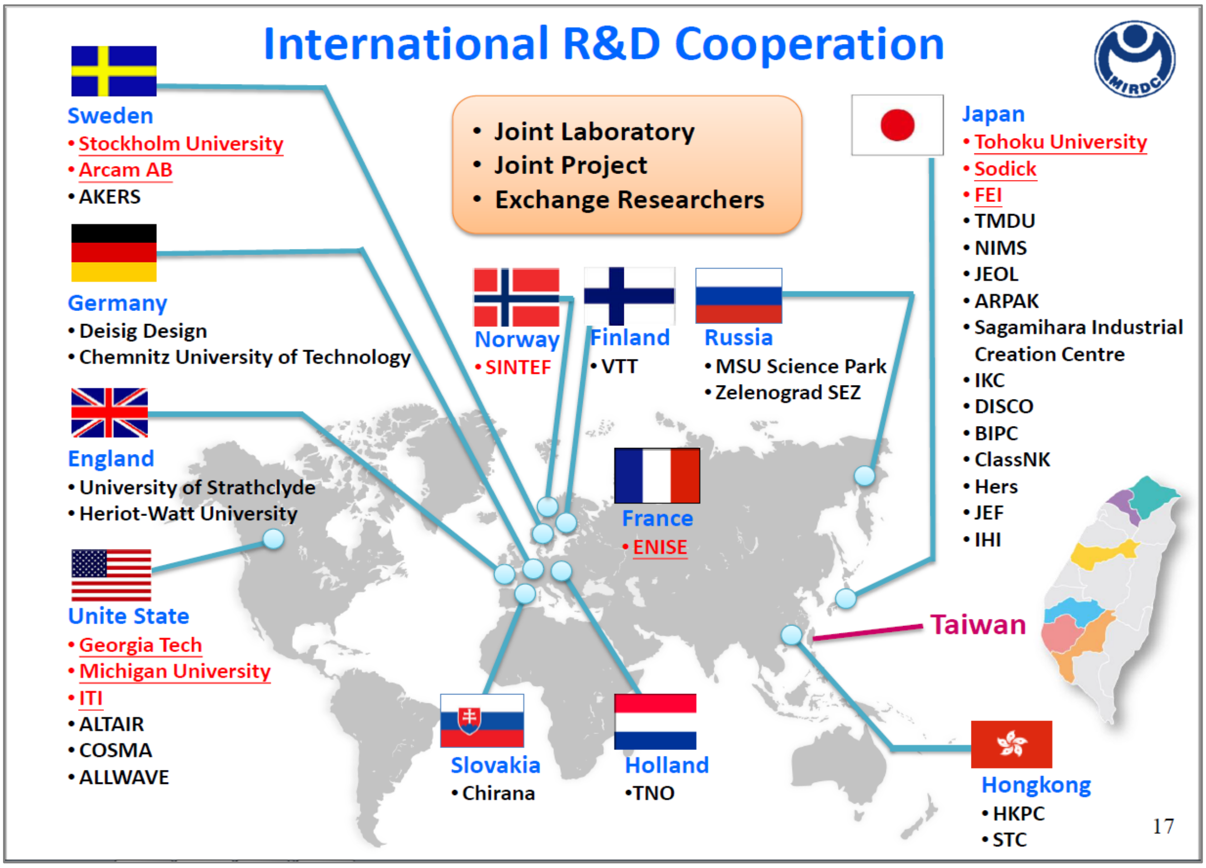


Figure 14. International R&D Cooperation

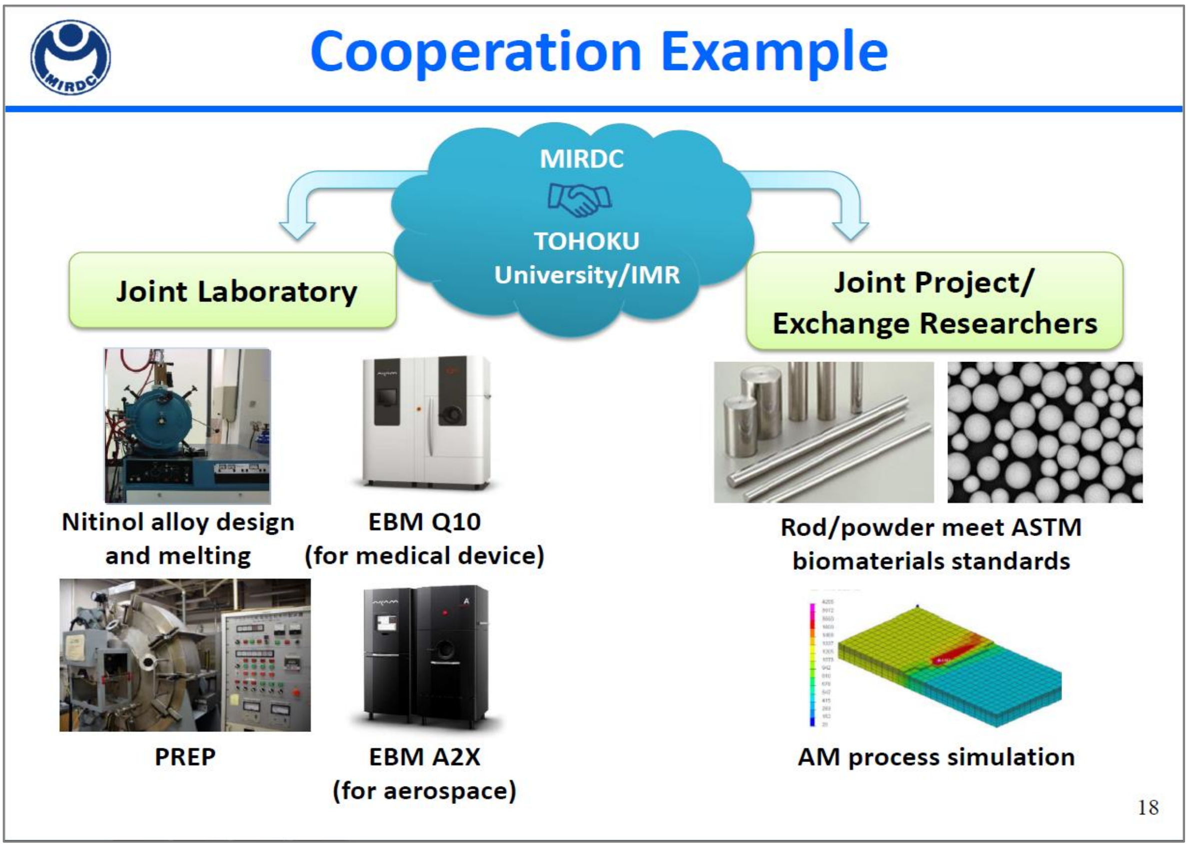


Figure 15. Cooperative Example

As we know, from the academic side, it's very hard to make achievement to industrialization. From the industry side, we need to quickly verify the industrialization feasibility of new idea. So there is a big gap between the innovation idea and industrialization. Considering this situation, our center organized a platform named the "I^3" AM Platform. "I^3" means intelligence, innovation, and integration. We hope this platform can speed up the pace from this innovation idea to industrialization (Figures 16 and 17).

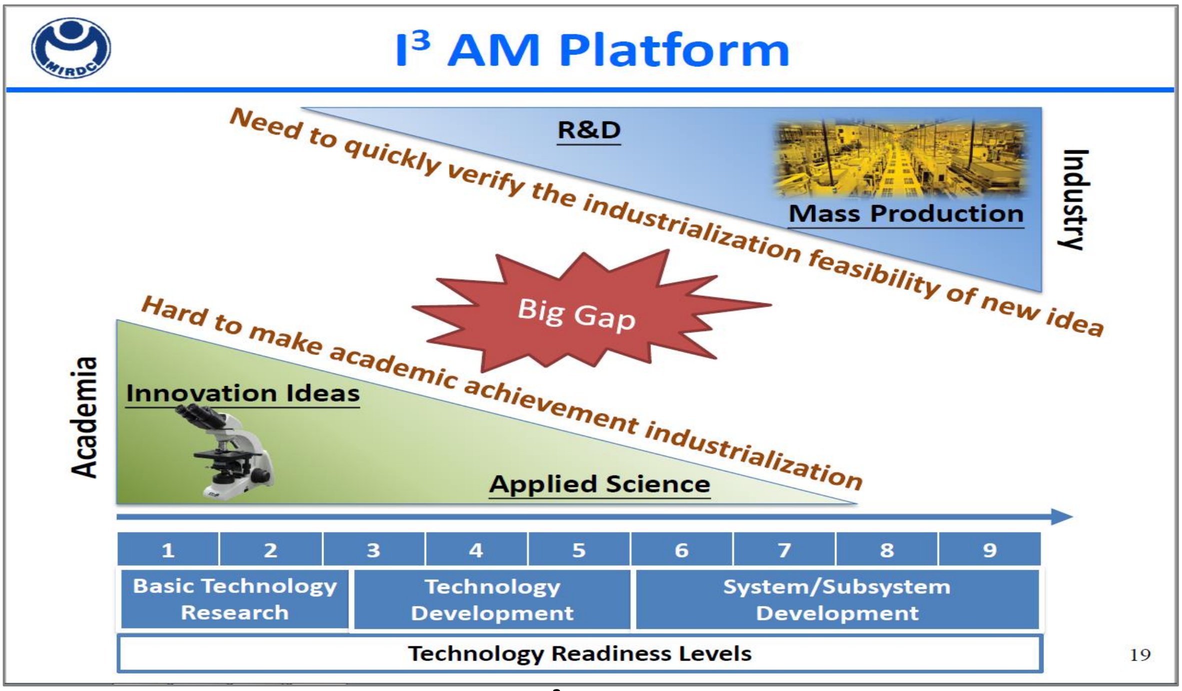


Figure 16. I^3 AM Platform (1)

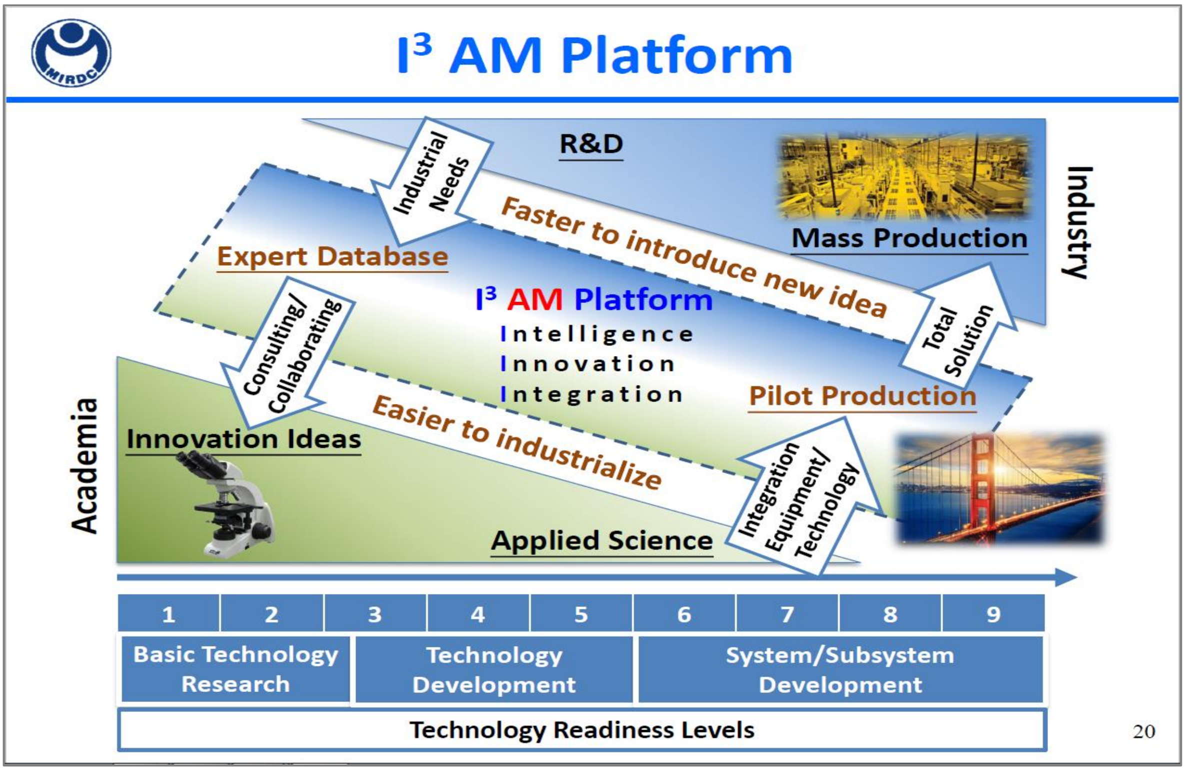


Figure 17. I^3 AM Platform (2)

Prospects of the AM Technology, Development, and Application

Then I will talk about the prospects of our AM technology development and application

We will have a new research campus for the AM technology application and development next year. This new campus started its construction last year in July. And the construction will be completed next year in January. And the total campus space is about 17,500 m^3. And after the complete construction, we will shift all the AM-related equipment to this new campus (Figure 18).

Finally, in the AM technology development and application, we wish our center to become a key player in Taiwan. And we will also organize the I^3 AM Platform and wish to achieve integration synergy in the near future. Regarding our center, our center always has emphasized that our center is not just an R&D institute. Our center has also been an R&C and R&S style institute. The C means connection. We have to connect with industry, universities, and research institutes, including (of course) the international cooperation. And the S means that our center can give a total solution to our industry to help the industry upgrade the competitiveness and increase their added value. So in this AM technology development and application, we will conduct more R&D, R&C, and R&S work to help them upgrade (Figure 19).

That's the end of my talk. Thank you very much for your attention (Figure 20).

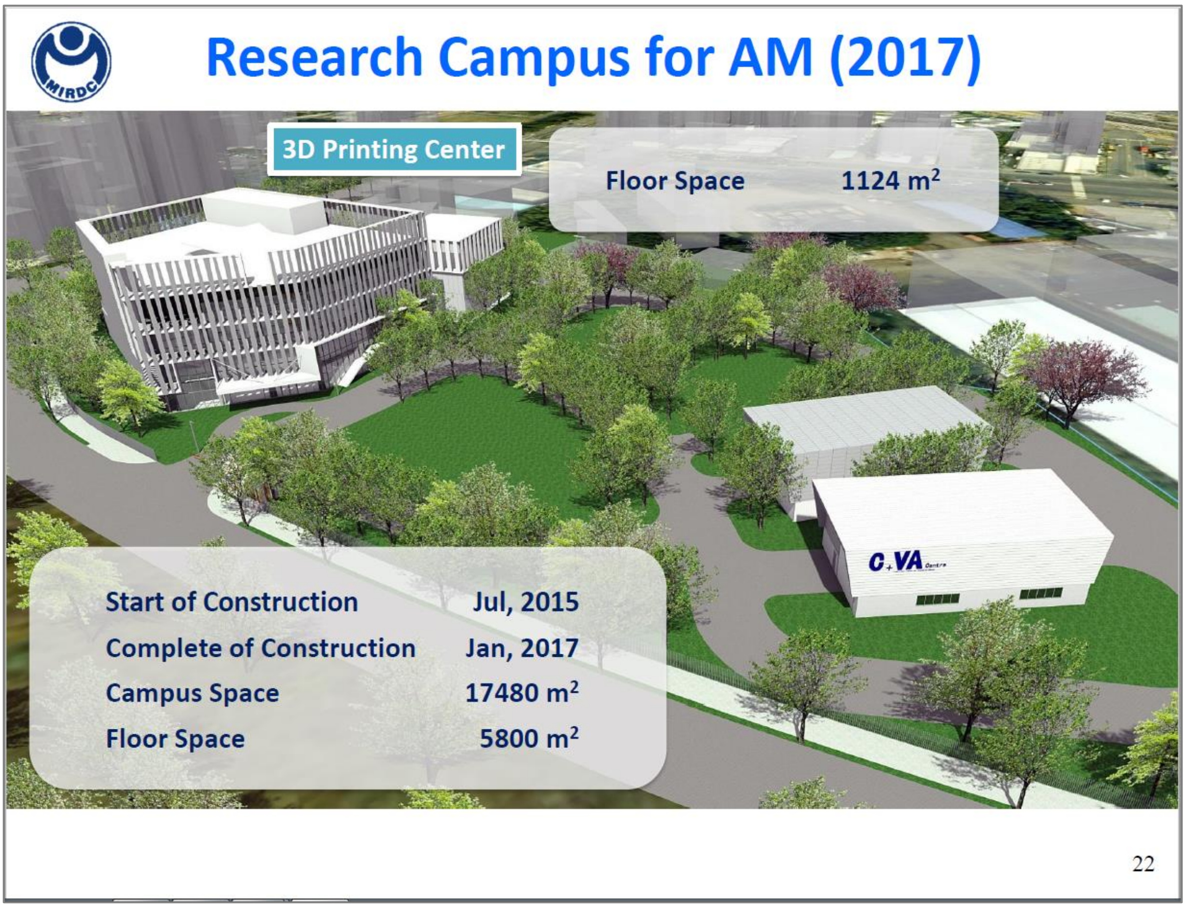


Figure 18. Research Campus for AM in 2017

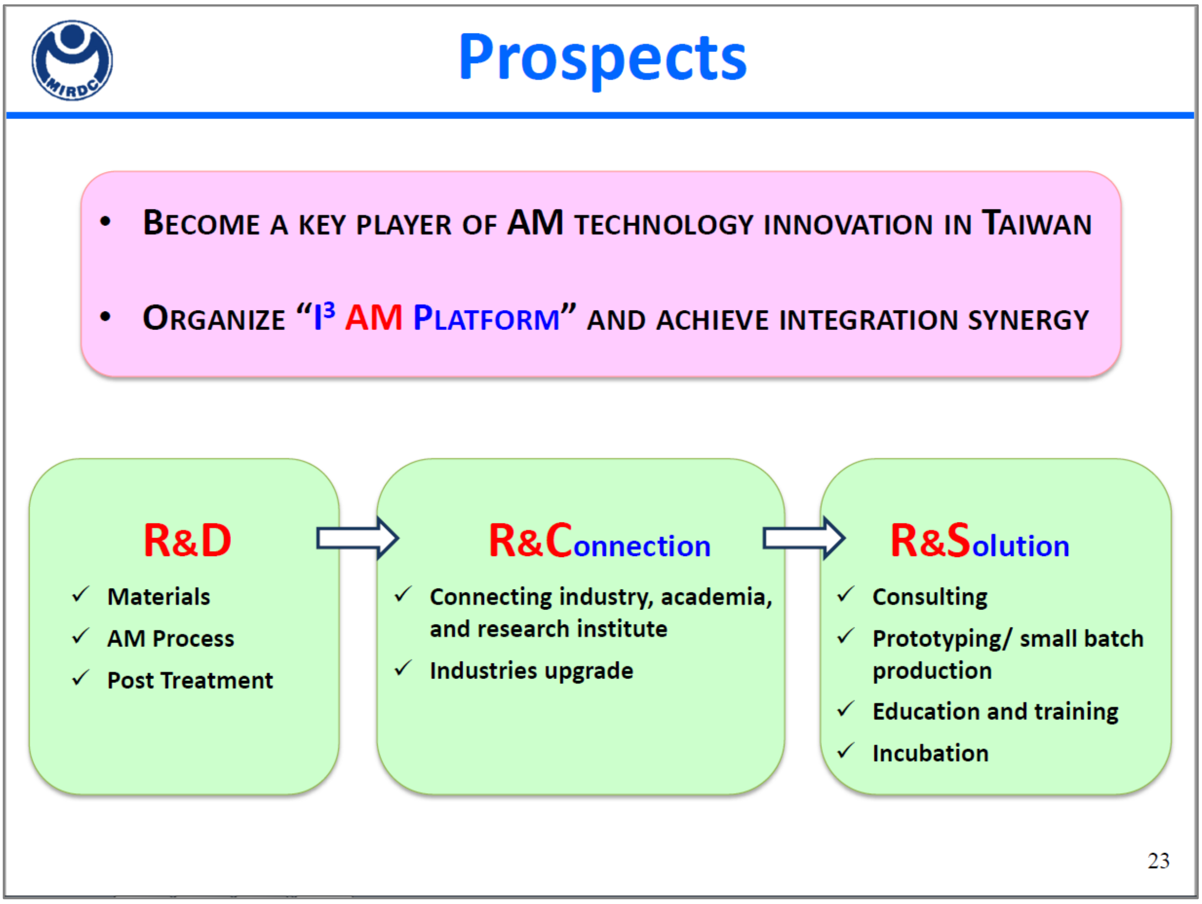


Figure 19. Prospects

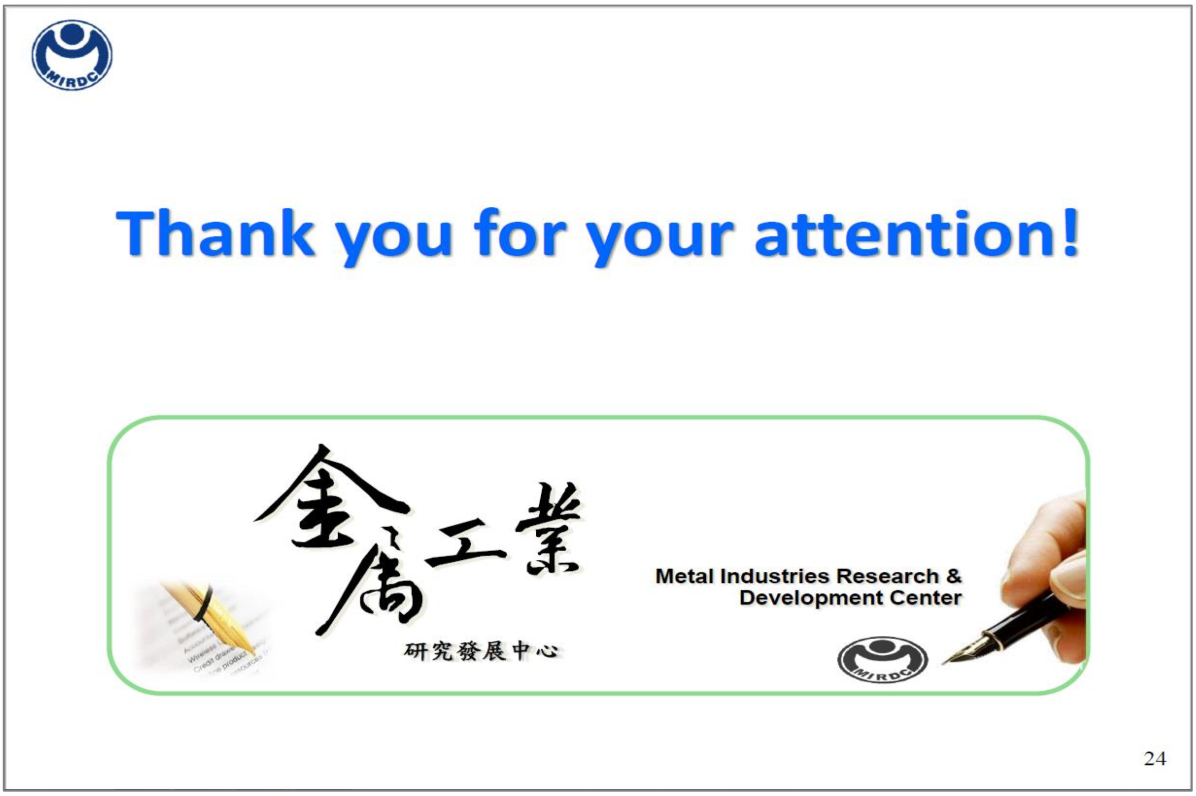


Figure 20. Thank you

Vision of Energy Sustainability

Prof. Choongsik Bae
Department of Mechanical Engineering
Korea Advanced Institute of Science and Technology

Thank you very much, Chairman. I am very much privileged to be here with the world-renowned specialists.

First of all, I would like to congratulate the 40 years of KIMM, and it's my honor to represent my department with 57 regular faculty members and 1,000 students. Traditionally, the Department of Mechanical Engineering in KAIST has been the everlasting friend of KIMM in five-minute distance, so this will continue again, forever. Today, I would like to talk about the vision of energy sustainability. It seems to be too big, but I would like to overview some scenarios of energy technologies, which is based on the International Energy Agency Energy Technology Perspective 2050, Then, I will give you some examples of the efforts to achieve this energy technology perspective in KAIST.

Introduction

First of all, I would like to give you an overview of the energy technology perspectives so that we have clear understanding of what kind of scenarios we have from the governmental point of view, and from the industrial point of view. So, I will start with the ETP 2050, which was initiated by the International Energy Agency (Figure 1).

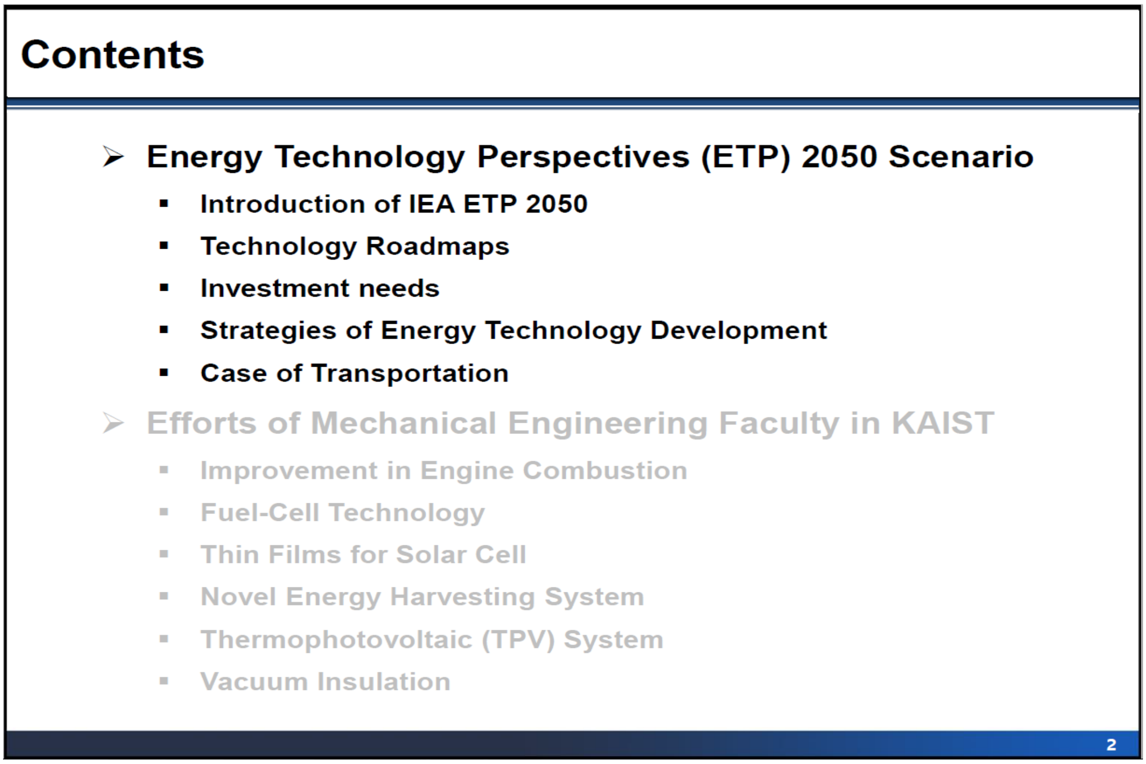


Figure 1. Contents of the Presentation

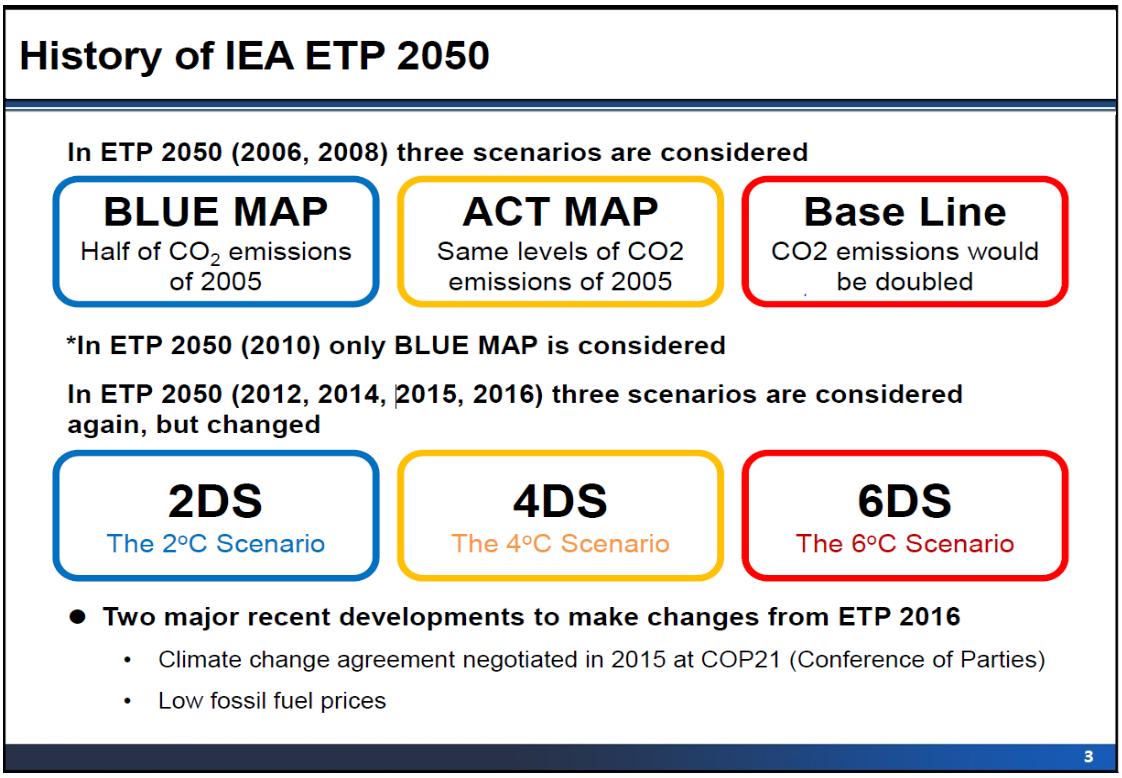


Figure 2. History of the IEA ETP 2050

The Energy Technology Perspectives 2050 of the International Energy Agency

In 2006, the International Energy Agency set up the ETP 2050. As a representative of Korea in the Combustion Implementing Agreement (now, renamed as the Task Collaboration Program in the International Energy Agency), I have come across this ETP 2050 scenario. This scenario was launched in 2006, and had been revised every two years until 2010 when we had too ideal of a scenario. But just after that, we had the unfortunate disaster in Fukushima in 2011, and the IEA decided to use a new name from the original scenarios. The titles of original scenarios were “Base line,” “Act Map,” and “Blue Map”. The Baseline Scenario basically represents the situation that follows the natural trend of energy technology development. So, the IEA made a plan that the CO_2 emission in 2050 will be doubled compared to that in 2005. That was the baseline scenario of the IEA which was set up in 2006. At that time, the ideal scenario was Blue Map. The target of Blue Map was to keep the CO_2 level the same in 2050 compared to 2005.

These scenarios were renamed and revised to the followings: 6°C Scenario, 4°C Scenario, and 2°C Scenario. Every government set up the energy technology policies, mostly following the Blue Map Scenario. The Korean government set up the Green Growth Policy, following the Blue Map in 2008. And now, it is following the 2°C Scenario. The name, itself, is very appalling to us. Since now we are experiencing a record high, high temperature in humid weather, if you consider the 6°C increase in 2050 compared to 2013, that’s the baseline of this scenario, which was the most recent one in 2016. You cannot imagine what will happen if the temperature increases by 6°C. Of course, there are some arguments that it may not happen even with this Baseline or the 6°C Scenario trend. Still, the United States, Japanese, and Korean governments are keeping the energy policy following the Blue Map/the 2DS (2°C) Scenario of the IEA. And this was enforced by the recent agreement by COP21 last year. I remember that was around October or so. And, it was the time when the fuel price, especially the petroleum price, was becoming very low because of the advent of shale gas. That was a big change in the fuel market. But, that gives some advantages and disadvantages in energy technology development (Figure 2).

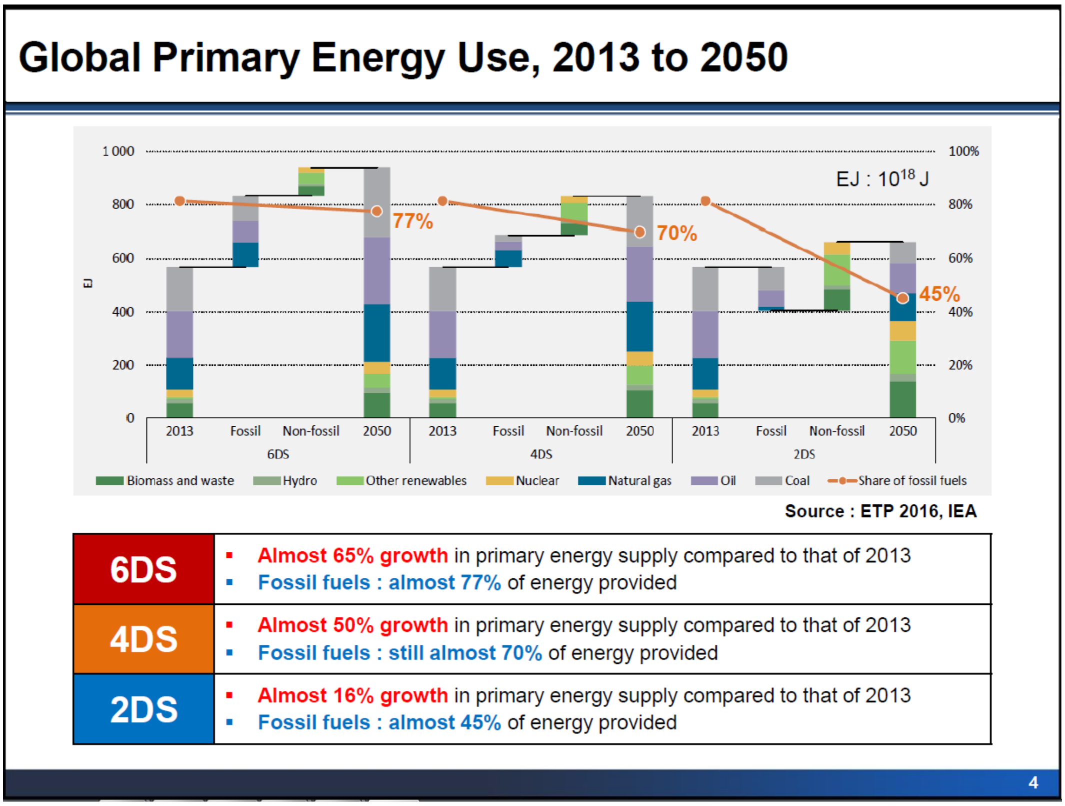


Figure 3. Global Primary Energy Use, 2013 to 2050

These are the details of the 6°C Scenario, 4°C Scenario, and 2°C Scenario. Compared to the Baseline Scenario here in 2050, compared to 2013, you will have this amount of increase of fossil fuel and the renewable natural resources. In the 2°C Scenario, you may reduce the consumption or supply of this fossil fuel energy resource while you will have a lot of increase of renewable energy. Renewable energy includes biomass and waste, hydro-driven energy, and other renewables like solar, wind, geothermal, and so on while these natural gas, oil, and coal will be still dominating even in the 2°C Scenario (Figure 3).

Comparing the 6°C Scenario to the 2°C Scenario or 4°C Scenario, one can realize that this amount of CO_2 reduction must be achieved through the contribution of these kinds of technologies. Among these optional technologies, the significant technologies are mostly renewable energy and end-use efficiency. Actually, this is the main message I would like to deliver today. When we say the sustainable energy technology, we always think about the renewables. But, the renewable energy cannot solve every problem, and the renewable energy cannot be acquired through cost effective methods and easy technology development. So, we must have a balance with the end-use efficiency improvement. We must tackle this parallel technological development: 1) the innovative renewable energy development, and the efficiency improvement based on the traditional energy technology (Figure 4).

This is another separation of the 2DS (I mean 2°C Scenario) compared to the 6°C Scenario in different sectors. As you could see in this figure, power generation is the biggest sector in consuming the energy, and it must contribute to CO_2 reductions with the 2°C Scenario technical development, industry, transport, buildings, and the transformation in the fuel supply or the natural resources supply. And, in each sector, you could see the contribution of different technology items (Figure 5).

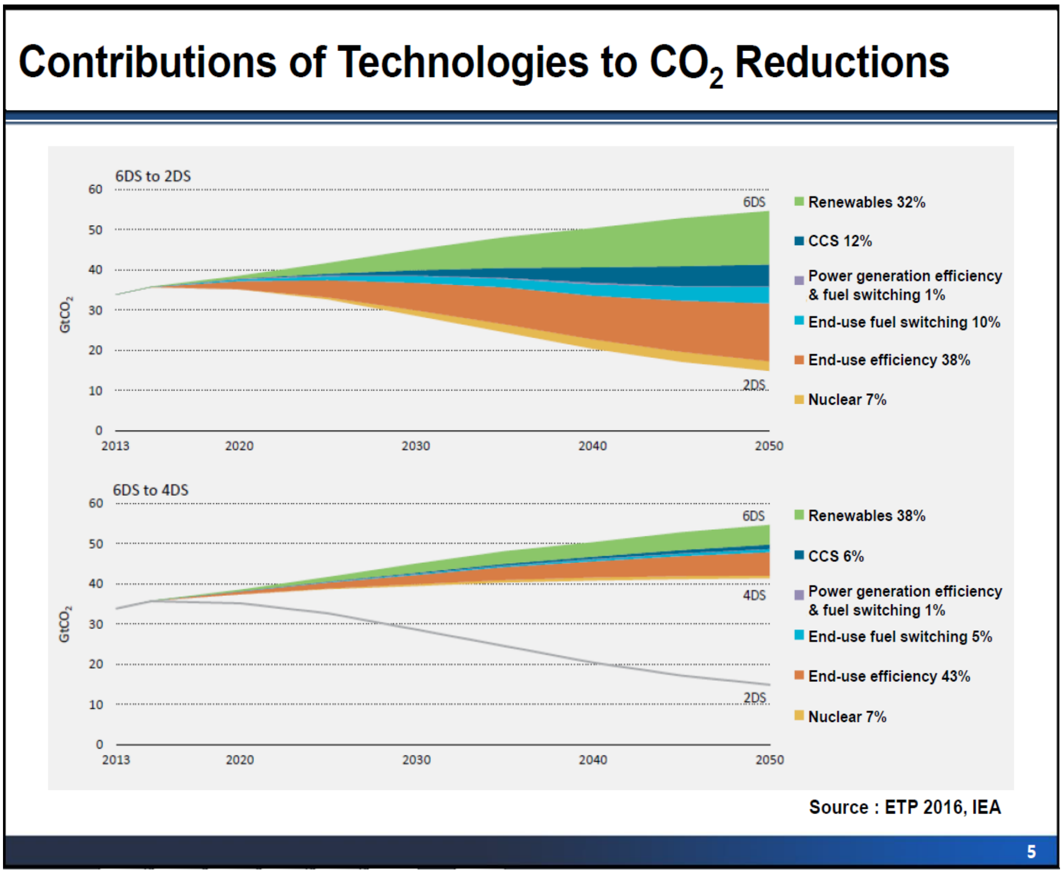


Figure 4. Contributions of Technologies to CO_2 reductions

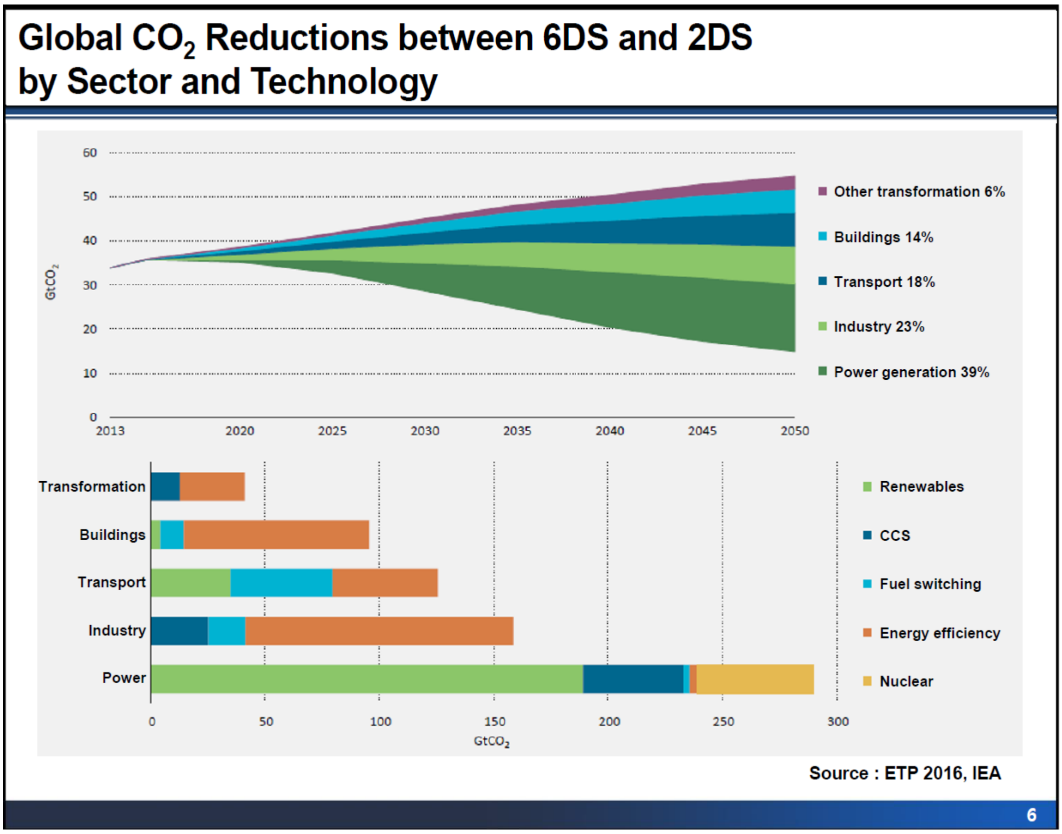


Figure 5. Global CO_2 Reductions between 6DS and 2DS by Sector and Technology

This is the energy flow from different energy resources such as renewable energy, fossil fuel, and nuclear energy to different sectors. Still, even for the 2°C Scenario, you could see that fossil fuel still possesses 40% of all. It means that you need the efficiency improvement with the traditional energy facility (Figure 6).

Technology Roadmap with Four Sectors: Power Generation, Industry, Transport, and Buildings

I tried to itemize all the possible issues which we must tackle, sector by sector, in the power generation. The coal and natural gas will still be the major energy resources for the power generation. When we are still using the coal and natural gas, we need to implement the Carbon Capture and Storage (CCS). Solar energy is trendy, but expensive. We are tackling the following: solar photovoltaic and solar thermal energies; wind; hydro, geothermal, and ocean energy; biomass; and nuclear. And, even in electricity systems, we need to improve the storage and transmissions (Figure 7).

The next sector is industry. The industries like iron and steel, cement, chemicals and petrochemicals, pulp and paper, and aluminum are responsible for making significant amount of CO_2. Thus, these sorts of techniques must be utilized in order to solve the CO_2 problems. Let me skip the details of those techniques (Figure 8).

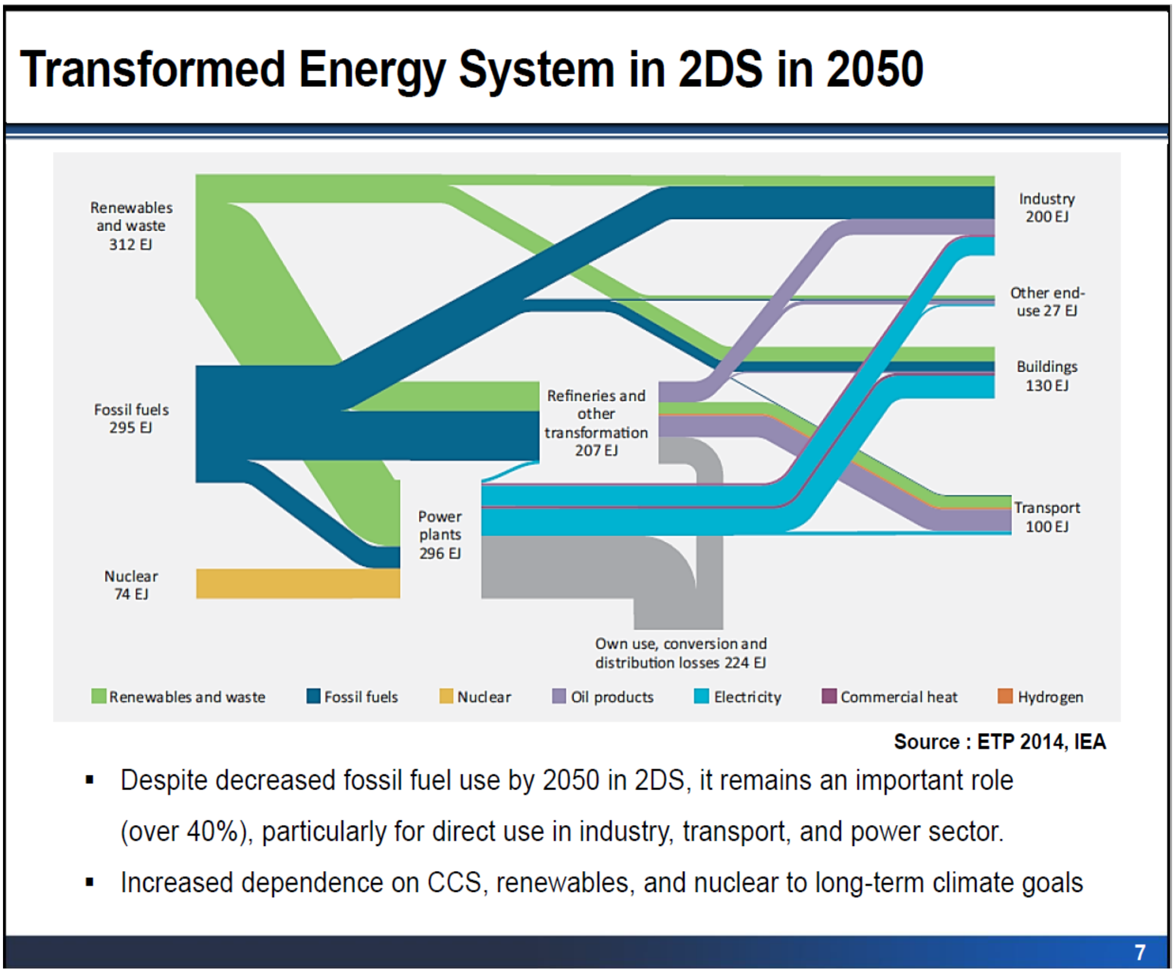


Figure 6. Transformed Energy System in 2DS in 2050

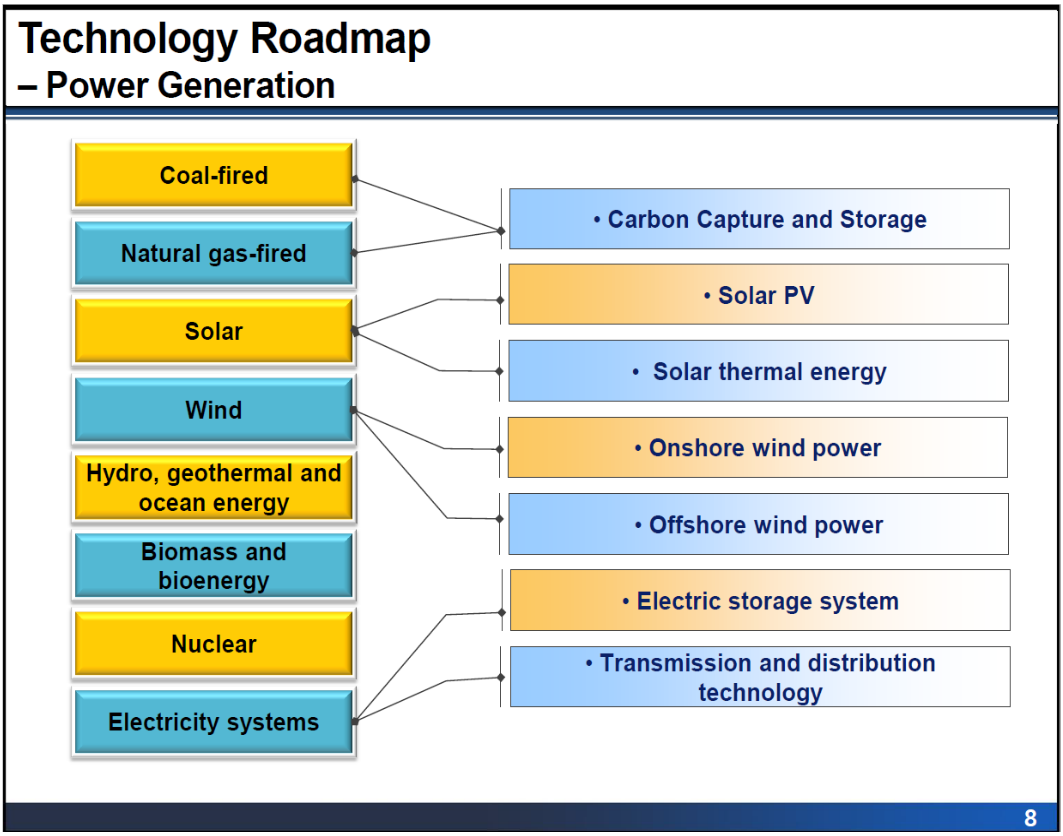


Figure 7. Technology Roadmap – Power Generation

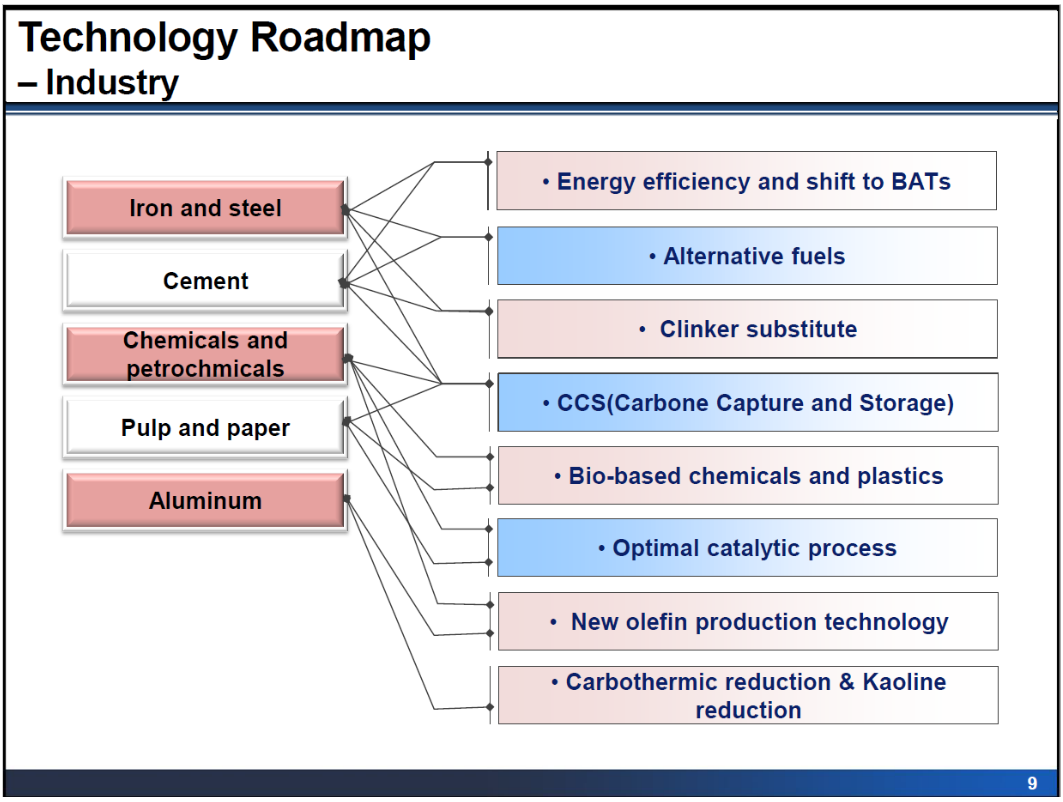


Figure 8. Technology Roadmap – Industry

And, another sector is transport. You may think of mostly light duty vehicles and passenger cars. While you must improve the efficiency of the traditional gasoline and diesel engines, you can also think of the innovative technologies such as plug-in hybrids, battery electrical vehicles, fuel cell electric vehicles. Also, the application of alternative fuel is an important item. And, in the commercial transport systems, you could think of intelligent transport and electrified infrastructures for a certain niche market and application of alternative fuel. And, modal shift is also very important. You need to shift the transportation mode, and the shipping needs the operational improvement. In the aviation, you have some limitations, but still, you could utilize some alternative fuels while you improve the efficiencies (Figure 9).

The last sector is buildings. For the buildings, you need to set up the new technologies for the envelope or the improved efficiency of insulation, heating, cooling, and water heating. And, lighting is also an important part to improve the energy efficiency. Now appliances, ventilation, etc. (Figure 10).

Investment, Energy Perspectives, and Strategies of Energy Technology Development

When you talk about this 2°C Scenario, the biggest problem is the economic burden. The Baseline Scenario or the 6°C Scenario still needs this huge amount of money for investment. 434 trillion dollars for 34 years is the routine investment. That's the basic. And to achieve this 2°C Scenario, we need additional 12.6 trillion dollars. Compared to original spending, 400 billion dollars some, it seems to be small, but that's 400 billion dollars every year. Additional investment at this economic situation looks almost impossible. So there is a big investment issue, and another thing is that, for this investment, transport takes around 80% of all even though the transport is emitting only 18% of CO_2. All the regulations and investment requirements are given to transport.

As a researcher in the vehicle technologies, especially power plant technologies, I always feel that it is really unfair that all the regulations, the push, and the financial burden are given only to the transport. For example, everybody is attacking the diesel engine. The diesel engine is producing only a single digit of dust or particles, but everybody is trying to kill diesel. The only reason for this is that all the other sectors like industry, buildings, and power are not easy to touch. But, transport is completely commercialized, so you can push this industry. It's unfair, but that's the reality (Figure 11).

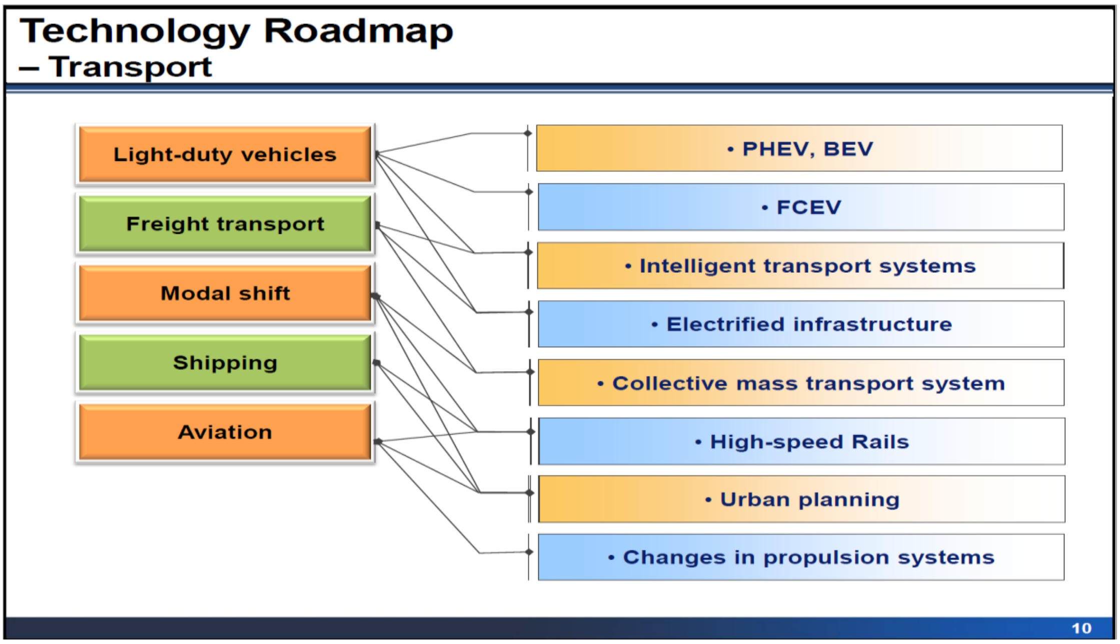


Figure 9. Technology Roadmap – Transport

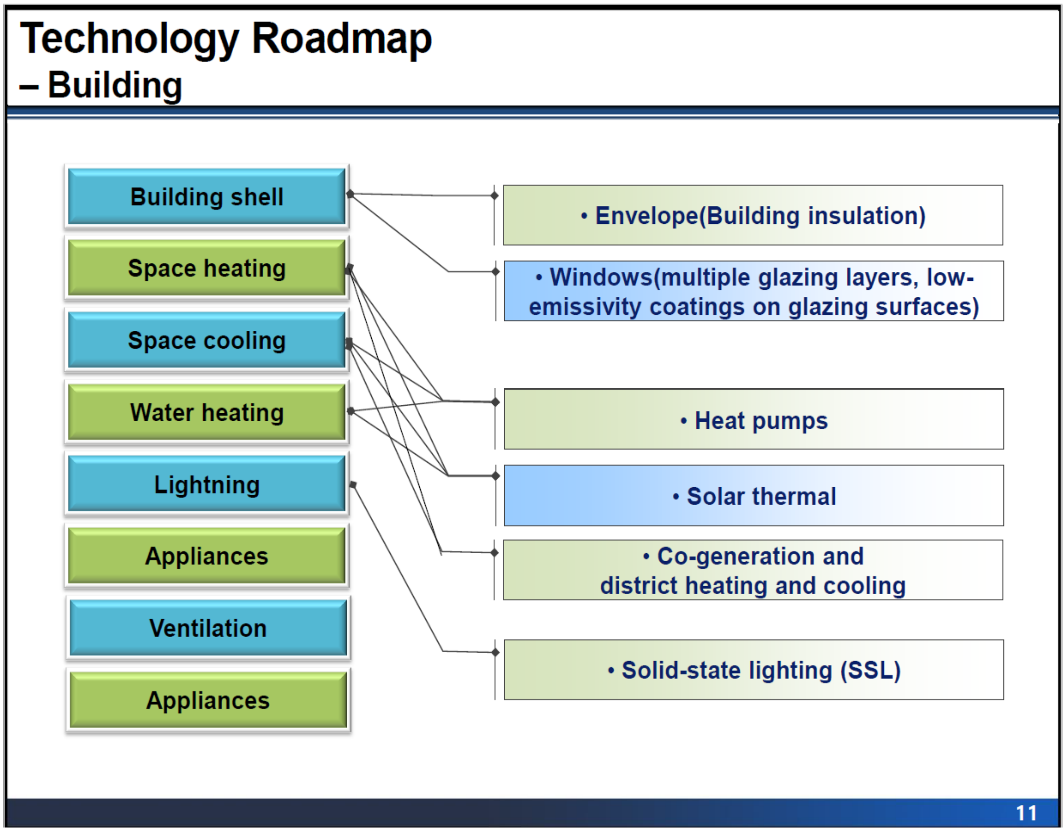


Figure 10. Technology Roadmap - Building

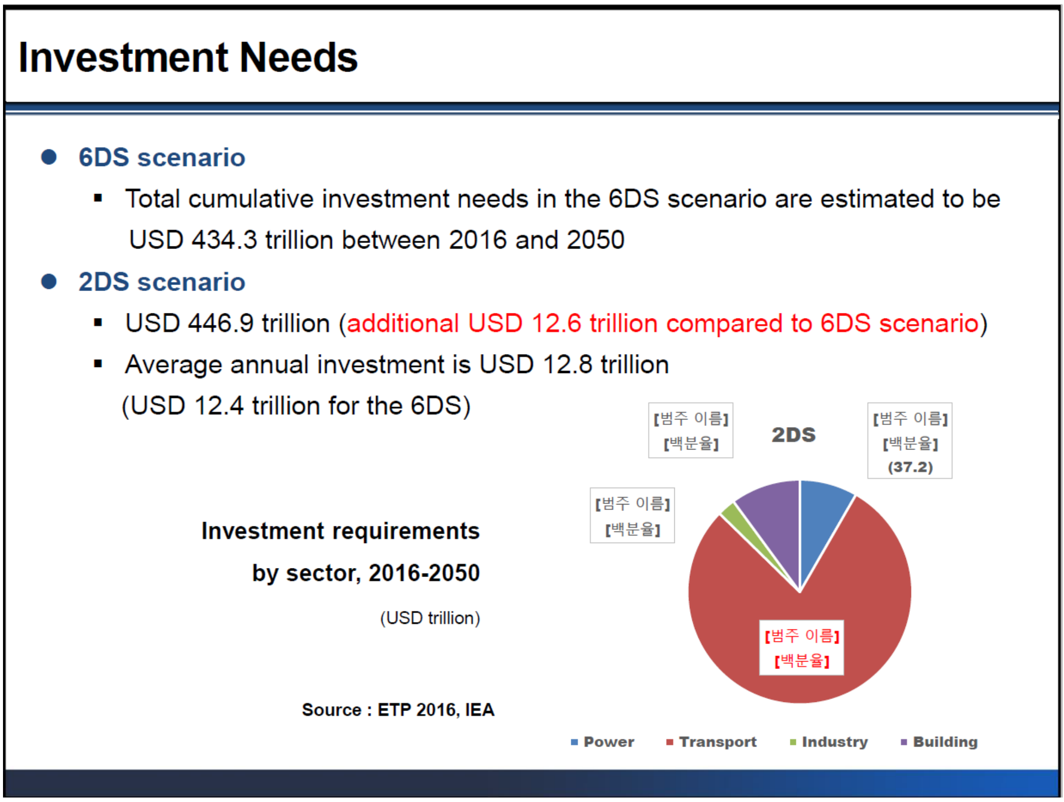


Figure 11. Investment Needs

Even though we are talking about the renewable energy, sustainability, and so on, we still have lots of fossil fuel supply. Until 2040, it is expected to have a quite stable supply of petroleum, coal, nuclear, and especially, natural gas. Actually, this was given last year, but still, they think of changing this value drastically because the shale gas supply is now demolishing the traditional energy resource market (Figure 12).

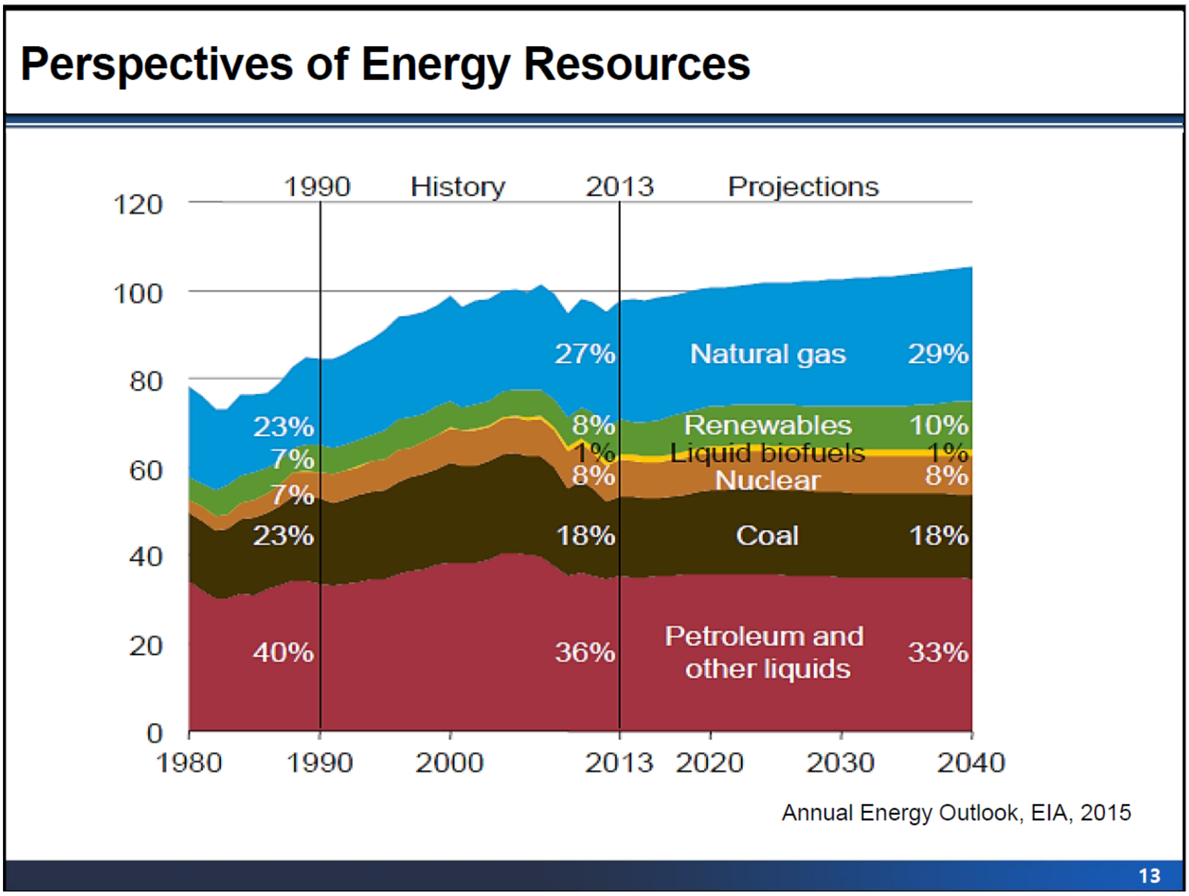


Figure 12. Perspectives of Energy Resources

This is actually the major part I would like to say. When you consider the optional energy technologies or the sustainable energy system, we must think of these four factors: energy security, economic viability, environment, and technical feasibility. Nothing is more important than the others. Sometimes you could give some priority to some options. For example, in Brazil, most cars are run by alcohol because they have lots of sugar cane. In Korea, all the taxicabs are run by LPG because Korea is very keen at the energy security, so we need to diversify the energy supplies. So taxicabs are run by LPG. Buses are run by natural gas, and the home appliances such as stove are run by the natural gas. And electricity is mostly given by the coal. Of course, we have 20% of gas and nuclear 30%. So, we need the balance among different energy technologies. So region by region, time by time, you have a different strategy, but you must think of the balance between these four considerations. That's what determines the local sustainable energy system policy. I feel obliged to be short of time because I found out that the program says I have only 20 minutes followed by coffee time. I will fly over some remaining pages (Figure 13).

Case of Transportation

Let me give some examples. The first one is transportation because in this scenario, transportation is the biggest part you need to invest in and you need to develop the innovative technologies. Among lots of options in the propulsion system for the car, the conventional internal combustion engines, gasoline, and diesel, have been dominating the market by more than 95%. But, all the people are talking about the battery electrical vehicles, fuel cells, and the hybrid electrical vehicles, and it seems to be shifting the technology from here to there tomorrow (Figure 14).

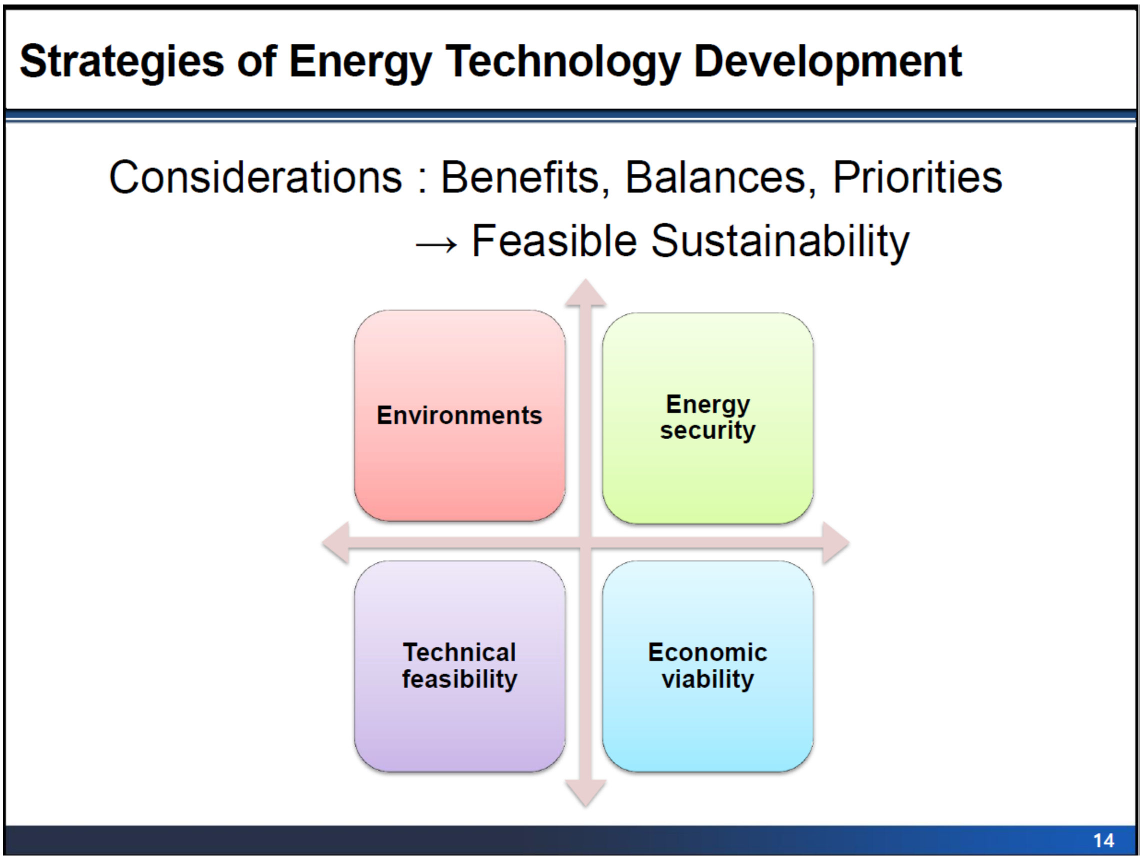


Figure 13. Strategies of Energy Technology Development

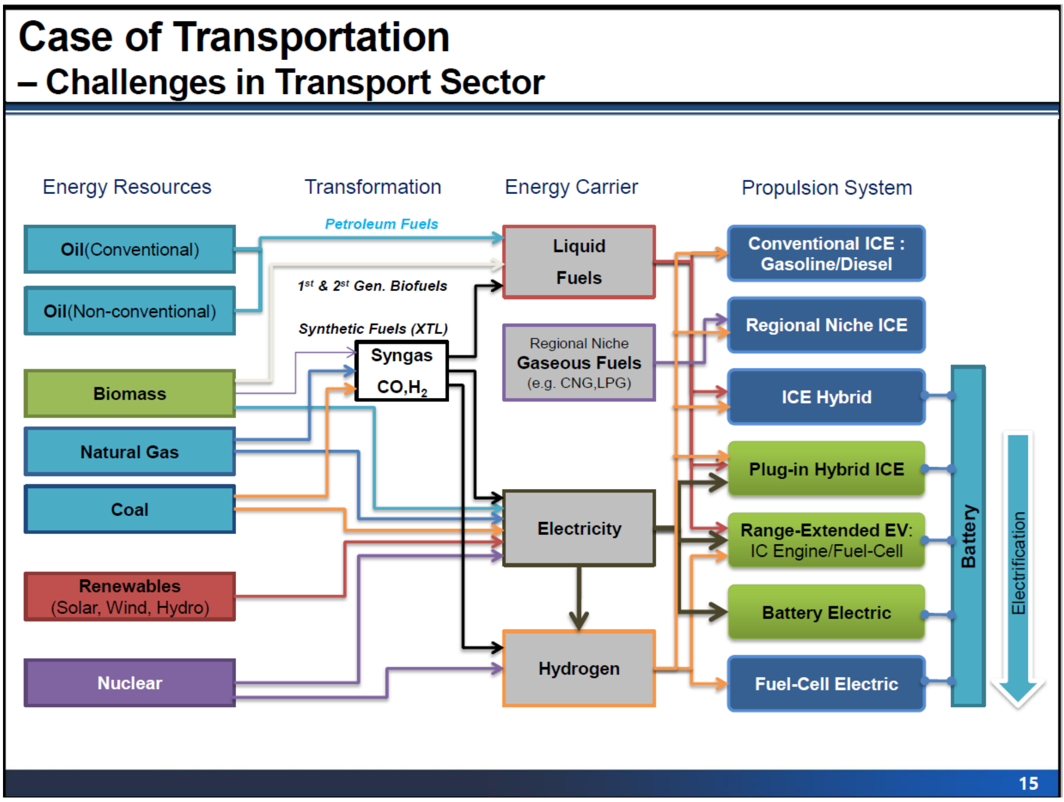


Figure 14. Case of Transportation – Challenges in the Transport Sector

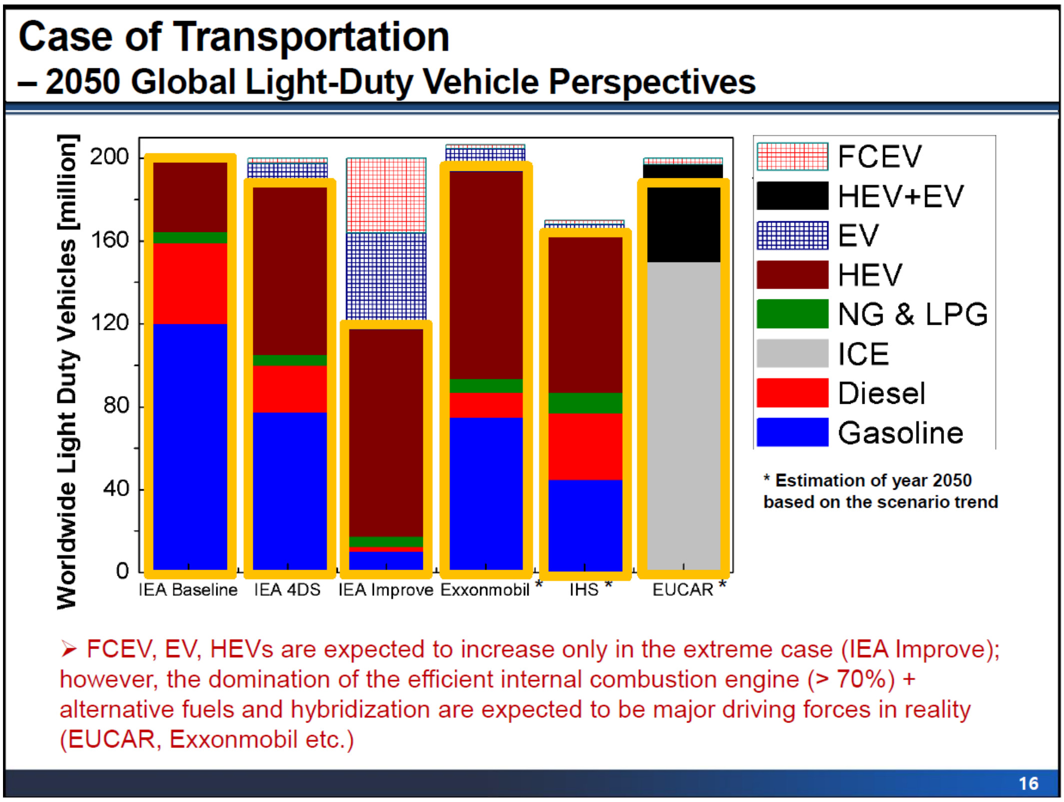


Figure 15. Case of Transportation – 2050 Global Light-Duty Vehicle Perspectives

But practically, it is not like that. This is the collection of the predictions of these car markets. This is the IEA Baseline or 6DS Scenario, 4DS, and improvements for 4DS, improved with modal shifting and avoiding strategy included. So that's the most innovative and drastic change in 2050. Still, you have gasoline vehicles and diesel vehicles. And, you have lots of hybrid electrical vehicles but still, those are run by gasoline or diesel. And, you have this amount of electrical vehicles and fuel cell electrical vehicles. Assuming you solve the problem of the economic viability of batteries and the hydrogen production, that's the basic prediction. And, these are predictions from ExxonMobil and the European Project and IEHS in the States. Here you could see that these yellow boxes are based on the conventional gasoline and diesel engines. So even in 2050, the cars are still run by gasoline and diesel (Figures 15 and 16).

Don't expect that all the cars will be shifted to battery electrical vehicles or fuel cell vehicles. It is impossible. It is impossible because of technical maturity, economic viability, energy security, and even environmental issues. The people think that this electrical vehicle is very clean. No, because in Korea, the electricity is made from 65% of fossil fuels. And, the energy efficiency to transform that to the battery is very low. It is worse in Germany. It is worse in the east part of the States. So, we need to make a balance among the options of energy supply (Figures 17 and 18).

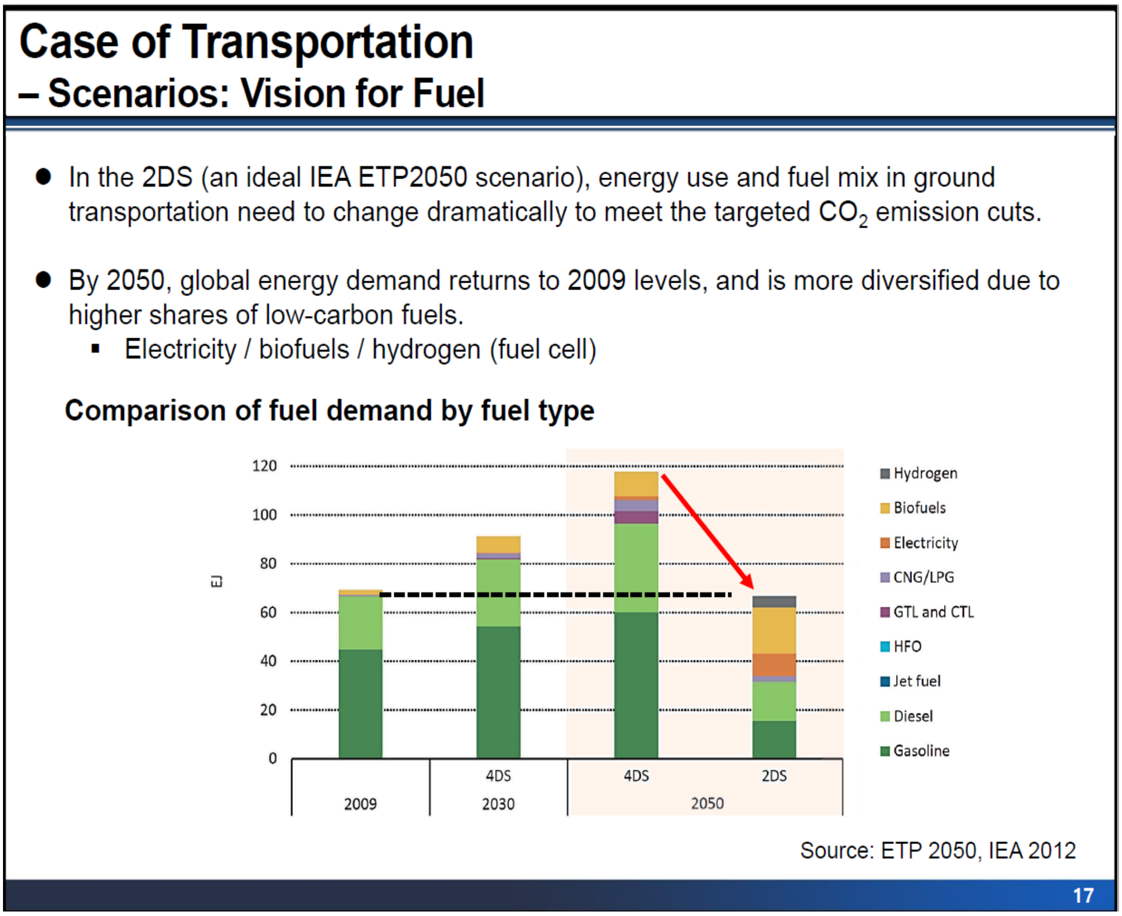


Figure 16. Case of Transportation – Scenarios: Vision for Fuel

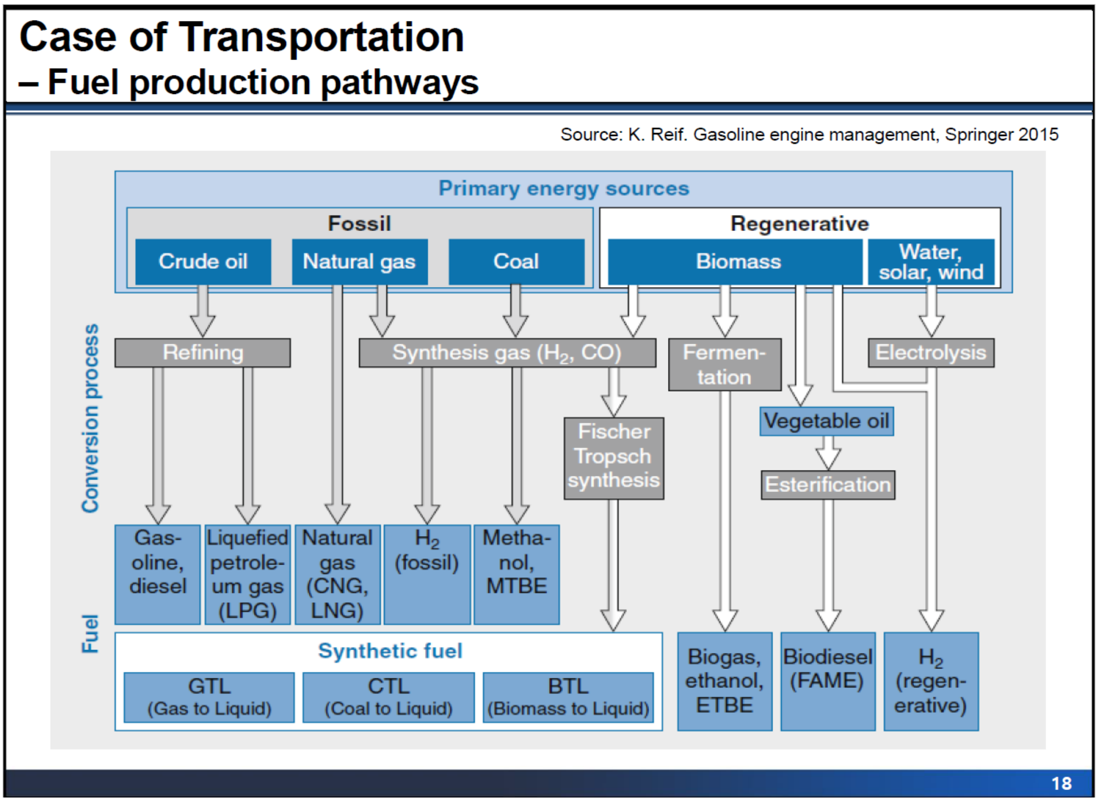


Figure 17. Case of Transportation – Fuel production pathways

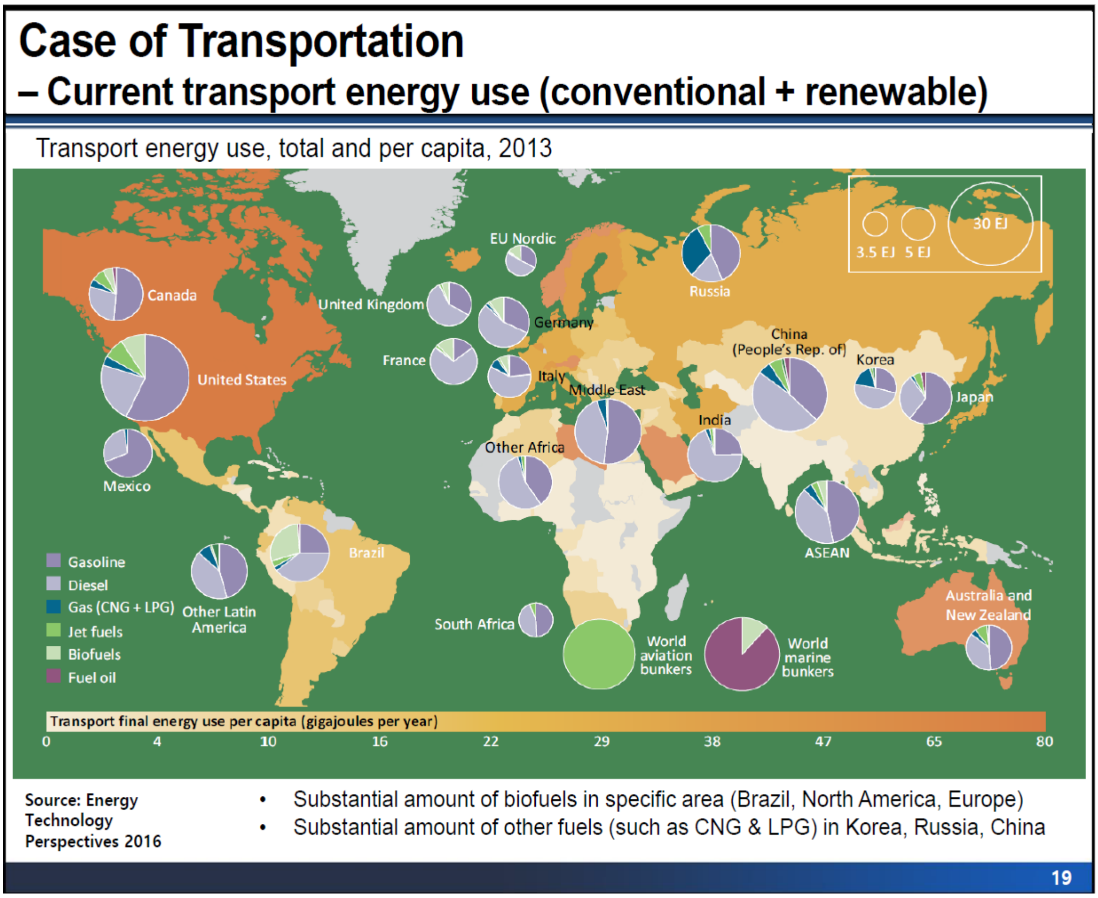


Figure 18. Case of Transportation – Current transport energy use (conventional + renewable)

Efforts of the Mechanical Engineering Faculty in KAIST

Let me give you some examples in my department. What kinds of things we are working on for energy (new energy) technologies (Figure 19)?

This is my work. When we apply this biodiesel, the combustion is better in that it reduces the biggest trouble – particulate matter, carbon monoxide, and hydrocarbon – while you may increase some nitrogen oxide (which could be dealt with by the EGR application or SCR). And, we have tried to utilize the DME (the dimethyl ether having oxygen in the fuel). You could see the difference in the combustion phenomena in that it is producing lots of carbon radiation while it is well mixed with a less amount of soot production (Figures 20 - 22).

One of my colleagues is working on fuel cells, not one of, some tens of people are working on fuel cells in mechanical engineering, chemical engineering, material engineering, and electronic, and electrical engineering. One of my colleagues in mechanical engineering is working on solid oxide fuel cells for the resilient power unit. This is reforming even diesel (Figure 23).

And, another example is all the polymer solar cell development. This is making quite good strength, ductility, and flexibility with fewer cracks. And, this has a very good conductance and is very flexible, so you could use this kind of thing as a wearable device (Figures 24 and 25).

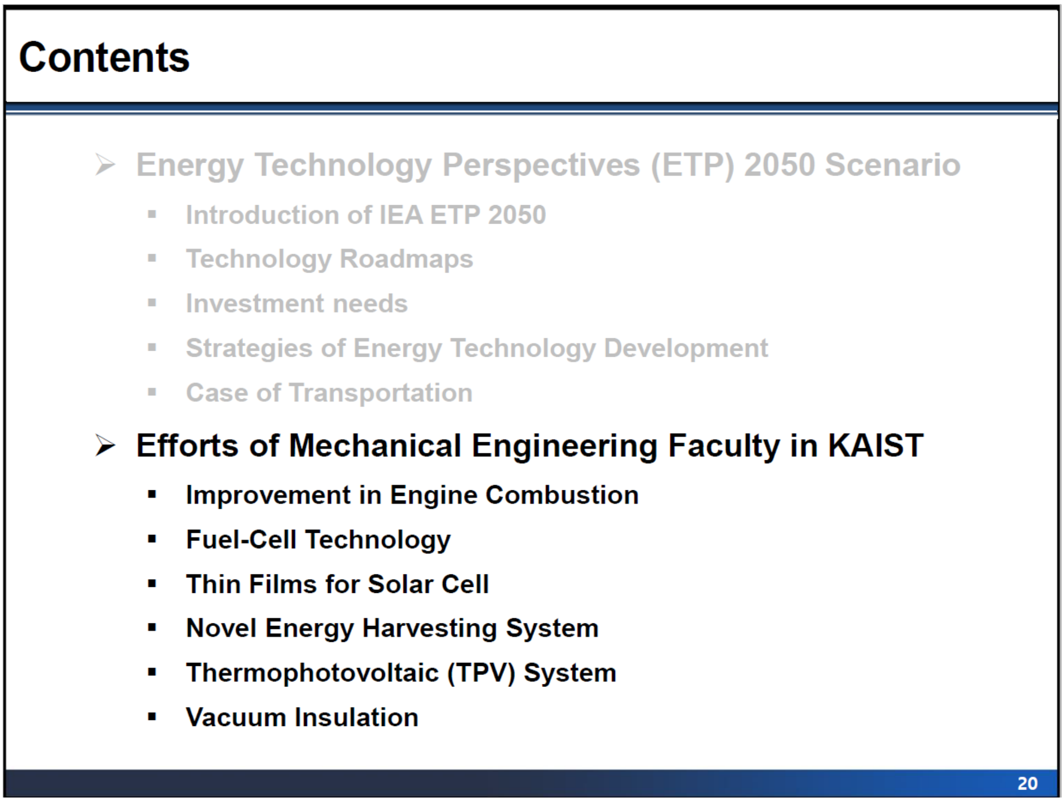


Figure 19. Efforts of Mechanical Engineering Faculty in KAIST

Improvement in Engine Combustion – Biodiesel; Direct Combustion Images

Engineering for Value Creation

Prof. Choongsik Bae

T_{inj} = -5 CAD ATDC, pinj = 80 MPa

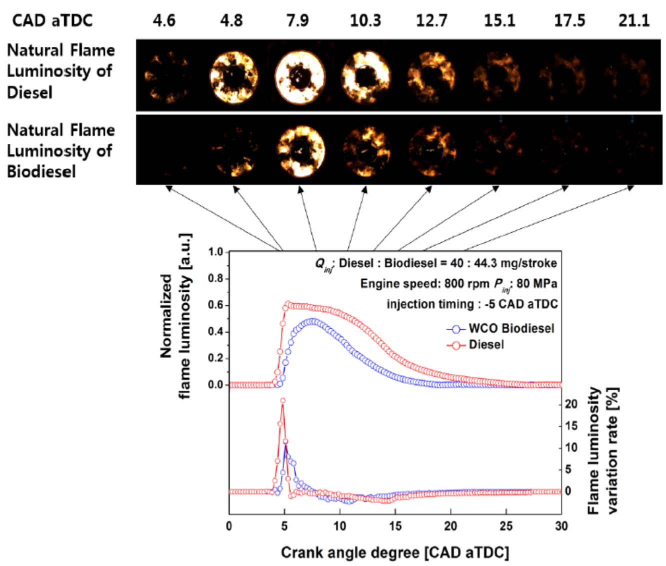


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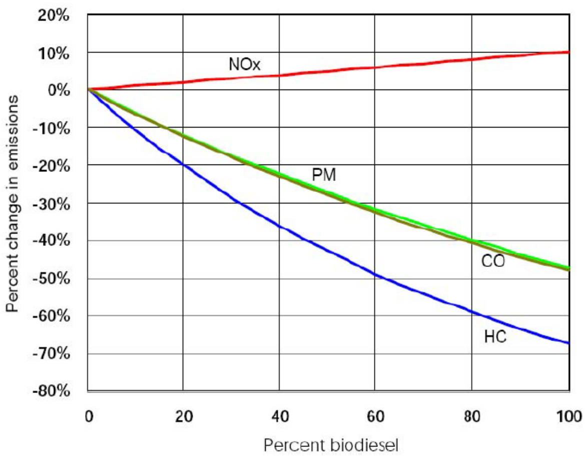
Figure 20. Improvement in Engine Combustion – Biodiesel: Direct Combustion Images

Biodiesel – Direct combustion images

Average emission impacts of biodiesel fuels in compression ignition engines



- It is generally accepted that, the use of oxygenated fuel such as biodiesel yields reduction of PM, CO, and HC emission due to the presence of oxygen atom.
- However, the NOx emission tends to increase.

Source: United States Environmental Protection Agency (EPA), Comprehensive analysis of biodiesel impacts on exhaust emissions, (2002) EPA420-02-001.

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Figure 21. Biodiesel – Direct combustion images

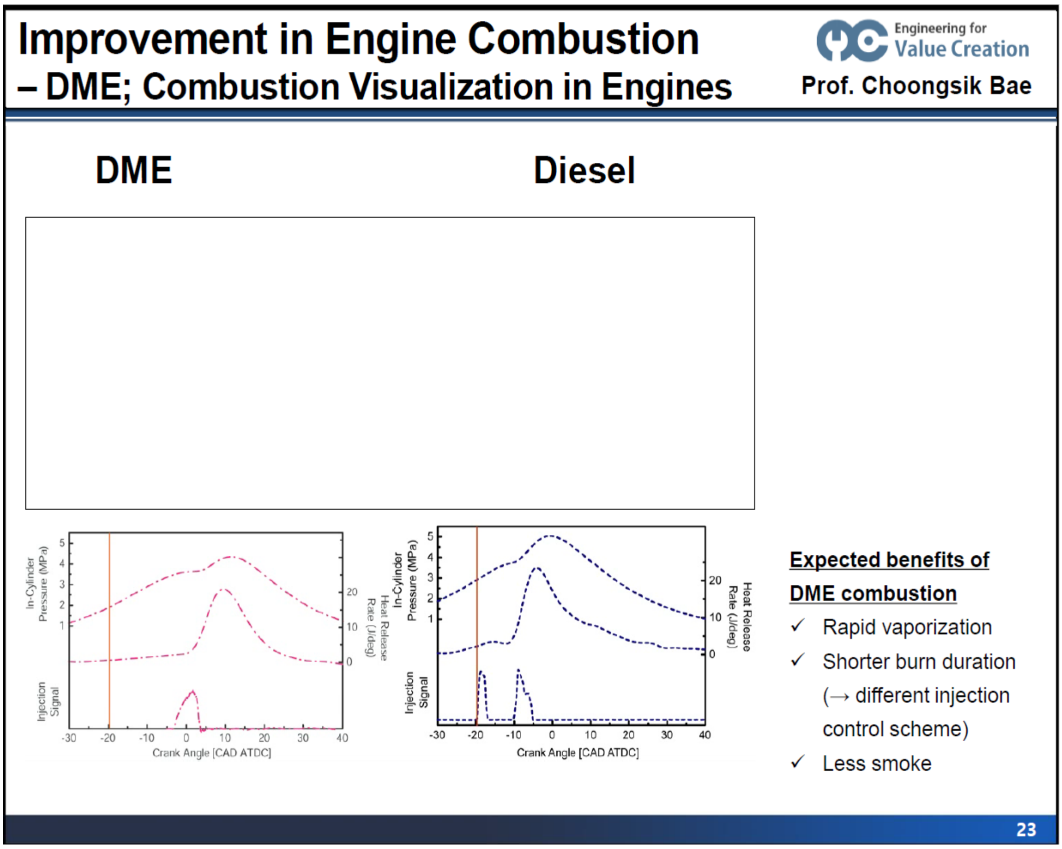

Figure 22. Improvement in Engine Combustion – DME; Combustion Visualization in Engines

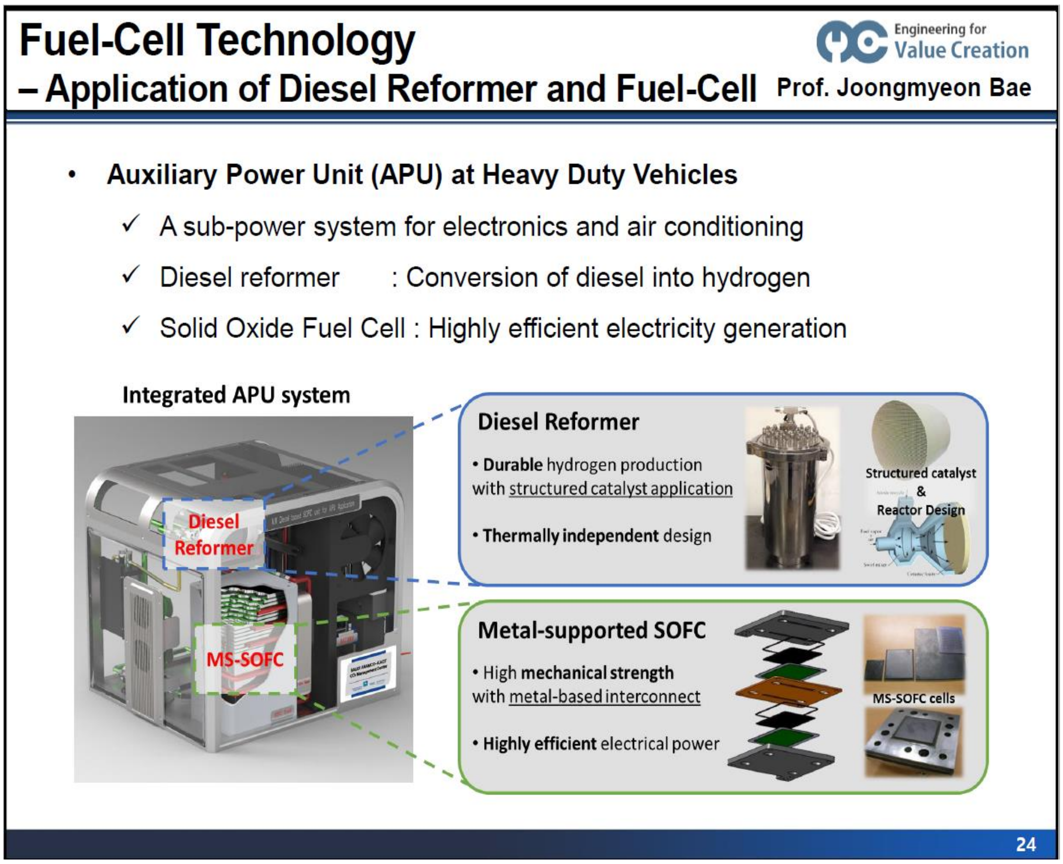

Figure 23. Fuel-Cell Technology – Application of Diesel Reformer and Fuel-Cell

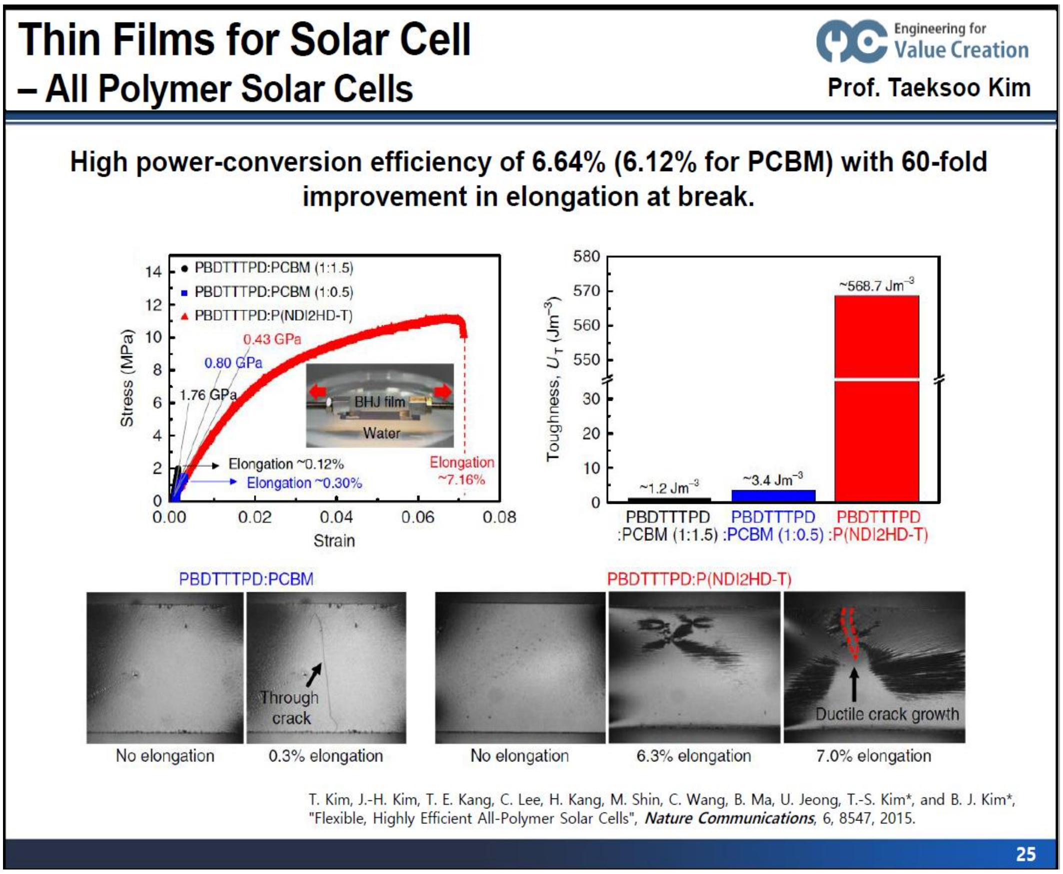

Figure 24. Thin Films for Solar Cell – All Polymer Solar Cells (1)

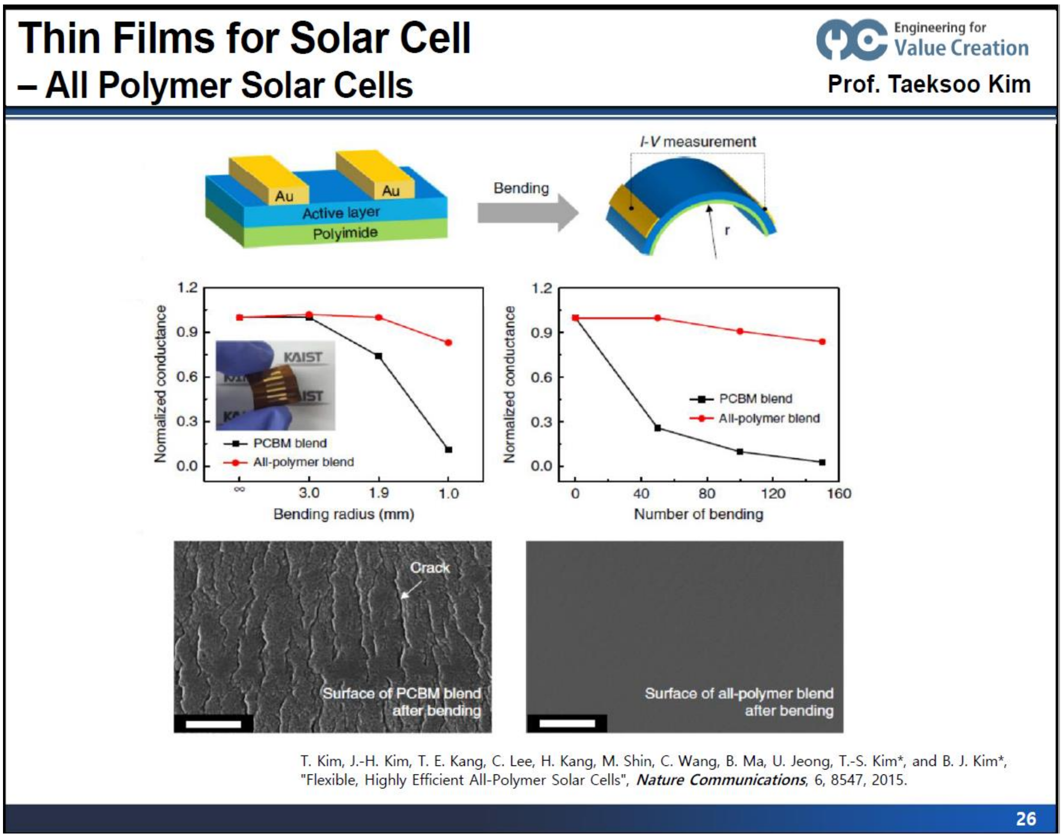

Figure 25. Thin Films for Solar Cell – All Polymer Solar Cells (2)

And, another staff is working on the energy harvesting. This is an example. You could see the membrane and this flutter. There, if you put the piezoelectric patch, which can generate electricity, this is refined energy harvesting. But still, it is very expensive, and technical maturity has ways to go for a long time (Figures 26 and 27).

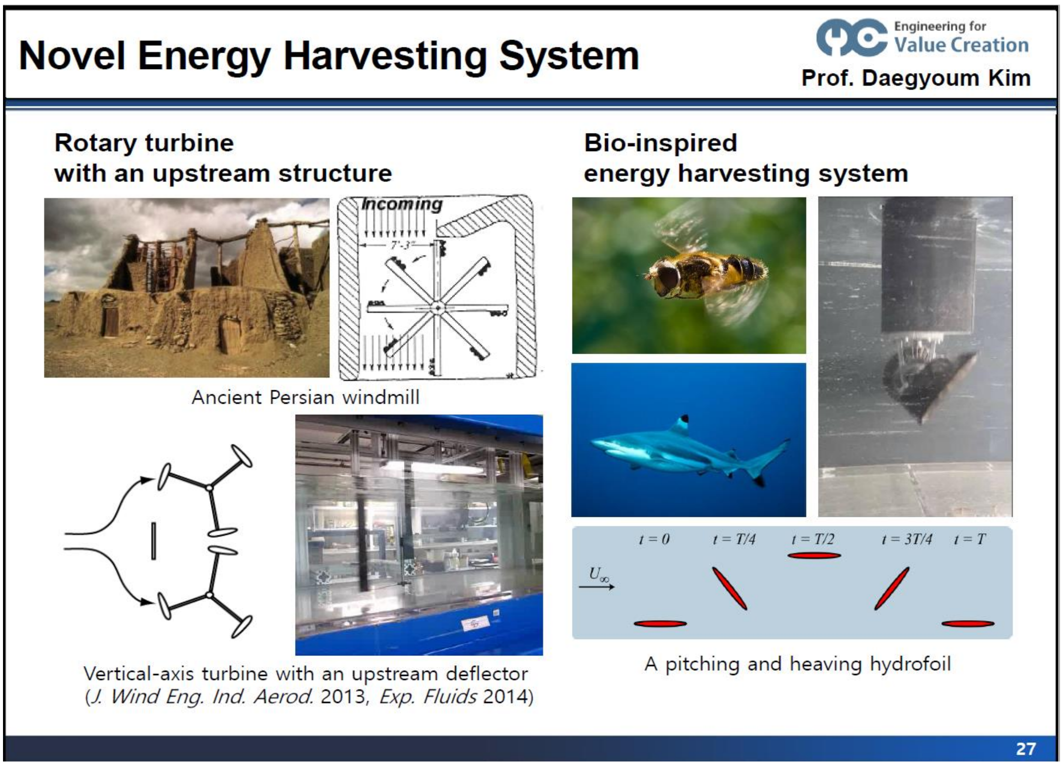

Figure 26. Novel Energy Harvesting System (1)

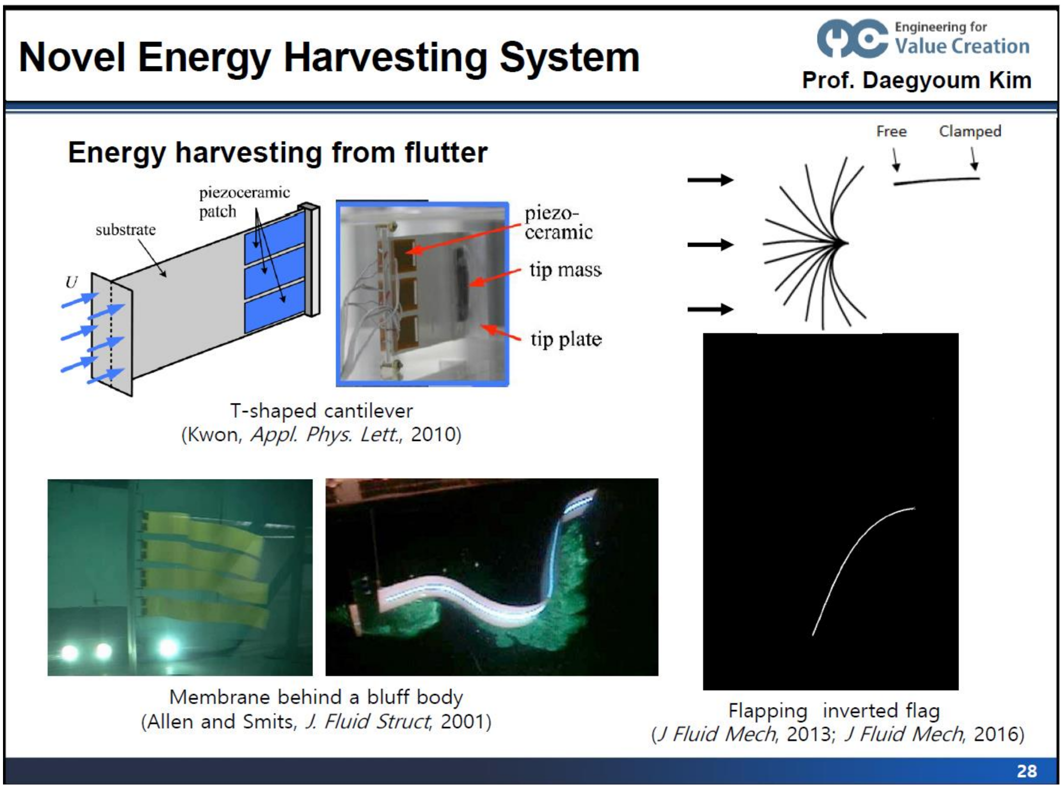

Figure 27. Novel Energy Harvesting System (2)

And this is an example of a graphene-assisted near-field thermo-photovoltaic system, which is regenerating the wasted heat in the energy systems (Figures 28 and 29).

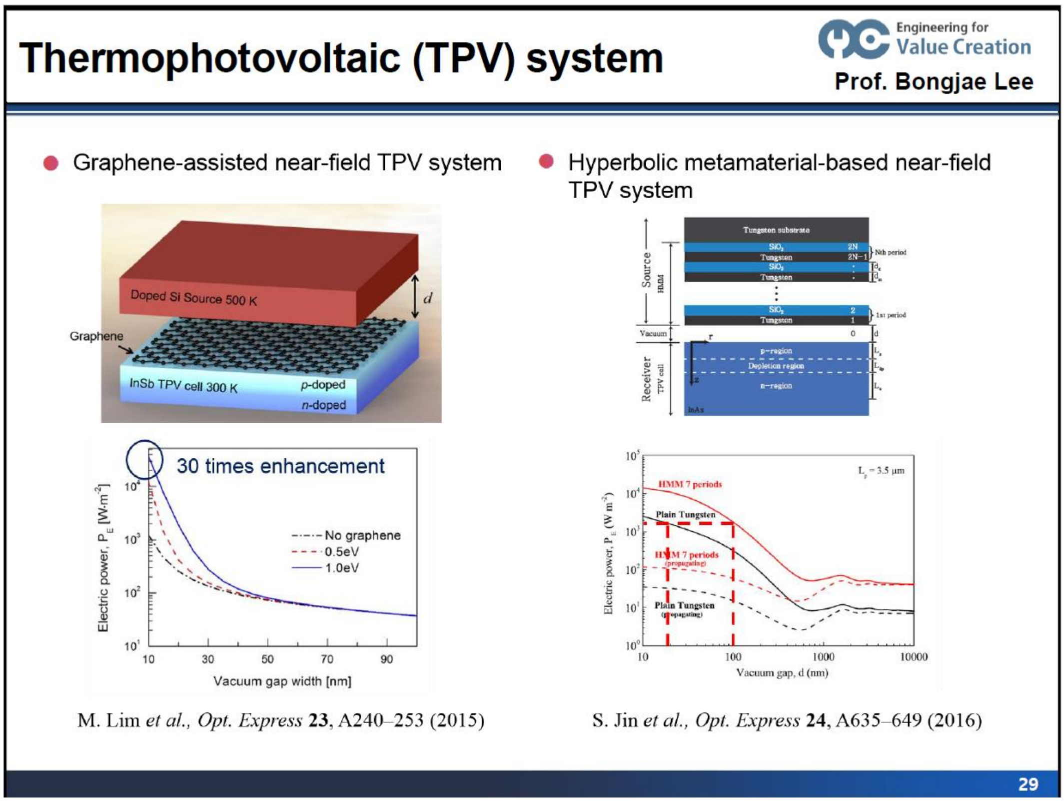

Figure 28. Thermo-photovoltaic (TPV) system (1)

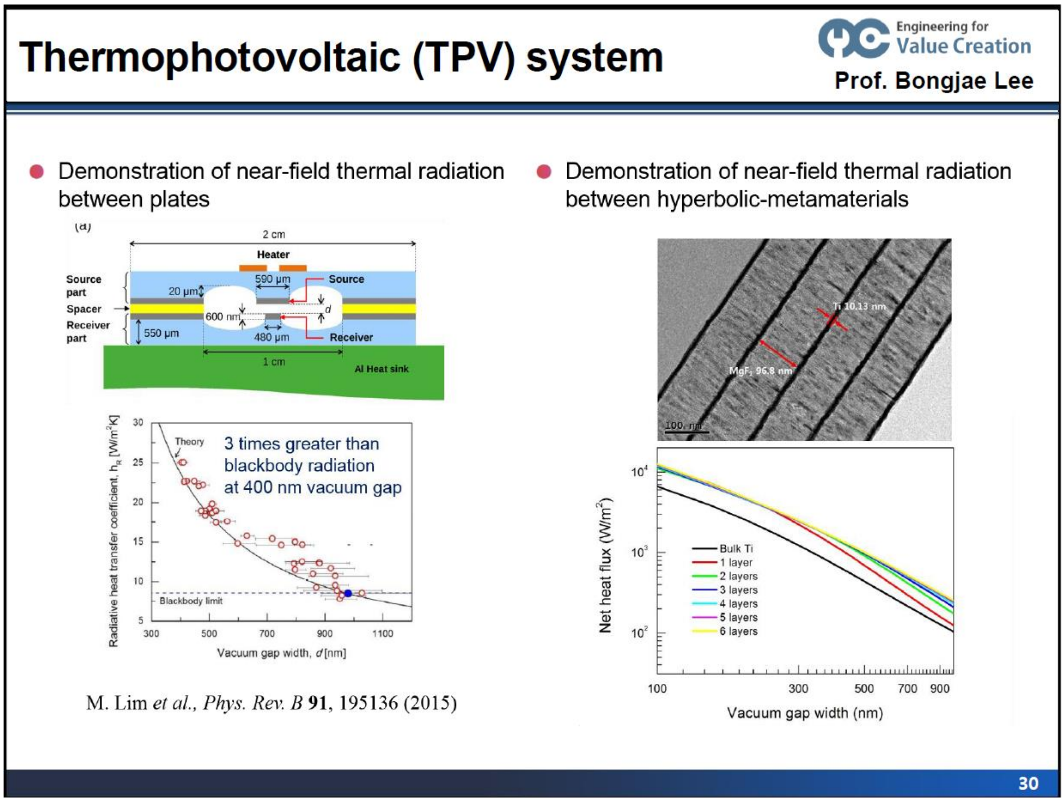

Figure 29. Thermo-photovoltaic (TPV) system (2)

And, one senior staff is also working on the insulation. He developed a very good vacuum insulation system which can reduce the energy loss. So, he showed a vision of the 70% of energy saving with less than 10% of thickness in buildings. This is applied to refrigerators and LNG tankers, parts of automotive systems, and all the other small systems as well (Figure 30).

He achieved this much of a heat transfer coefficient: almost nothing. His graduates are making the companies to sell this insulation material and systems (Figure 31).

Summary and Conclusion

Let me summarize my talk even though my message is very simple. Looking at the three scenarios from the International Energy Agency for 2050, we could see that the 6°C Scenario is realistic although it has this appalling number 6. For 2050, this ambitious 2°C Scenario is still very idealistic, and it needs a lot of investment.

Whenever we think about the energy systems, we must make the balance among these four considerations: environment, energy security, technical feasibility, and economic viability. And for us, for the scientists, we still need the mix of conventional and economically viable energy systems and innovative renewable energy systems. And, we need R&D to break this bottleneck of the sustainable and real energy systems in the long term (Figure 32).

That's it for me. Thank you very much (Figure 33).

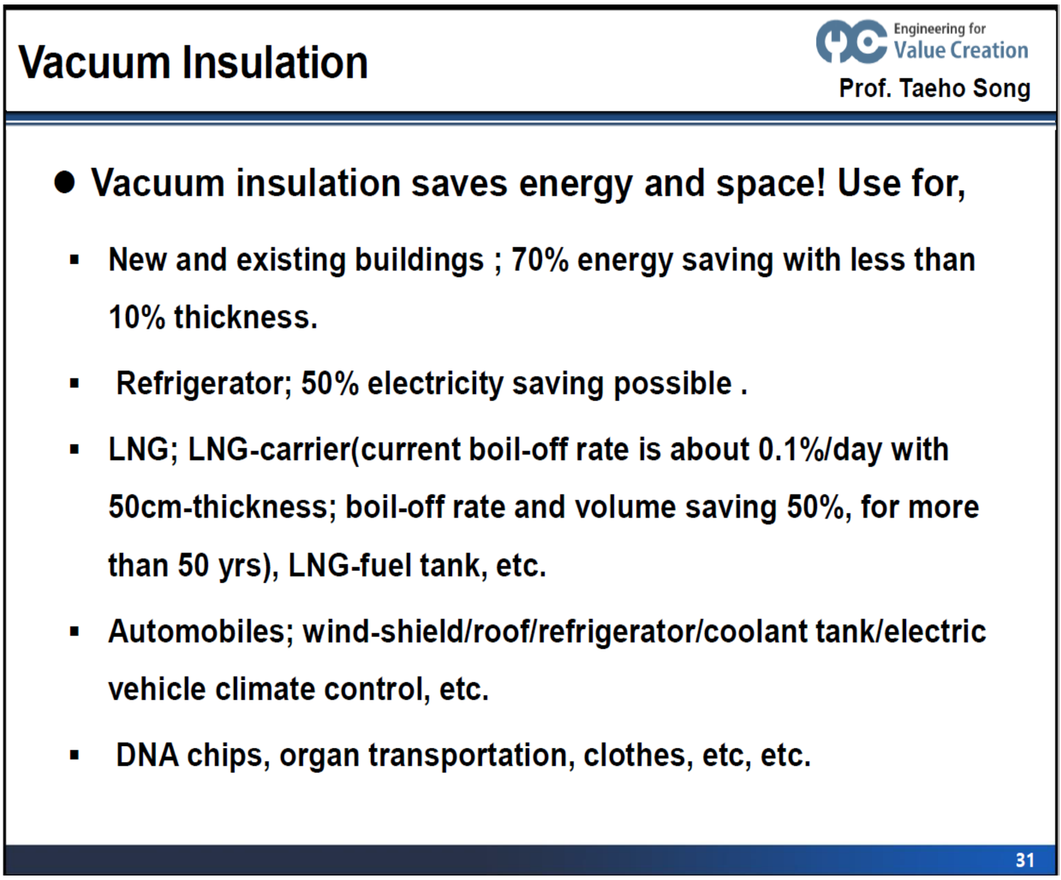

Figure 30. Vacuum Insulation (1)

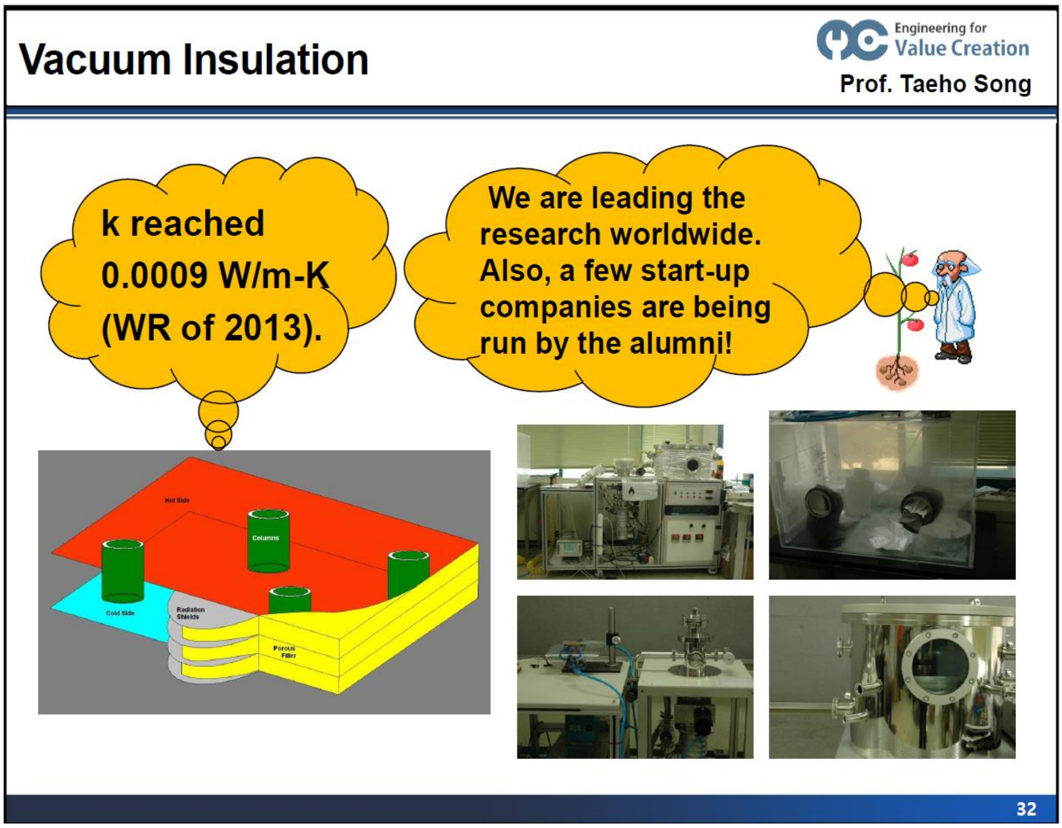

Figure 31. Vacuum Insulation (2)

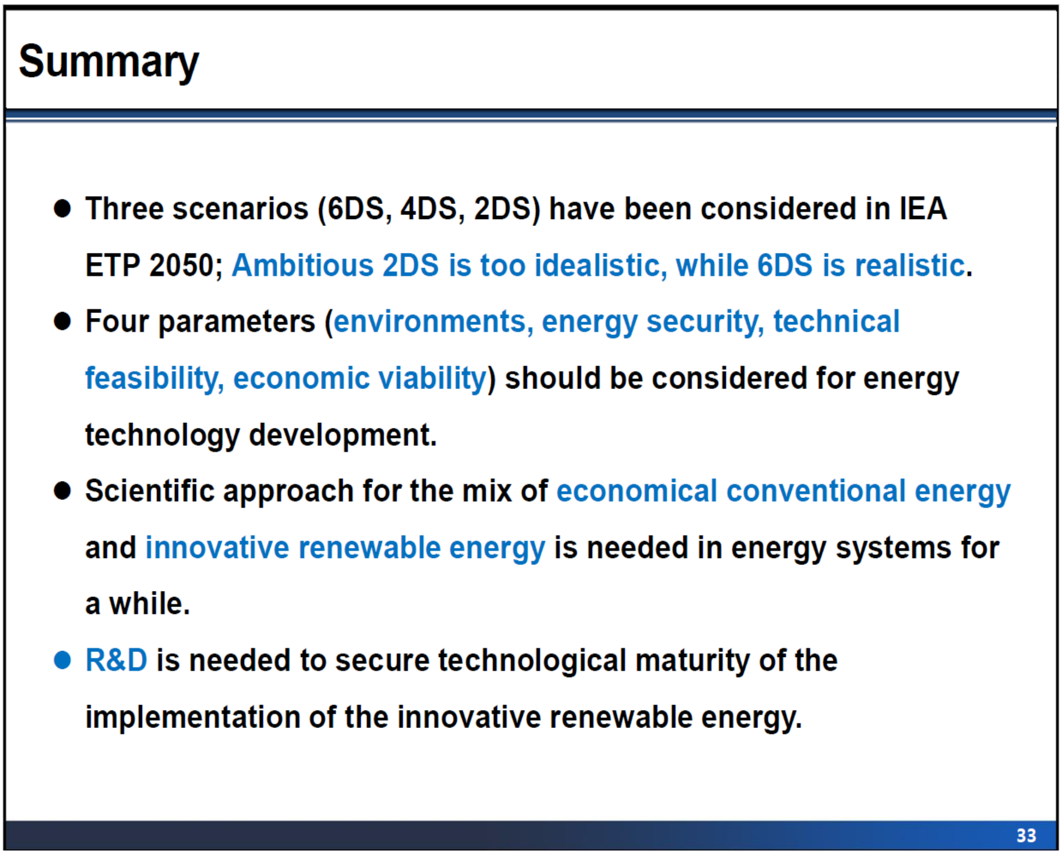

Figure 32. Summary of the presentation

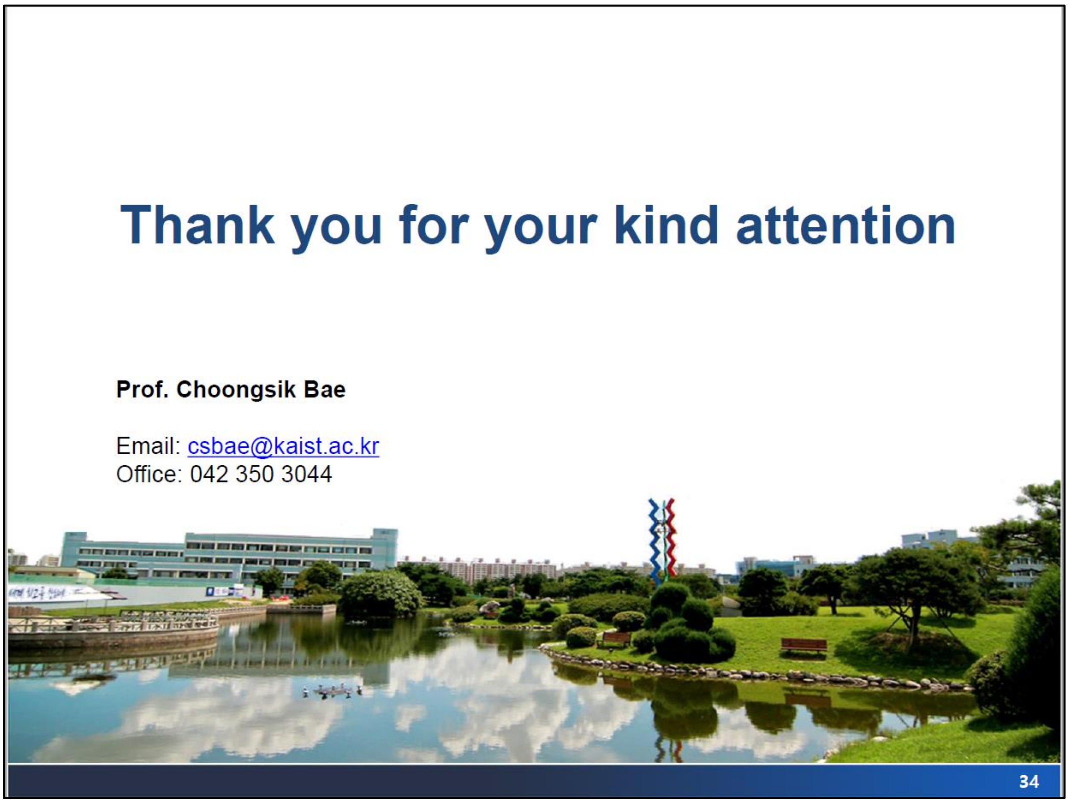

Figure 33. Thank you

Session 3

National Initiatives for SMEs

Korean SME Policy Innovation for Creative Economy
Dr. Young-Sup Joo

KIMM for Creative Economy
Dr. Yong-Taek Im

Korean SME Policy Innovation for Creative Economy

Dr. Young-Sup Joo
SME Minister
Small and Medium Business Administration Korea

Good afternoon, everyone. My name is Young-Sup Joo. Thank you for a very nice introduction of my background. Actually, I am really pleased and privileged to have a wonderful opportunity to present Korean SME policy innovation for the Korean economy, which the Korean government has been strongly driving for more than three years as one of the Korean key economic development initiatives.

Introduction

Today, I am going to cover this topic by introducing briefly the Korean situation, especially related to the change of the national growth strategy, and then followed by the current status of Korean SMEs. Actually, small and medium enterprise has many meanings. The definition is different country by country. Actually, the Korean definition is a little bit, much larger than most of the foreign countries. I am going to elaborate more about that later. And then I will briefly cover our current attempt to innovate the SME policies and cover briefly new SME policies for the increasing and expanding exports and the innovative R&D, research and development, for Korean government research R&D programs. And also, I will cover the startup policies (Figure 1).

Figure 1. Contents

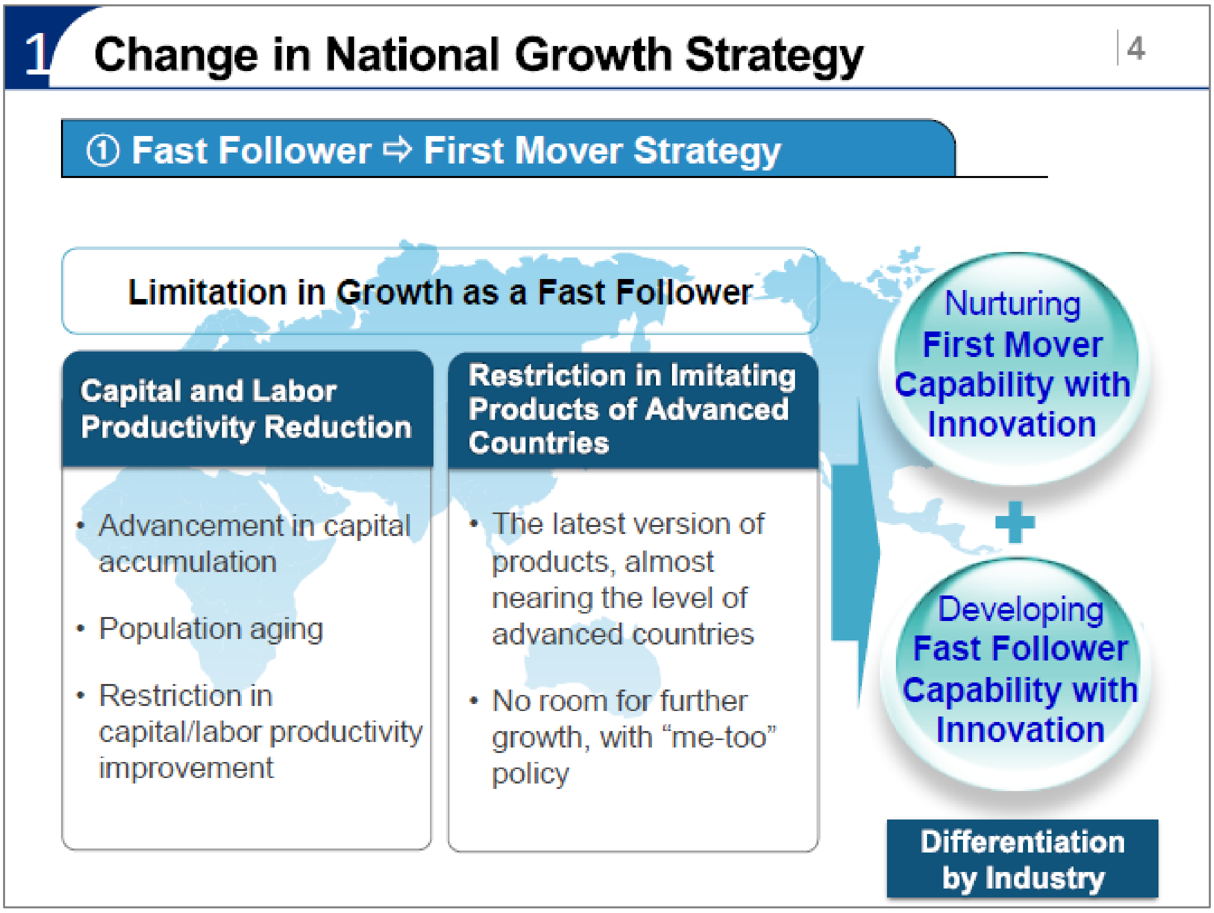

Figure 2. Change in National Growth Strategy: Fast Follower to First Mover

Change in National Growth Strategy

First, Korea has been making a phenomenal development and growth. For the past 50 years, actually, Korea is the only country which has developed from the economic aid recipient to economic aid donor. So, actually, one of the critical, most effective contributors for this kind of growth has been the so-called "fast follower" strategy. So Korean industry has developed and achieved a kind of top tier, global top tier position in many industries by the means of the fast follower strategy so far. But as of today, this fast follower strategy will not work as effectively as before. So, nowadays, it's time to change Korean strategy from the fast follower to the so-called "first mover" strategy. But, I don't think it can apply to all of the Korean industry. I'd like to say that in the industries where Korean companies are doing well, actually, we need to go for the first mover strategy in the coming years. But still, in many industries where Korean companies have not yet reached the global top tier, still the fast follower strategy will be very effective for the time being. In other words, the Korean government and Korean companies need to combine the first mover strategy and the fast follower strategy together (Figure 2).

Figure 3. Creative Economy and 4th Industrial Revolution_1

And as I briefly commented in the beginning of this presentation, the Korean government has been driving the so-called "Creative Economy" for three and a half years. And as the Korean government's core industry economic development initiative, that is to create new, basically, more high quality jobs. So, actually, by means of the creating new growth engines and value added through convergence of the industry by industry and the convergence of industry by culture using science and technology and the information communication technology based on creativity. That is the kind of definition of Korean creative economy. Actually, as all of you know, earlier this year, January this year, the World Economic Forum announced the so-called "4th Industrial Revolution" in Davos. Actually, simply speaking, the 4th Industrial Revolution is a kind of the convergence of three worlds: the cyber world, physical world, and bio world. So actually, its literal meaning is the industrial revolution driven by the convergence of digital devices, humans, and the physical environment. But as I speak to you, how to combine, how to converge the physical, cyber, and bio worlds is the key concept of the 4th Industrial Revolution. Actually, this 4th Industrial Revolution is completely in line with the Creative Economy. So, that's why the Korean Creative Economy has been acclaimed by G20 meetings and many countries as one of the most innovative government policies as of today (Figure 3).

Figure 4. Creative Economy and 4th Industrial Revolution_2

Korea has been developing more detailed development models for a Korean style of Creative Economy which fits the Korean environment. Actually, the most important is the convergence of core industries and ICT (Information and Communications Technologies). So, it is aimed at upgrading the core industries. Many manufacturing industries are in Korea. So, actually, manufacturing industry is a kind of backbone and cornerstone of Korean core industries. So how to upgrade Korean core industries by means of ICT convergence is the key issue of the Korean government and Korean industry.

And the second model is based on the product-servitization. So, actually, based upon the excellence in the manufacturing industry, we need to develop a new service industry out of the servitization of the manufacturing industry. So that product-servitization is one of the most widely acclaimed business models with innovation in global industry as of today. So model 2 has also become very important at this point.

And the third model is to develop a new creative ICT industry that mostly covers contents business, software business, or so-call artificial intelligence, and ICBM. ICBM stands for IoT, Cloud, Big data, and Mobile. So it's a kind of business in Korea. Anyway, this new creative ICT industry is also a very rapidly growing area as one of the creative economy development models.

So there are many models which cover the convergence of healthcare and ICT. That is called the wellness industry as of today and the convergence of biotechnology with ICT or many others. So actually, we need to further create development models for the Korean creative economy in the coming months and years (Figure 4).

Figure 5. Strategic National Industry Portfolio Development

Ok, so the next slide shows that the kind of changing direction, actually, that is, simply speaking, a kind of balance between core industry upgrade and new industry creation. So, actually, I would like to call this kind of strategy the "two-track development" strategy. Actually, any country or any company cannot rely on the core industry only. So one side is to develop and upgrade core industry; at the same time, we need to create new industry. This looks very natural and somewhat obvious. But sometimes, the kind of the unbalanced concentration into one of these two is a kind of easy happening in these days. So, I'd like to emphasize the importance of the balanced investment for the two sides, which covers core industry upgrade and as well as the new industry creation together (Figure 5).

The next point I'd like to mention is related to SMEs. Actually, the Korean economy is currently shifting from a so-called large-sized-enterprise-driven economy to small-and-medium-sized-enterprise-driven economy. So, LSE, the large-size enterprise, has been a kind of main driver of the Korean economy so far. So for the past 50 years, large-size enterprises, especially Korean chaebol conglomerates, have been making a lot of contributions to the development of the Korean economy. But now, large-size enterprises are globalizing very rapidly. As a result of that, the large-size enterprises do not make any significant contribution to the creation of jobs. So, most of the new jobs are coming from small and medium enterprises as of today. As you can see from this slide, actually, this one, the blue bar means large-size enterprises including the so-called high potential enterprise. I'd rather explain the next slide first (Figure 6).

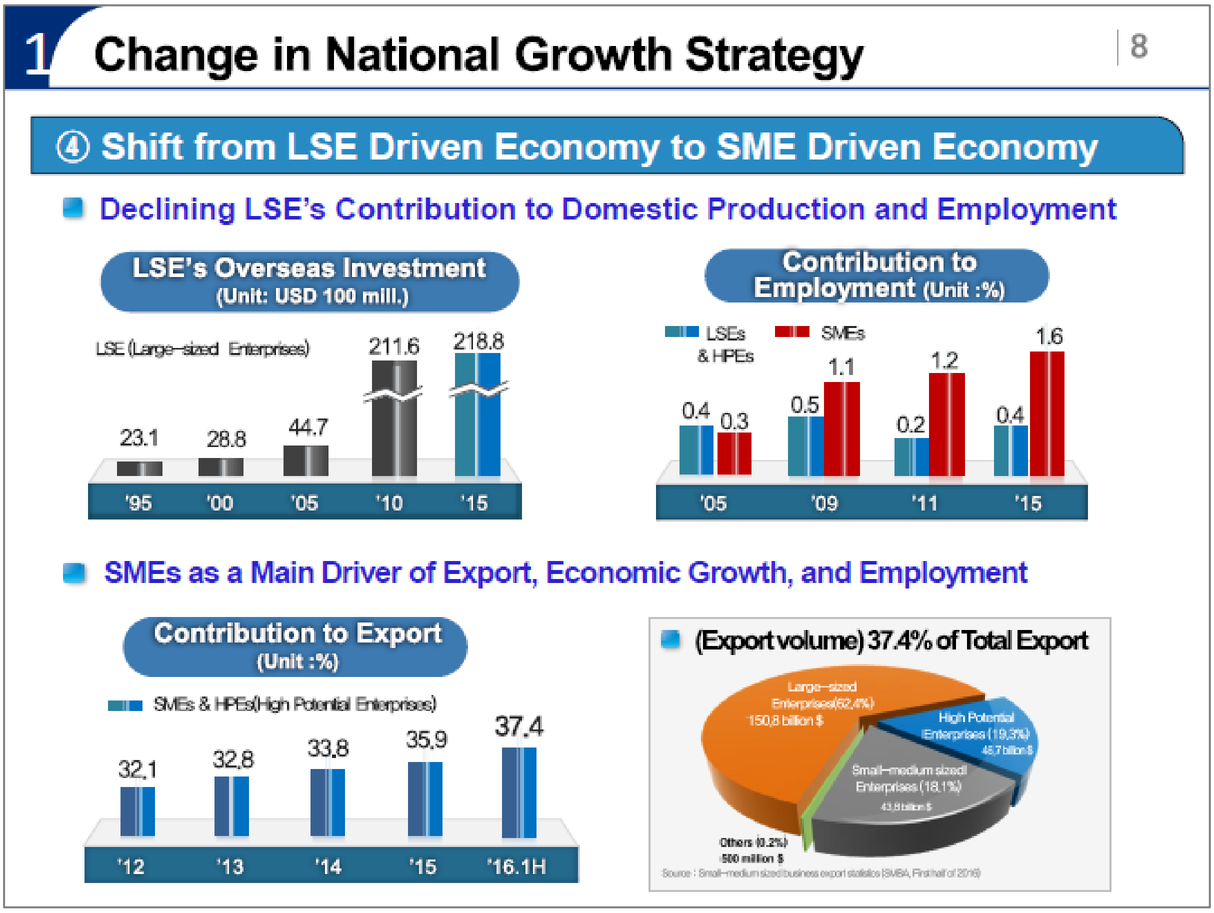

Figure 6. Shift from LSE-driven Economy to SME-driven Economy

Stature of Korean SMEs

This is the current state of the Korean enterprises. Korean SME, we have roughly 3.5 million SMEs in Korea. Then, I'd like to divide Korean enterprise in three parts. First, the lower part is SME, and the upper part is large-size enterprises. We have 1,671 large-size enterprises in Korea. Actually, from a couple years ago, we created a new segment, the third segment, to facilitate the development of this segment. That is called high-potential enterprises. In Korean words, "*Joong-Gyun-Gie-Up (중견기업).*" So, the high potential enterprises, we have currently roughly 3,000 high potential enterprises in Korea. So one is large-size enterprises, the second one is high-potential enterprises, and the third one is SMEs. So, right now, this SME represents 88% of total employment. But including HPEs, high potential enterprises, it goes up to 94%. So, in other words, only 6% of the employment is coming from large-size enterprises. And when it comes to production and value added, roughly half of the value added in Korea is coming from SMEs. And if SME includes HPEs, almost 70% of Korean production and value added are coming from, in large meaning, small and medium enterprises. So, SMBA, my organization is responsible for not only SMEs, but also the high-potential enterprises. So, all Korean enterprises except for large enterprises.

This data, the blue part includes LSEs and HPEs together. So if we include these HPEs into SMEs, if you combine these two, actually, it is almost everything of the Korean total new employment as of today. So what I mean is, this fact, in other words, most of Korean new jobs are coming from small and medium enterprises and HPEs. That is a very important phenomenon and an important fact.

So that's the reason why the Korean economy is currently, I can say, rapidly changing from a large-size-enterprise-driven economy to an SME-driven economy. So now the contribution of the SMEs, SME's contribution to export is also increasing very fast. So over the past four years, it almost increased by 5%. So I expect, in the next five years, this contribution to the export of SMEs will exceed 50% of Korean total exports. So that is the importance of the SMEs in the Korean economy (Figure 7).

Paradigm Shift & Innovation of SME Policies

So now, I'd like to briefly cover, how we need to change our policy paradigm, the paradigm of Korean SME policies. Actually, so far, Korean SME policy has been centered on the fact that SMEs need to be protected. That's true. But, actually in the coming years, because the Korean economy will rely on SMEs more and more, because of that, SMEs need to be ready for playing a leading role, rather than a supporting role, in the coming years. So in order to make it happen, actually we need to change the paradigm from the left-hand side to the right-hand side. The left-hand side is the Korean SME policies to provide Korean SMEs with the fish. But the right-hand side, the new paradigm, must be based upon the direction that we need to provide SMEs with skills, skills to catch fish. So that is the strength and competitiveness of Korean SMEs. That is the core theme of the Korean SME policy. So, simply speaking, we need to shift Korean SME policy from seeding support to focused development, especially development of the competitiveness; especially global competitiveness is very important (Figure 8).

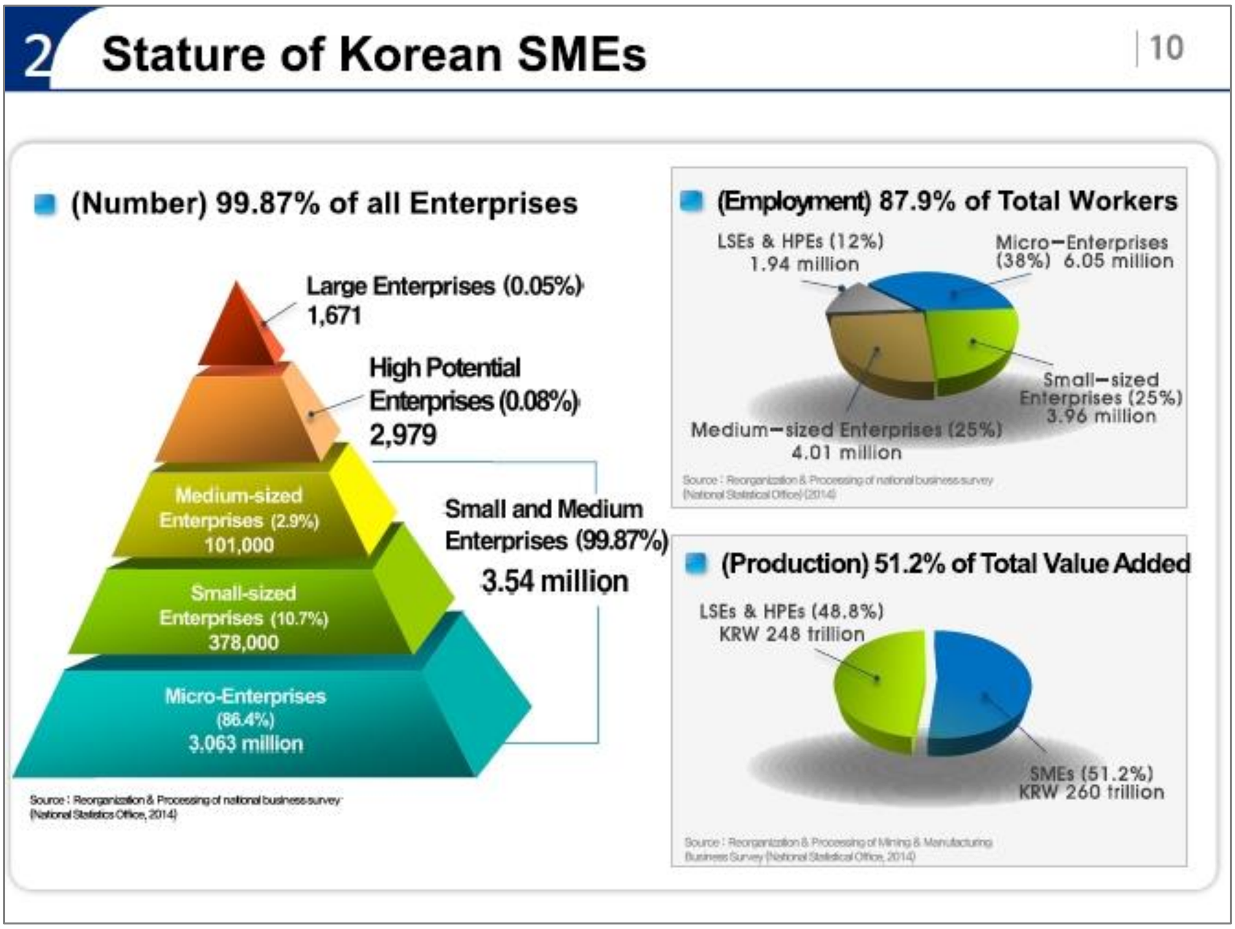

Figure 7. Stature of Korean SMEs

Figure 8. Shifting from "Seeding Support" to "Focused Development"

Actually, Korea has the highest dependence upon the overseas market, exports among the OECD countries. So Korean GDP reliance on the exports is kind of, highest in OECD countries. Because of that, in order to become the main player, the leading player of the Korean economy, SMEs must globalize themselves. So, globalization is the key goal, the most important goal to SMEs. So in order to globalize Korean SMEs, actually, we need to develop and secure the global competitiveness of Korean SMEs. In order to make it happen, actually we need to revitalize the growth ladder. Actually, after a startup becomes an SME and then high-potential enterprise and large-size enterprise, this is a kind of growth ladder. Actually, it's kind a shame to say that the Korean growth ladder is not working as of today. In other words, SMEs try to stay as SMEs because SMEs have a lot of benefits from the government taxation system or any kind of subsidization system. So, that's the reason why we create the new segment: to encourage Korean SMEs to develop themselves into high potential enterprises. And then, they move to develop themselves into large-size enterprises. So, we need to vitalize, revitalize this growth ladder to make, achieve this kind of goal.

And another issue is one of the weaknesses of Korean SMEs and even HPEs. It's the fact that they do not have very high class engineering talents within their organizations. So, most of the Korean engineering talents try to join Korean conglomerates like Samsung and Hyundai Motors. And also, they like to be professors in Korean universities, or they join Korean research institutes like KIMM. Actually, in other words, the most important weakness we need to fix as soon as possible is that SMEs and HPEs have sufficient engineering talents within their organization. So, of course, it will take some time to fix that problem. But as a short-term remedy, remedial action for all of that kind of problem is to expedite and activate the industry, academy, and research institutes' collaboration. Actually, everybody knows the Industry-Academy-Research Institute collaboration is important. We need to achieve very effective status of this collaboration. So, I'd like to encourage more and more university professors, as well as Ph.D. students or master's students, researchers within public-funded research institutes, and even the engineering service providers in the industry to help Korean SMEs and Korean HPEs develop more qualifying products in the coming month and years. So that's another important initiative. So, by means of these kinds of initiatives, we will be able to make SMEs to lead Korean economy through globalization (Figure 9).

So let me finish by explaining a couple of slides more. Actually, with the aim of achieving a creative economy, as I told you, the creative economy is to create high quality jobs. There are three contributors to create high quality jobs. One is the export from Korea. Especially in the Korean economy, export is very, extremely important as I speak to you. And to activate the startups. There are the main two pillars for creating new quality jobs. Actually, the creating new growth engine is also very important in the initiative, which is to support these two at the same time. So three pillars, they are the main source for creating high quality jobs. In order to achieve these three goals, SMBA, my organization is currently innovating SME policies especially for R&D, exports, startups, new growth engines, and micro-enterprises—how to develop all of them. Based upon that, we are revamping the Korean SME process over the last six months (Figure 10).

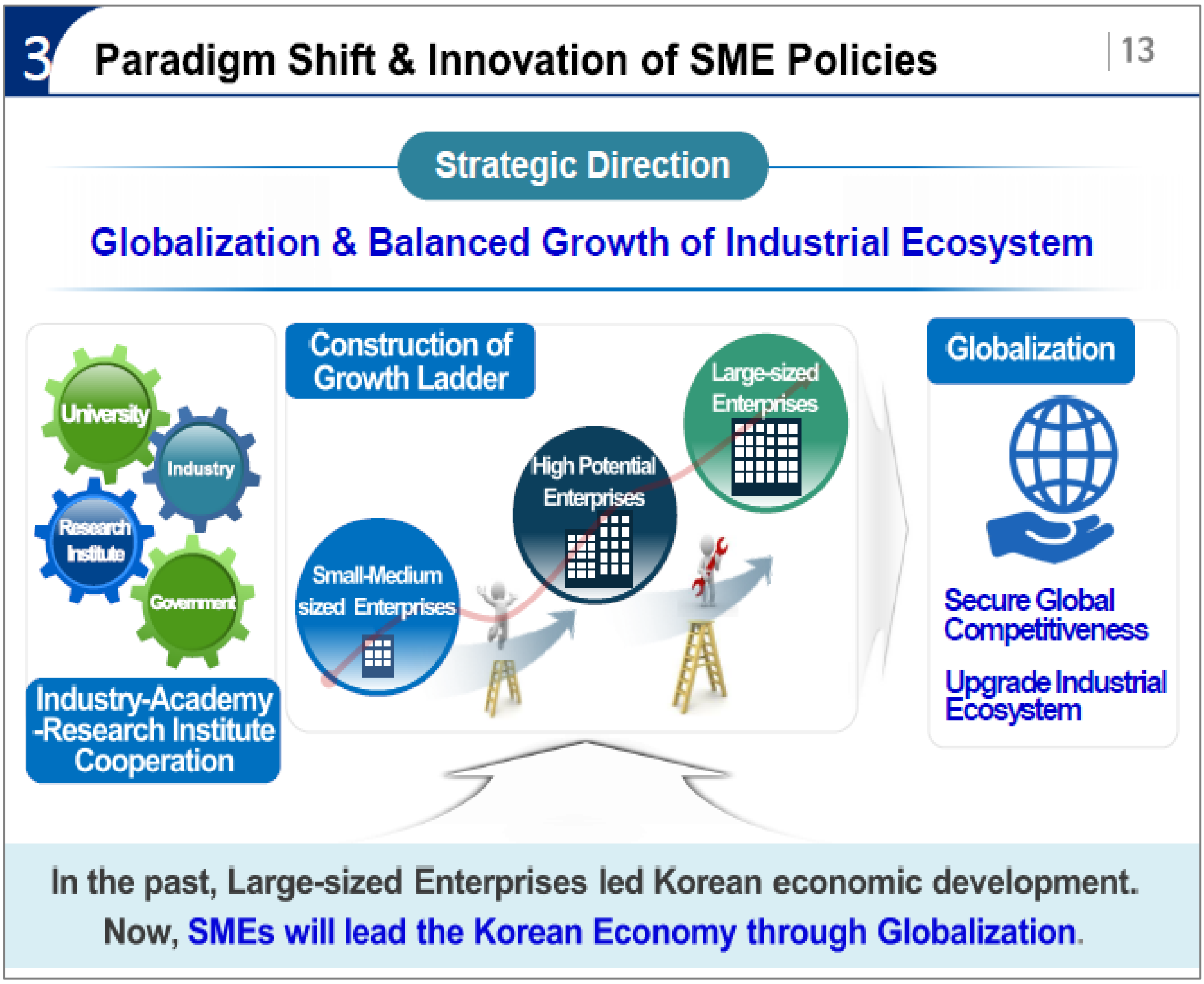

Figure 9. Globalization & Balanced Growth of Industrial Ecosystem

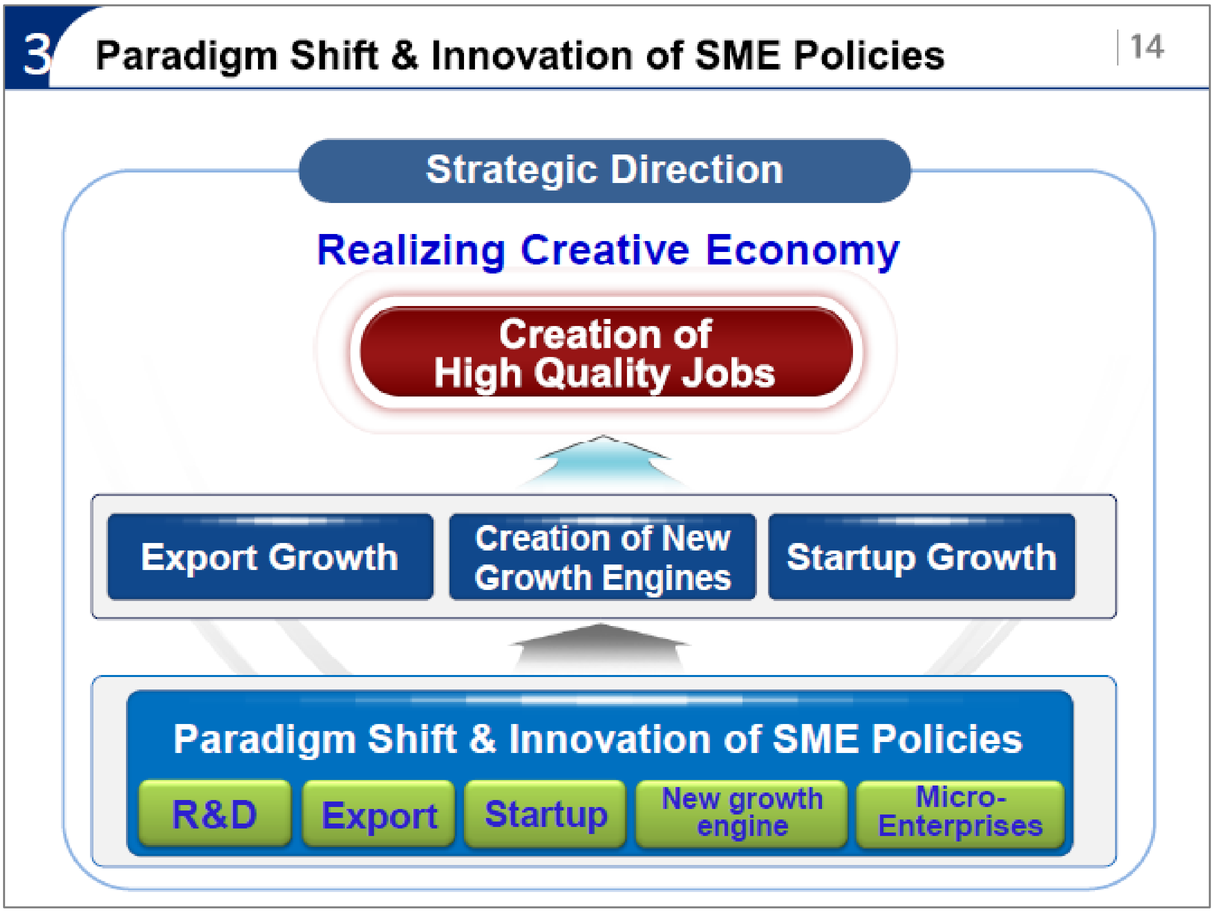

Figure 10. Realizing Creative Economy

I'd like to finish today's presentation by explaining this slide as the last one. Actually, we create new SME policies to expand Korean exports and many policies, innovation, R&D, and startups. But actually, these are several more innovative policies that have already been announced. So, there are common principles among, within the new SME policies. That is, principle one covers the intrinsic characteristics principles. The first one is a strategic approach. In other words, we need to develop the Korean SME policies with clearly defining what the role is. That is very important. So a goal-oriented strategic approach is one thing. And then, just like the case of the private sector, the public sector also needs to work on the basis of performance and results. So performance- and result-oriented mentality is also a very important part of the principle. And there are many areas which can be expected. There are more results, effective results by means of the strategy driven by the private sector. So private sector driven is also very important. And so SMBA has around five policy tools. One includes the R&D budget, research, and development funding. And then, marketing funding and domestic as well as the exporting. And financing, and human resource development. And finally, legislation as a kind of new rules and new legislation and regulation is also important. So we need to align these five key policy tools to achieve our final goal. So, alignment of the policy is very important. And then, this policy must center on the industrial ecosystem. So it includes not only enterprises, SMEs, but also the large-size enterprises and universities and research institutes, and engineering service providers. So this kind of industrial ecosystem players must participate in this policy. Efficiency is of importance

And also, the right-hand side is more general. We must align the SME policy with the creative economy. And then government ministries must work together. And as the global collaboration is becoming more and more important, right now, Brexit and Mr. Trump's "America is the first" strategy, so this kind of protection, protectionist approach is what we need to avoid in the coming years. So global collaborations, especially government to government collaboration, is extremely important. And then the corporate culture, a new business model to change into more and more admired companies within, among the industries, that is very important (Figure 11).

Conclusion

So, because of time, I'd like to stop here. Actually, finally, I'd like to mention briefly, this kind of growth ladder is currently starting to work. And then we have been investing a lot of efforts as well as the financial resources into startups. So how to connect startups with the existing ecosystem, that is the innovation pipeline pushed by means of active M&A, merger and acquisition. So, I'm currently strongly encouraging Korean SMEs and Korean HPEs, as well as large-size enterprises to acquire startups to get more innovation, innovative ideas from startups (Figure 12).

This is a kind of brief introduction to Korean SME policies.

Thank you.

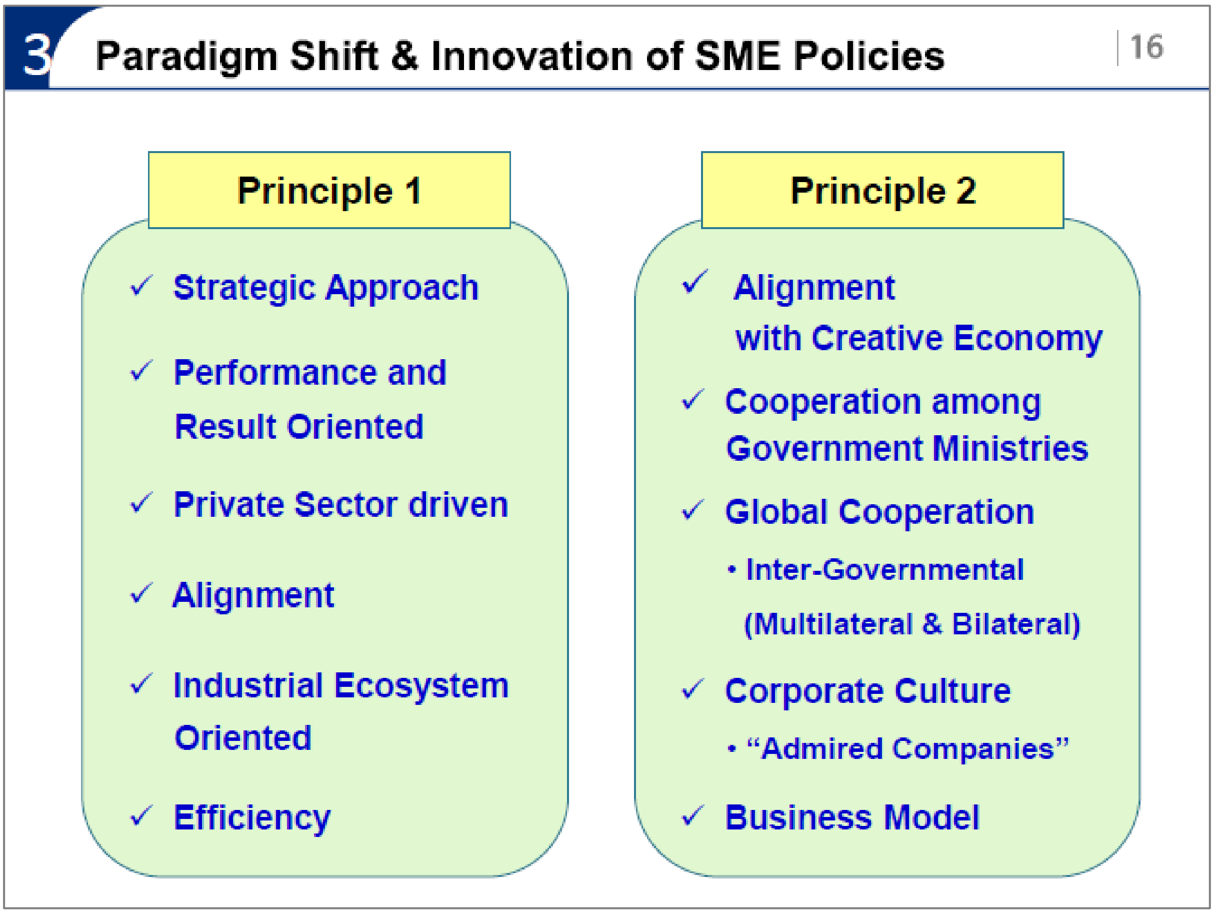

Figure 11. Paradigm Shift & Innovation of SME Policies

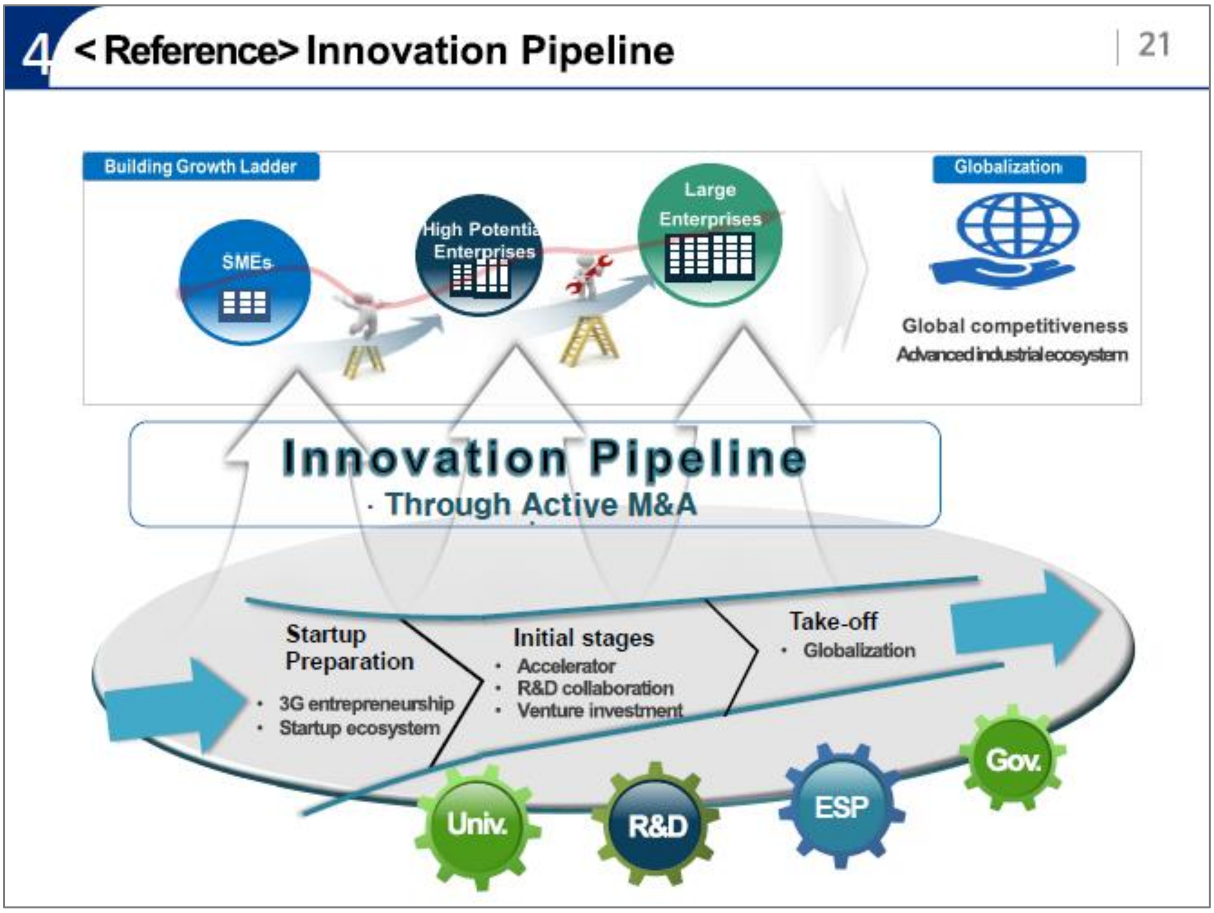

Figure 12. Innovative Pipeline

KIMM for Creative Economy

Yong-Taek IM
President
Korea Institute of Machinery and Materials

Creative economy is a keyword for the current government to maintain the sustainable growth of Korean economy since 2013. The gross domestic product (GDP) per capita did not increase for a decade and the birth rate is the lowest (1.24 in 2015) in the world recently. As a new leader of the Korea Institute of Machinery and Materials (KIMM), I interpreted the creative economy into a continuum of creating Knowledge, Innovation, Motivation, and Marketability and tried to forge it into the operating system of KIMM. In this talk, the governance change, research challenge, and technology transfer to the industry during my tenure will be highlighted. In result, the research productivity defined as the royalty income divided by the direct research cost was improved from 6.8% to 7.6% and the medium and long-range research project system was newly introduced. The new way of working and decision process introduced can be further augmented in promoting the sustainability of research activities at KIMM to enhance the quality of our lives in the future. I really hope challenges and change experienced so far will play a pivotal role in revitalizing and further strengthening the international competitiveness of manufacturing sectors of Korean industry.

Introduction

As the new government was established in 2013, the Ministry of Science, ICT, and Future Planning (MSIP) was newly introduced to set up and promote 'creative economy.' It was interpreted as the creative economic activities to make new jobs by launching new start-ups and to find a new cash cow to lead the Korean economy to the bright future breaking up US$ 30,000 barrier of GDP per capita, as shown in Fig. 1 since 2006. As part of this campaign the MSIP opened 18 creative economy innovation centers at different cities similar to the 7 high value manufacturing centers in UK, as shown in Fig. 2.

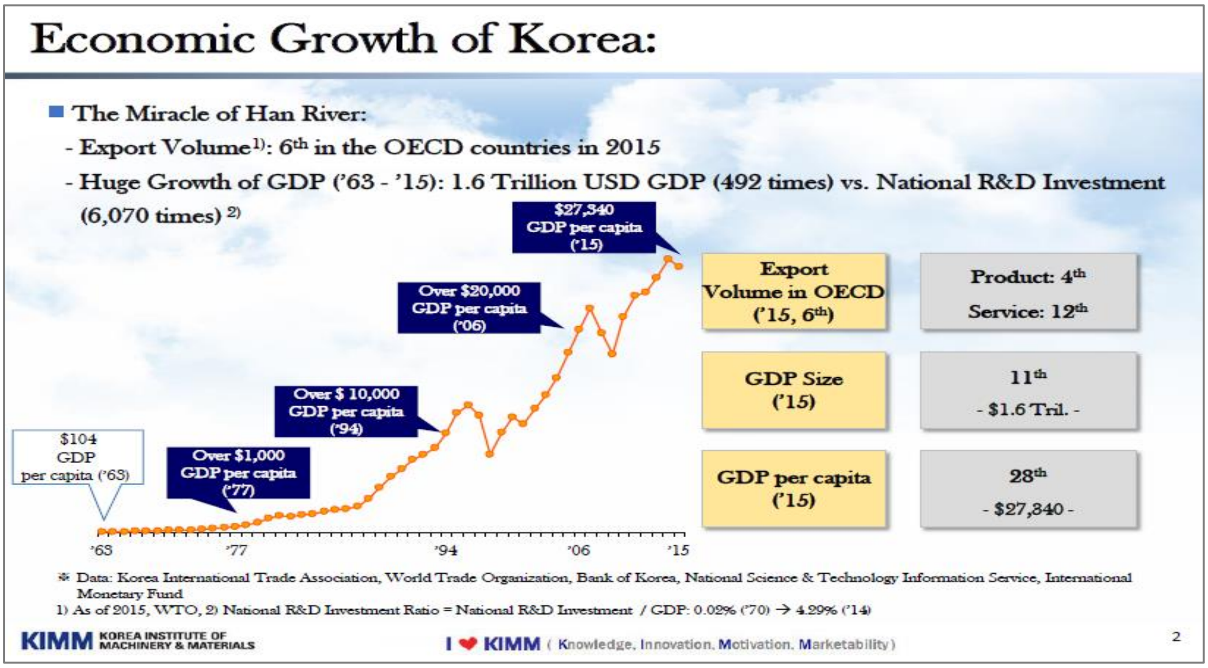

Figure 1. Economic Growth of Korea

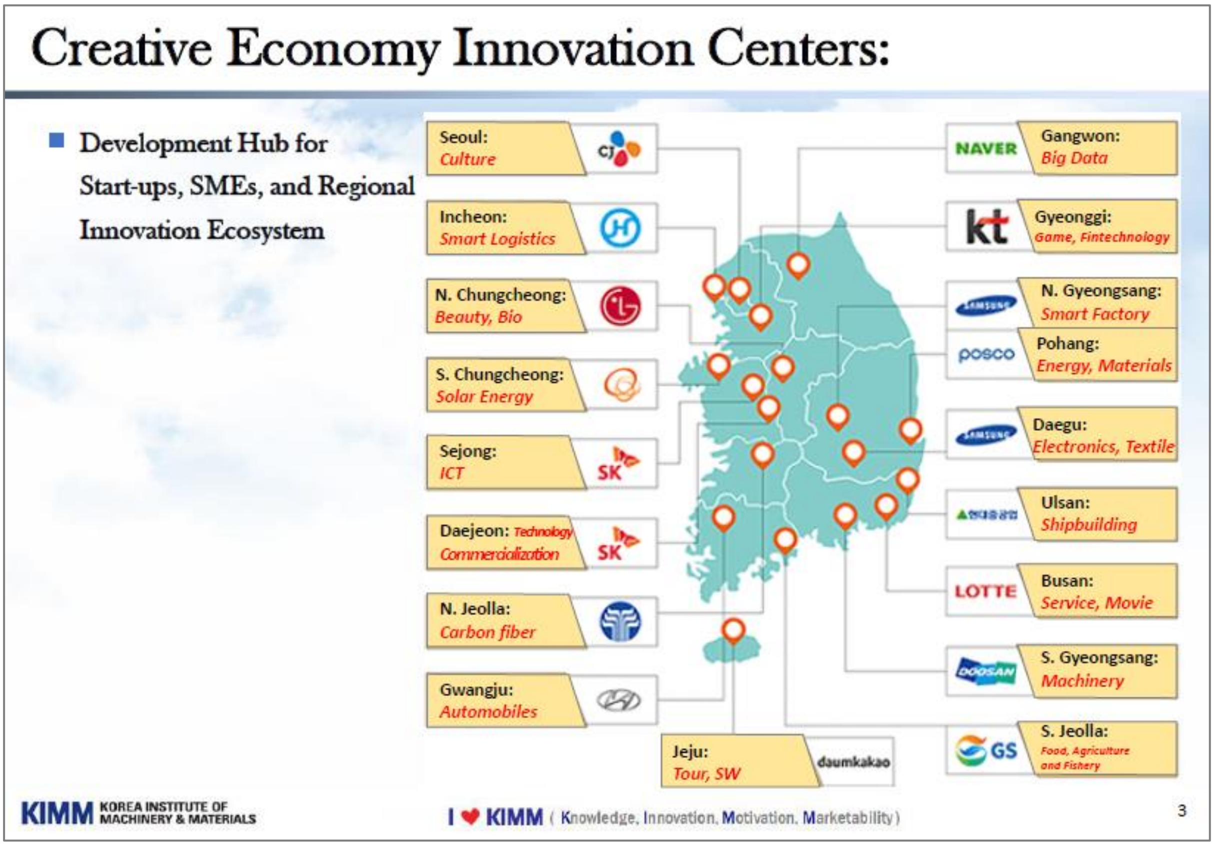

Figure 2. Newly Established Creative Economy Innovation Centers by MSIP

In February of 2014, I interpreted creative economy in reference to the initials of Korea Institute of Machinery and Materials as a continuum of creating Knowledge, Innovation, Motivation, and Marketability. In order to implement it into the operation and management of the research institute, the mission should be redefined accordingly to spearhead to solve the domestic industrial needs and global problems to improve the technical competitiveness in the world and the research productivity as well. To this end, the original mission has been restated as follows: Original one was to contribute to economic growth of the nation by performing R&D on key technologies in mechanical engineering and materials, conducting reliability test evaluation, and commercializing the developed products and technologies. The new one is to become a global research institute in the field of mechanical engineering by introducing a new governance system to foster knowledge, innovation, motivation, and marketability, resulting in enhancing the research productivity and capability, as summarized in Fig. 3.

As part of new government initiatives, the MSIP also selected 6 research institutes, Electronics and Telecommunications Research Institute (ETRI), Korea Electrotechnology Research Institute (KERI), Korea Research Institute of Chemical Technology (KRICT), Korea Institute of Materials Science (KIMS), Korea Institute of Industrial Technology (KITECH), and KIMM as Korean Fraunhofer type in 2015. Fraunhofer is well known practical research institutes in Germany located in 68 places with around 24,000 research people working for various disciplines, as depicted in Fig. 4.

Fig. 5 shows the recent data for R&D budget in Korea. This figure clearly shows that the total research fund from the private sectors is much larger than the one from the public. The research fund from the private is mostly sponsored by the major conglomerates. Thus, the government is trying to support the small- and medium-sized enterprises to sustain the Korean economy more effectively.

In addition, the birth rate of 1.24 on average in 2015 is the lowest in the world starting from 2001. This might bring up the socio-economic issues in the future of Korea in various ways.

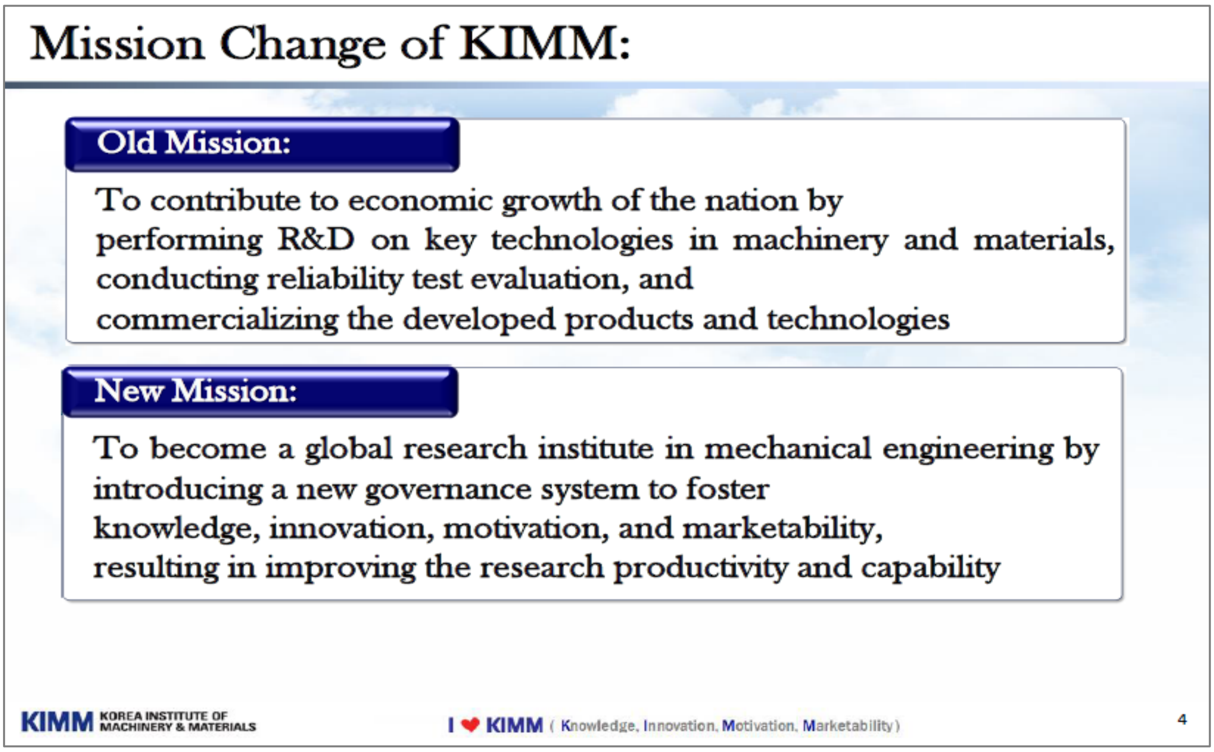

Figure 3. Change of the Mission of KIMM

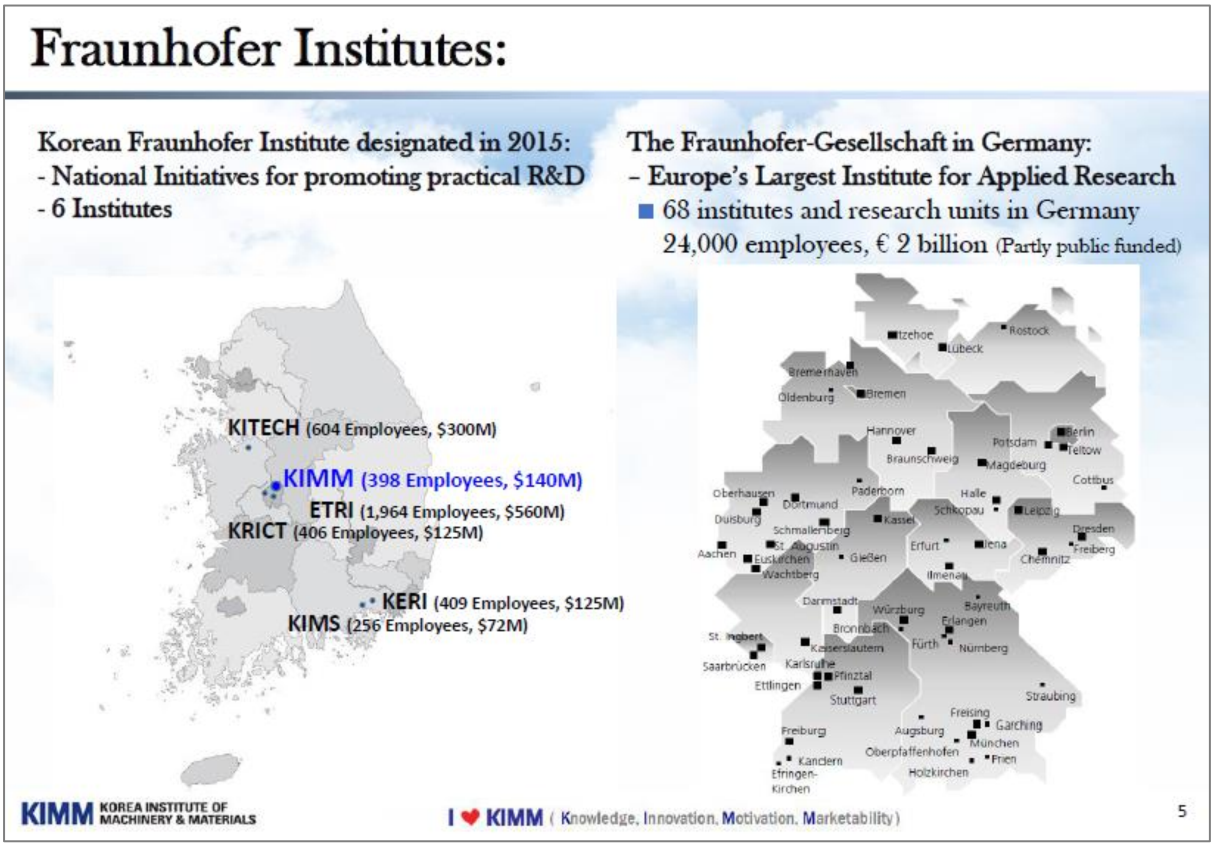

Figure 4. Comparison of Fraunhofer Type Institutes in Korea and Germany

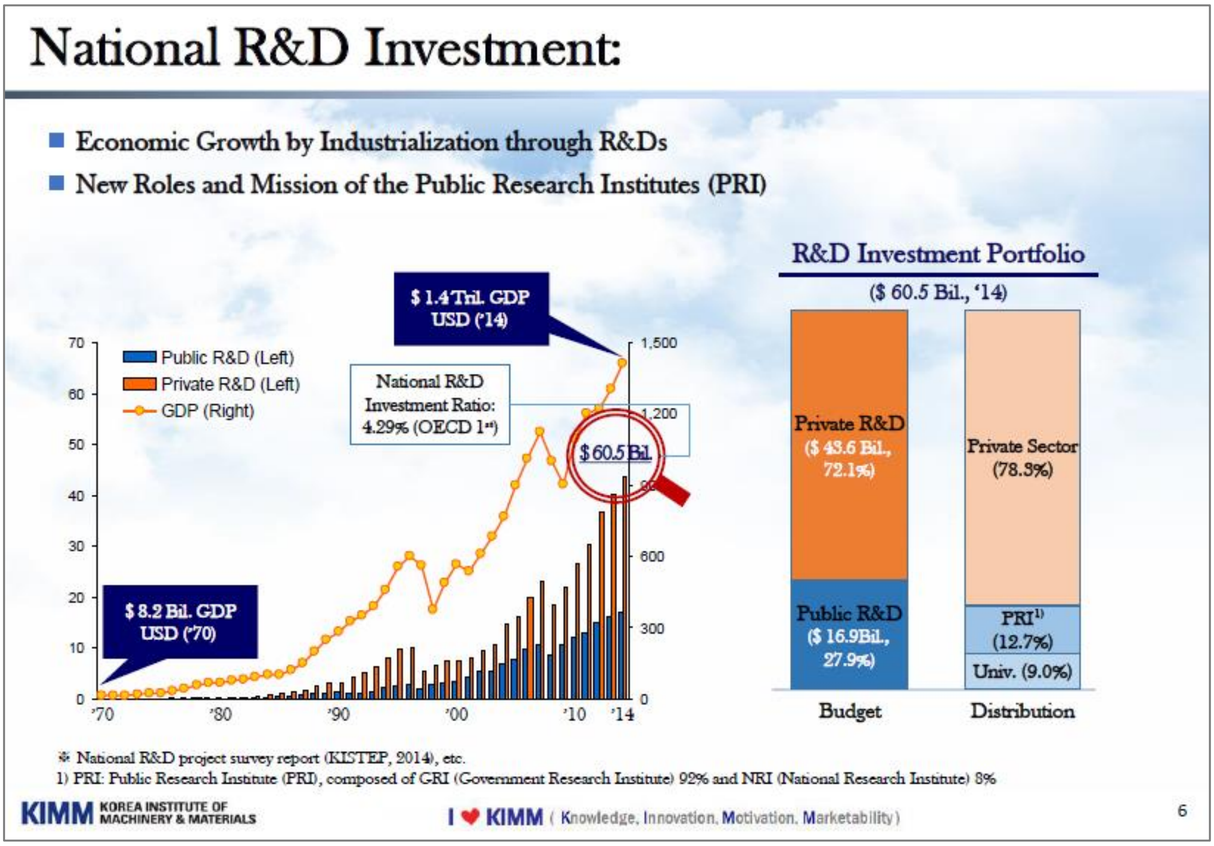

Figure 5. Recent Data for the R&D Budget in Korea

In order to cope with such socio-economic issues, new governance, internal research funding system, technology transfer and support for the small- and medium-sized companies, and some thoughts on major R&D accomplishments will be highlighted in the following.

New Governance system: Internal Research Funding and Technology Transfer and Support

Currently, KIMM has 398 employees and its annual budget is around US$ 140 M, as shown in Figs. 6 and 7. It has five research divisions (advanced manufacturing systems, nano-convergence mechanical systems, environment and energy systems, extreme mechanical systems engineering, and mechanical systems safety) and three regional research centers at Daegu (medical devices), Busan (laser technologies, automotive, and nuclear power plant parts verification), and Gimhae (LNG and cryogenic technologies).

Internal research funding supported by the MSIP is around US$ 28 M per year. The allocation was almost equal to every researcher in the old system. However, it is now changed to the merit and competition base. In addition, the long-term (more than three years contract) flagship project was newly introduced and the performance will be monitored carefully by external committee members including industry partners. With this new funding system, ground for carrying out the gas turbine project, medical assisted robot and maglev system was prepared internally.

Why is it so important to introduce such a funding system? As introduced earlier, funding and personnel resources are very much limited compared to the domestic private sectors, as pointed out in Fig. 5. Considering the resources available at international institutions in Fig. 4, it is more obvious.

Thus, careful monitoring of funding and personnels with proper research strategies is one of the most critical issues to keep up with the international competitiveness.

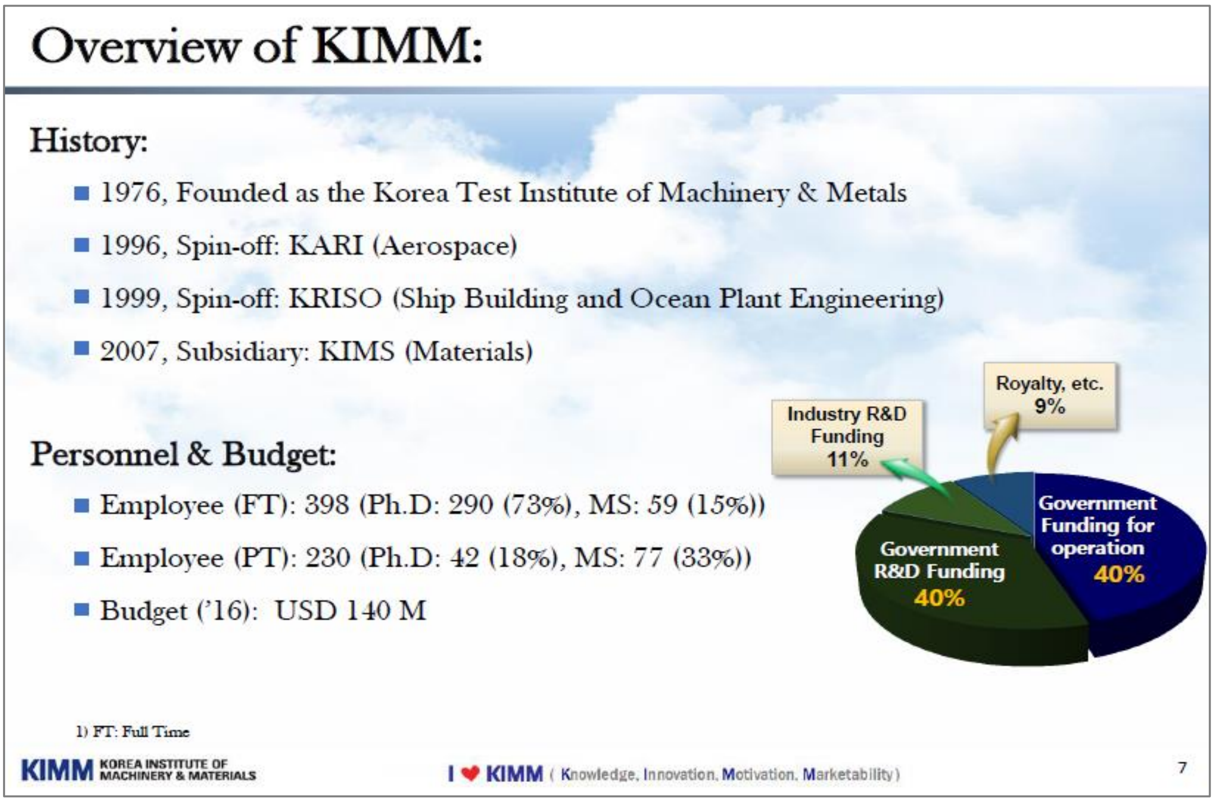

Figure 6. Overview of KIMM

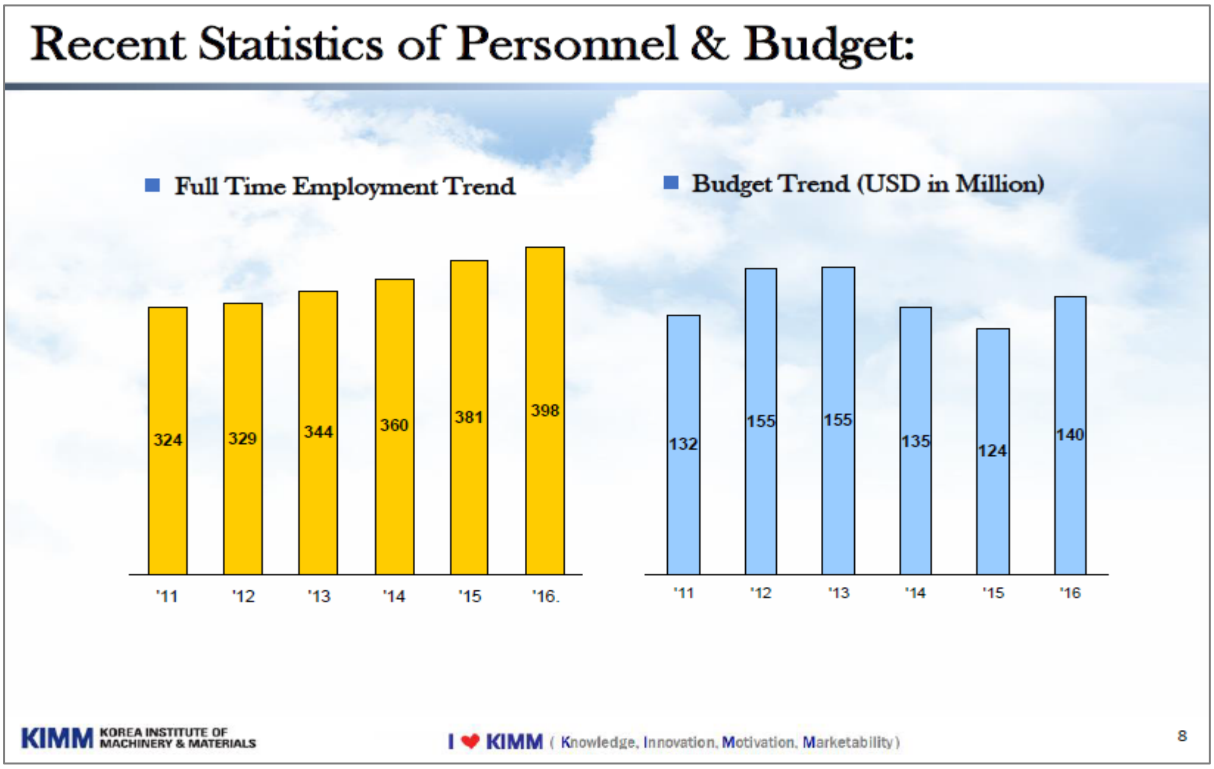

Figure 7. Recent Statistics of Personnel & Budget

In order to help research activities of small- and medium-sized enterprises and encourage opening start-ups launched by the research scientists of the Institute, the administrative division of technology transfer and support in addition to the division of external relations is upgraded and moved directly under the control of the President's Office. This set-up helps promote the technology developed at the Institute to the public and finding the investment or collaboration partners from the holding companies or venture capitalists.

Fig. 8 shows the overall structure of the technology transfer system consisting of the ACE program, buy KIMM technology (BKT) program, and technology marketing/support. The current programs keep generating the royalty income around US$ 3 M in total including 12 new positions as summarized in this figure. It is not big but a good start of creating a continuum of creating Knowledge, Innovation, Motivation, and Marketability.

In 2014, the biggest royalty income was made by selling the shares of JPE which was established as one of KIMM family in 2008 by the technology transfer and continuous support on roll-to-roll imprinting technology, as shown in Fig. 9.

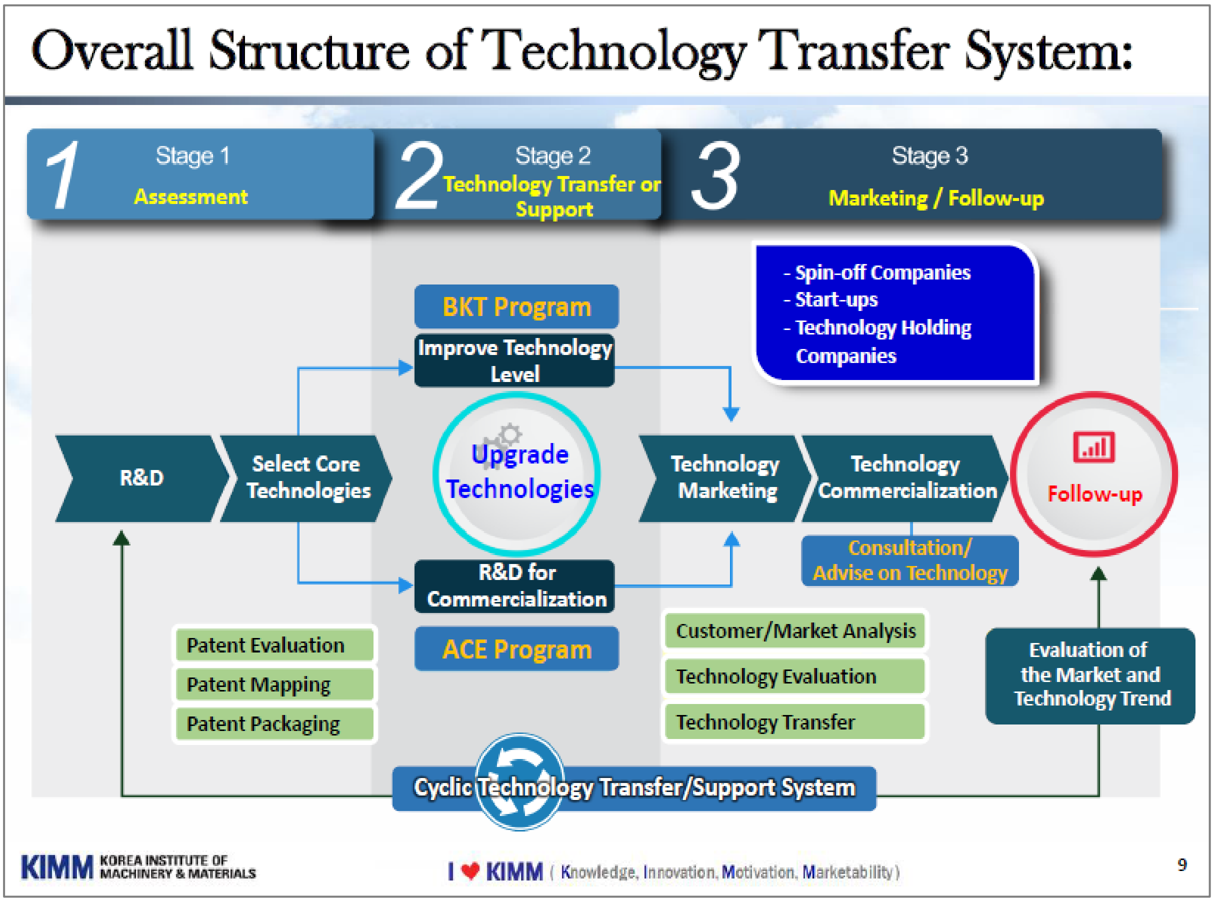

Figure 8. Overall Structure of Technology Transfer System of KIMM

In Figs. 10-12, the recent major technology transfer cases are summarized. Three spin-offs such as VI solutions, FlexCom, and BlueSys were established with the help of Korea Science and Technology Holdings. In 2015 only, 150 technology support cases including management consultation were provided to the small- and medium-sized enterprises with this new technology support system.

At the end of 2015, Dr. SungHyun Byon at the plasma laboratory opened up Speclipse as a new start-up in the field of non-invasive real-time diagnostic solution for skin cancer, as shown in Figs. 13 and 14. This start-up won the TIPS program to secure US$ 0.6 M from the Korean government and recently wins the first prize in the KOTRA/SMA start-up contest in the States.

Another success story is available for technology support for KIMM family company, JinYoung HNS in Fig. 15. KIMM is running the KIMM partners and family programs. JinYoung HNS contacted KIMM to acquire the analysis and measurement technique for precision injection molding products like impeller for turbo machinery. With successful support from KIMM, they supplied the product to the major domestic supplier. In addition, they worked together with a KIMM's engineer to commercialize the non-invasive laser blood sampling device for diabetic. This device acquired the Conformité Européenne (CE) mark in European Union, resulting in making the export contract of US$ 270 M. In addition to this kind of success story, there are several interesting technology support stories with Uniwell, LoT Vacuum, Sungil Turbine, and Prosave, to name a few.

Figure 9. Major Technology Transfer Case to JPE Co.

Figure 10. Major Start-up Case of VNI Inc.

Figure 11. Major Start-up Case of Flexcom Inc.

Figure 12. Major Start-up Case of BlueSys Inc.

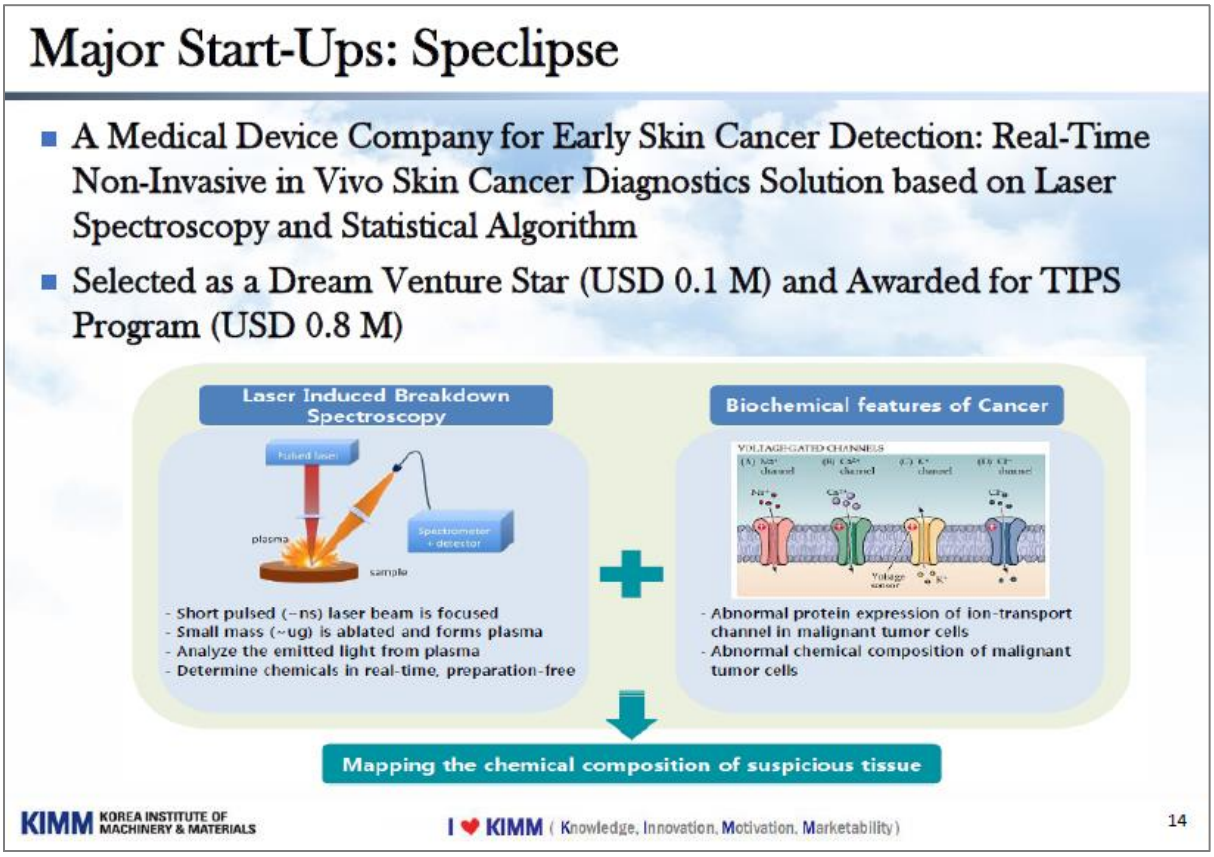

Figure 13. Major Start-up Case of Speclipse

Figure 14. Major Start-up Case of Speclipse (continued)

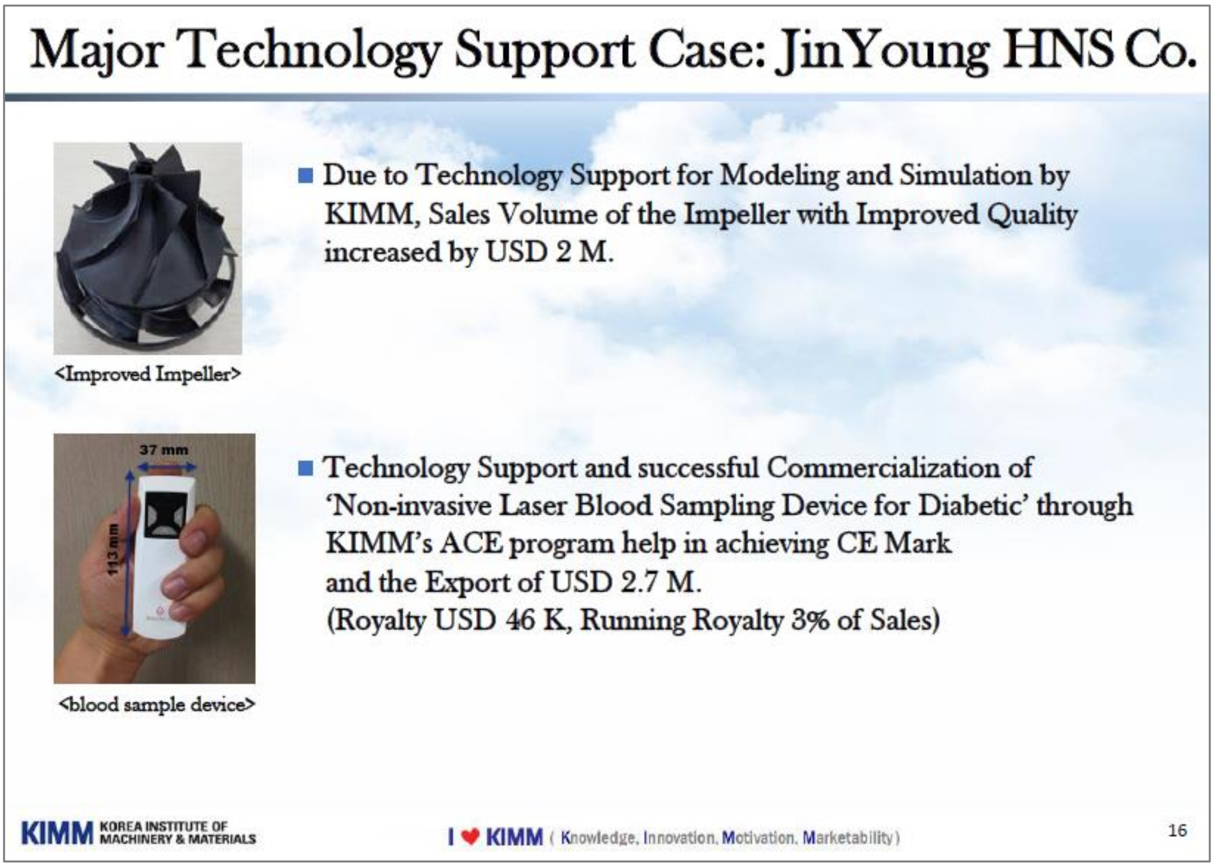

Figure 15. Major Technology Support Case for JinYoung HNS Co.

Figure 16. Major R&D Accomplishments for Commercialization of Maglev

Major R&D Accomplishments

In the 3rd of February, 2016, as shown in Fig. 16, the environment friendly Maglev train began its first commercial service at the Incheon Airport for 6.1 km at the maximum speed of 110 km/h. From 1989, KIMM has been working on the project in direct or indirect ways. The first maglev train manufactured by Hyundai Rotem was officially approved by the performance verification team led by Dr. HyungSuk Han at KIMM in May of 2014, as depicted in Fig. 17.

In Fig. 18, the low-pressure plasma burner developed by the research team led by Dr. Younghoon Song for last two decades was finally applied to the semiconductor processing line of Samsung electronics and SK Hynics through LoT Vacuum company. It increases the service life of vacuum pump and burned down the micro-particulate generated by the semiconductor manufacturing line. This technology was not new but very useful in solving the real problems involved in the real production line. Recently, this technology has more attentions to enable Diesel Particulate Filter or Selective Catalytic Reduction filter to function properly in reducing the level of the No_x and So_x pollutants from the emission gases from the automobiles, cargo ships, and power plants.

Fig. 19 shows the combustor installed in the Namdong Power Plants through Sungil Turbine Co. Four combustors were designed by the research team led by Dr. Hanseok Kim. The technology was transferred to the small-sized company Sungil Turbine Co. who manufactured and installed them properly for the power plant. Another positive change introduced recently is the interdisciplinary research. There is a clear boundary and wall between the different divisions of research team inside or outside of the institution. But now the active research collaboration is happening across the research divisions including the outside institutions. As a result, the number of joint projects and publications reported by Thomsen and Reuters are increasing recently, as shown in Fig. 20.

Figure 17. Major R&D Accomplishments for Verification of Maglev

Figure 18. Major R&D Accomplishments for Low Pressure Plasma Technology

Figure 19. Major R&D Accomplishments for Low NOx Gas Turbine Technology

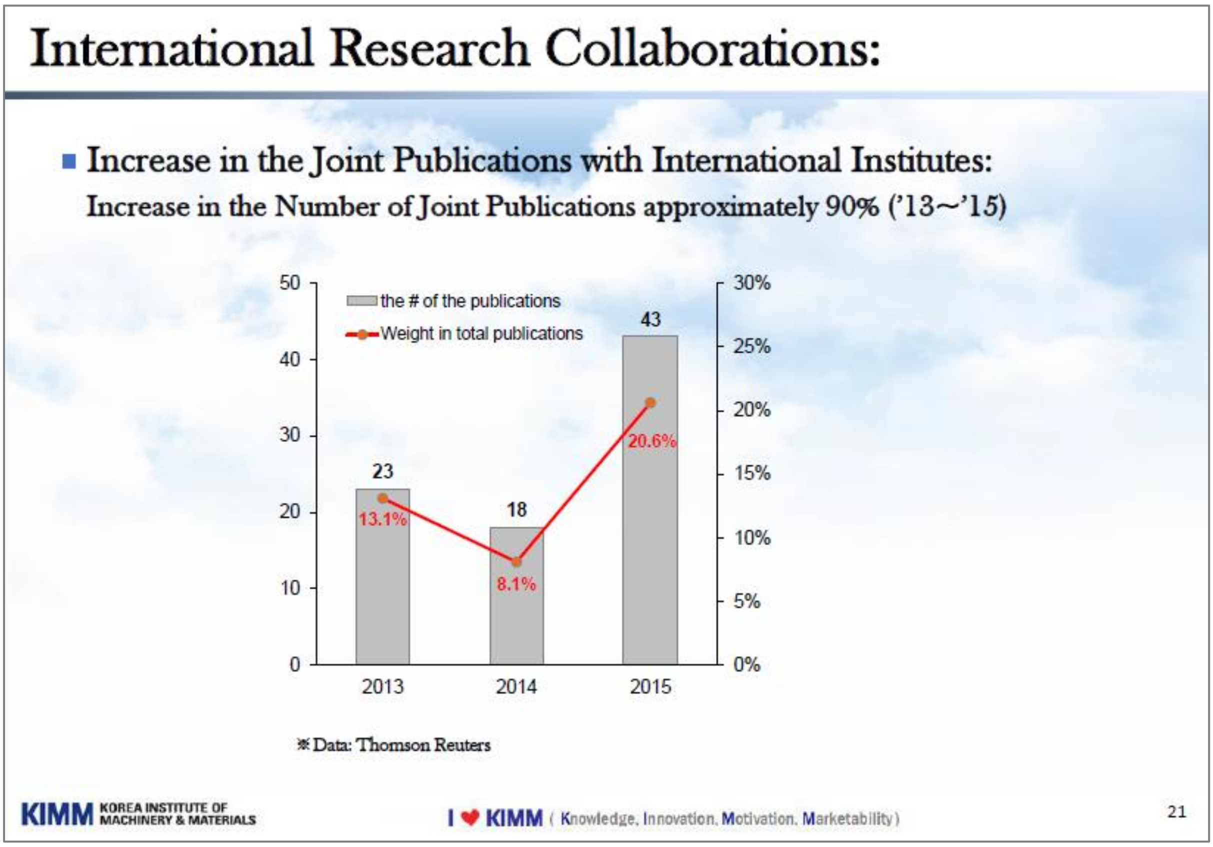

Figure 20. Change of the Number of International Joint Publications

Globalization

After signing the MoU on July, 2016 with the Institute of Production Technology at University of Aachen recently, as shown in Fig. 21, I found out the importance of the globalization, and the consistency and continuity of German research works are the major strength of each institute again. I saw the experimental set-up of water machining at both institutions of University of Aachen and Technical University of Berlin. In Korea, it is very difficult to find a research scientist in this area because of lack of funding. Another strength is based on the close collaboration with the university and private laboratories. Unfortunately, Korea has a different educational and R&D system which needs to be changed for better efficacy.

Recently, one domestic newspaper pointed out that the maglev technology installed at the Incheon international airport is nothing new and behind of Japan by 11 years. I agree that the key technology is known to everybody similar to the other cases of plasma and combustor technologies. But how to assemble the technology and materialize to make it commercial is something else. Also, if the funding was continuous and steady in the late 90s, maglev technology might be completed much earlier. We should not forget about this kind of inconsistency and discontinuity of the funding. To sell the product in the market is also something different from the technology itself, depending on market status including finance, cost, and other socio-economic-political issues involved. It is easy to imagine that if we did not ever started investment on heavy industries, we cannot live in the same living conditions as now.

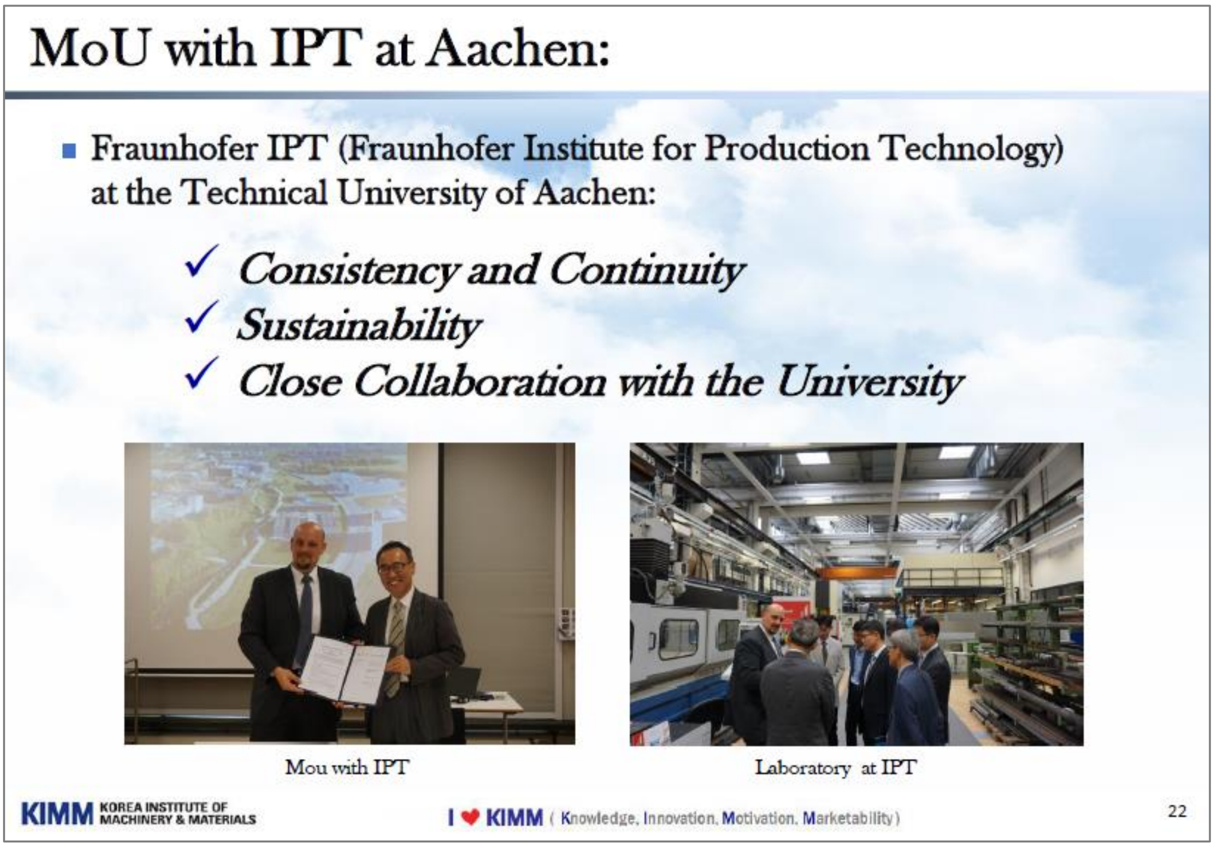

Figure 21. MoU with the Fraunhofer IPT at Aachen

Although the internal and external collaborations are increasing according to the joint publications data, what we need to overcome is to change the institutional culture or spirit to be competitive at the global domain. It is easy to invite the people for a short stay or Conferences, but it is not easy to make them long-term stay for real collaboration. From this point of view, I really appreciate the support from the German government to establish the Institute in 1976 and the presence of Dr. Hellmut Schmücker shown in Fig. 22 in this Forum in celebration of the 40th anniversary of the research Institute. Today, as a small token of appreciation it is my great honor to give the Certificate of Honorary Research Scientist of KIMM to Dr. Helmut Schmücker to recognize his contribution as the first advisor for the late first President Prof. Dr. NakEun Chung.

In order to solve Mers and Jika virus, climate control, yellow sand, and national security issues, we have to work together to save the globe. However, it is well known that many promising international research scientists and scholars stayed at the famous institutions are leaving Korea to other countries like HongKong or Singapore because of salary on surface. In reality, they are afraid of the educational system for their children and relatively poor working environment. Without solving such issues it is not possible to attract good international scholars for a long term stay. I strongly suggest to carefully rethinking about our educational and R&D systems how to improve the practical research productivities of public and private sectors. Fig. 23 summarizes some of these issues that I can think of.

Another important factor we have to face at is new wave of Chinese students studying at the international universities, especially in the States. Recently, I met the professor from the American university. He said it is getting even tougher for international student to get an admission from the American universities because of the Chinese applicants. Chinese students are everywhere nowadays. Around 75% of the incoming international students these days are Chinese according to him. Thus, the international competition will become much tougher as time goes by.

Figure 22. A Photograph of Dr. Hellmut Schmücker

Figure 23. Major Issues involved with Globalization

Conclusions

Luckily enough, KIMM achieves the 7.6% research productivity during my tenure which was defined as the ratio between the royalty income and the direct research cost according to the graph in Fig. 24. I just want to point out that we can improve our research throughput by setting up right research environment for each research institute although there is no unique solution.

Since the research manpower of the German Fraunhofer institute is almost 6 times larger than the total of 6 Korean Fraunhofer types, it is so obvious that we can easily become a champion in every research discipline. That is why we must focus on the select topics in which each institute has its own strength and the market is interested. I am not saying we do not have to carry out the basic fundamental research at all.

As pointed out earlier, here is a big dilemma of investing the R&D funding for real benefit, something new or old but necessary. Therefore, we need a check and balance system to develop a healthy continuum consisting of creative activities of knowledge, innovation, motivation, and marketability to make a sustainable growth in the worldwide market.

This reminds me the Kaiser Wilhelm Gedächtnis church in Berlin, as shown in Fig. 25. Germans just leave the remnant of the broken wall bombarded during the war. Similarly, German research scientists in the field of machining area at the Technical University of Berlin are thinking of using robots to substitute for machining specialists instead of changing their majors. In order to win the Gold medal in the technology olympics, it might be more practical to make the machining robot instead of dancing robot.

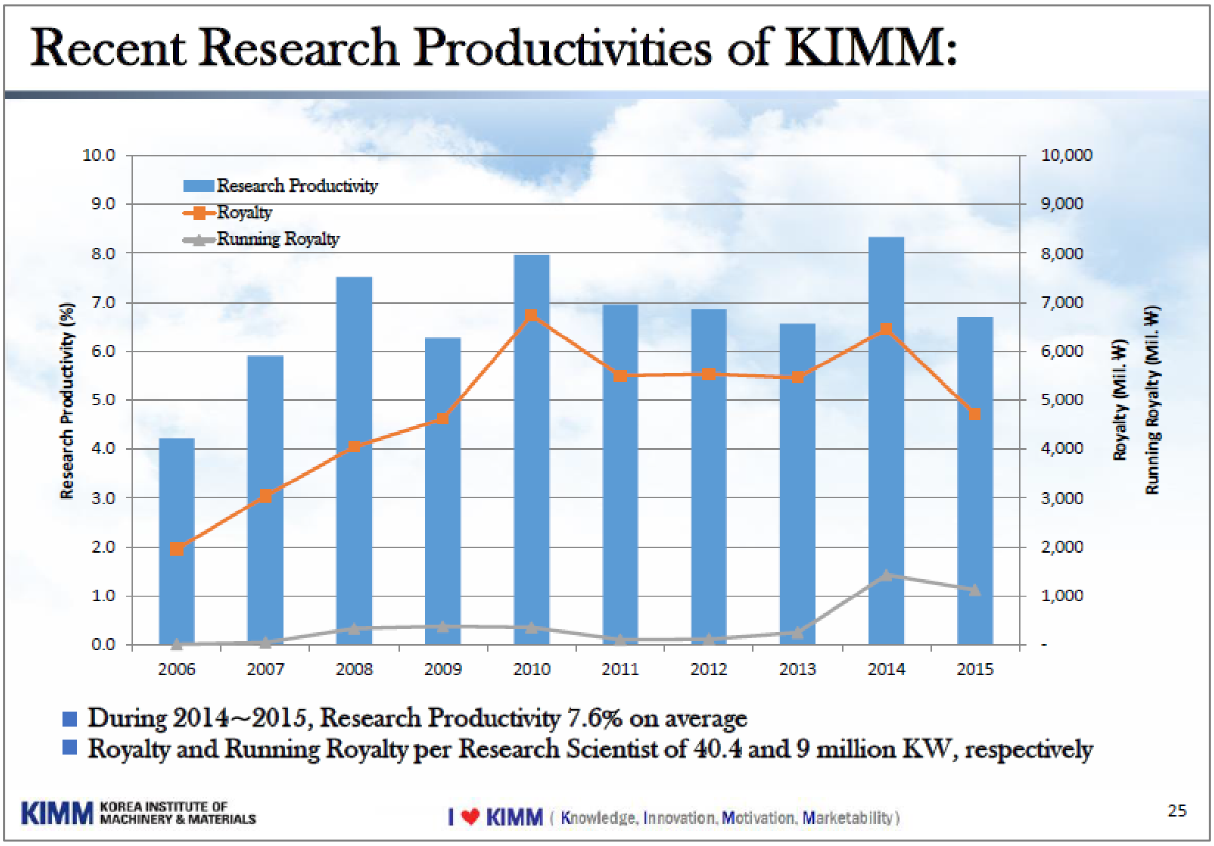

Figure 24. Variations of Recent Research Productivities of KIMM

Figure 25. Lesson from the Kaiser Wilhelm Gedächtnis Kirche of Berlin

Also, we should not underestimate the time and effort to make a new trial and error successful, especially in the technology area. We should keep the current jobs available and then is looking for every possibility to create new jobs. Sometimes, this simple rule of thumb is overlooked too much even in the technical field in Korea. I really hope KIMM is continuously growing into a global R&DB leader in mechanical engineering and contributing to make the people happier and the future brighter with the wisdom of consistency and continuity.

Thank you.

Panel Discussion

Chair: Dr. Yong-Taek Im

Dr. Yong-Taek Im

So I will give you, each of you, probably five to six minutes. And I just want to ask you a very simple question. What should be the best way to make this mechanical engineering sustainable for the development of our welfare and our prosperity? How can we achieve that? And you heard about so many things, even this afternoon, from Minister Joo talking about the importance of SMBA. So, now the emphasis is on the value added through SMBA. So, compared to that, what is your idea about that value addness and mechanical engineering worldwide?

So, I think I will just pass this microphone to Dr. Jack Wang. So you can just start. You don't really have to talk for five or six minutes. You can make it short. That's the way I just opened this panel discussion, and after that, if somebody from the floor wants to ask some specific questions to some of us, we just address that question.

Dr. Jack Wang

In my opinion, it's not just for mechanical engineering. In my opinion, maybe new materials and new processes for the new products are developing ways to achieve high value-added products. For example, in our center, we develop some new materials like limited materials, for example. For the new material development and the new process, to create the new product, I see this can help us in industry to change from low-adding-value to high-adding-value products. Thank you.

Dr. Choong Sik Bae

Shall I continue? Ok. Actually, the question, common question is about basically the mission of mechanical engineering and the service of mechanical engineering for the sustainable and economical society. At first, the impact of mechanical engineering for this rapidly changing society must be secured by extension and convergence of mechanical engineering. I'm now at the academy, academia. So we must give the mechanical engineering students who will be mechanical engineers for 30 years to 40 years in the society, serving the society and the globe. We found that the wording, "machine civilization" itself has been evolved by the value added by information and so-called "4th Revolution" and so on. So we need to expand the principles from, say, not only R&D and technical development. For example, we have focused on the mechanics. Solid mechanics, fluid mechanics, dynamics, but, we may have to drag other principles as well, such as electromagnetism. All the machines now run by the motors. And these motors are controlled by the other principles. And we need to combine all these to add the value of the mechanical engineering.

So, my first wording for the improvement of mechanical engineering or the impact of the mechanical engineering for the future should be the expansion and the conversions with many different principles. And secondly, actually, sustainability was the one word of my title today, which was mainly energy sustainability, but, sustainability can apply to not only energy, environment, economy, and many different, even cultural aspects as well. When we talk about sustainability, we cannot rely on only the quantum leap innovations. We must combine both the traditional efficiency improvement and the innovative quantum leap technical development. So, I think we must have the parallel tactics to challenge the efficiency improvement for traditional technologies—whatever it is—while we attack the quite new quantum leap technical innovations. So, the second, sustainability issue should be resolved by combining both traditional and the new findings, a so-called, I'd say, compromise. So, I can summarize my talk: first, expansion, second, compromise. Thank you very much.

Dr. Hellmut Schmücker

Well, first of all, I'd like to thank you all for this playing vigorous and interesting scheme of technology development so close. In Korea, that was very fantastic for me to see. We have to keep in mind that Korea has a very long history of culture, but a very short history in engineering, only. So we need to be a little bit more patient I think. And if I see the minister talking about the 4^{th} Revolution, I'm a little bit doubtful if this is not too far ahead for our approach. Let me have a few statements. Value-adding processes. In my understanding, in our industry, it normally starts with mechanical engineering. If this is molding, if that is a semiconductor, you need mechanical engineering. So that is the basis for all value-adding processes. Value-added is not in banks, it's not accomplished in administration, but it's accomplished by mechanical engineering. You have clever and very dedicated engineers with an excellent education. The problem to me is, and this is the one of the points I wanted to elaborate this morning, is that universities have about 72% of Ph.Ds but account only for 10% of government spending's on R&D. That is an imbalance. What has to be increased also, I think, is the efficiency of R&D investment. What is also very important is the improvement of R&D management systems and evaluations processes, advice, and so on and so forth. But, I think, to summarize, you are on an excellent path and trail. And the world knows that the next competitor is Korean competitors. Thank you.

Dr. Pamir Alpay

So my colleagues will describe the advances in mechanical engineering. I'd like to say a few things about the evolution of material science engineering and what have been the recent developments in my field. It started off, material science engineering, essentially, started off with metallurgy, which is metal science or metallurgie in German which is perfect word that describes understanding of metals, essentially. It spun off from mechanical engineering department and the field changed significantly in the 80's with the discovery of high-temperature super conductors. These are extremely complexed ceramic materials. And these are exotic materials created in the lab. And while there is an overarching goal of trying to get high-temperature super conductors at room temperature, there were no specific applications in mind for the industry. So people started looking into unique phenomena, which is essentially the realm of condensed metal physics, and not material science. And people started looking into these kinds of unique phenomena, unique metrologies that actually steered science and engineering towards material science, which has elements of condensed metal physics and chemistry. So it is now changing in terms of industrial applications. A lot of materials people are realizing that there is this engineering component into it, too, that we need to serve in terms of finding more viable materials for new applications. So, this kind of re-dedication towards engineering has the potential to transform the technological landscape. There are certain physics based on the models that help them design. I've shown some of those in my talk in this afternoon. But there are also a lot of physics-based models that go into describing processing now. So some of you used already this Procast or ESI that has a lot of 3D printing kind of process modeling applications. So a lot of times, what you need in this case is reliable material properties as an input so you can get meaningful results from commercially-available processing software.

Dr. Peter Hoffmann Thank you. I'm now working for 25 years in terms of laser technology, and I had a chance to do basic research. And we had to understand processes very well. And then we had a task of transferring our knowledge into industrial applications. And I learned a lot about how you can do it efficiently. It's very, very important to have institutes like KIMM who contact the industries, who have young engineers who can learn more about these technologies and start doing business with customers with such laboratories. And the next step; and that is the best you can have is that young guys say, "Ok, I understand a lot of technology, and I will do the job and I take the risk on me to start an enterprise." I think it's important to have the environment which makes it possible for young people to go their own way and have a passion and be supported by universities or by research institutes. In my case, it was exactly so. I had many people who supported me. And today, now I have a company with 120 employees. We are worldwide, active, and successful. Thank you.

Dr. Helmut Schift I can underline what other speakers have said. Particularly, I like what Dr. Bae has said—combining tradition and new findings, and these need to be compromised. And what does "comprised" mean? In Switzerland, we know what "comprised" means. It's not a perfect solution sometimes. It's a solution which works out for a certain kind of time. Maybe, Korean people are very perfect, could it be? You need to teach people to be mature players in the market, and that means they take the different knowledge from the sources, they test out new things, and I think what Dr. Schmücker was saying that we need some kind of systems in engineering approach. I think this is sometimes lacking in research. That means you should not just teach people the fundamentals. That's very important. That's a very traditional thing. But you also need to teach people how to combine things. And in my opinion, this is mostly possible by a project, sometimes, more projects, kind of exposure to a kind of industrial environment. And also, what you said, with a kind of tutoring systems. You need a, really, a kind of ongoing tutoring where older people teach younger people. But sometimes, even the older people need a kind of tutoring because knowledge which you have gained 20 years ago is maybe not the knowledge we need to give this knowledge, your own knowledge, further to other students. Therefore, it's a little bit of a kind of general answer. In terms of processes, which we do with 3D processes, replication processes, I know from European projects that the networking approach is extremely important. That means, you do not need to search for solution only in your own laboratory. Sometimes, you have to get the idea about who else could help you with solving a problem. Sometimes a colleague knows it better, and then you have to make these networks. Sometimes, only for the knowledge exchange, what we have, for instance, in PSI and KIMM, sometimes, you need some kind of joint projects. For that you sometimes need seed money. It's a really a kind of network approach that helps you go beyond your own boarder. And I think the earlier I learned that, the better. And sometimes the older people, they also have to learn about that.

Dr. Chang Jin Kim

I think I understand the question was what I think about what should be the future of mechanical engineering. This is a very difficult question to me also. In these years, all these new things are micro, nano, bio, information, communications, more and more away from the core of mechanical engineering. The definition of mechanical engineering is in tough position. So I've been struggling with the anti-mechanical trend for the last 20 years, being a mechanical engineer. So honestly, I don't think I have a good answer. But when things are difficult, fundamentally, for anybody for mechanical engineering, in this case, my opinion is always go back to the fundamentals. I think it will be really difficult for mechanical engineering to come up with big, new breakthrough directions. In these cases, I think what we can do secondly is to support other breakthroughs using fundamental mechanical engineering. So my tendency is usually to go back to fundamentals. And if something happens, we can break through. I usually, being in academia, usually, I am in the opposite side of trying to plan. Just do what you do best, and when the time comes, the opportunity knocks on the door. And then you can maybe make contributions. I don't like my answer that well, but that's my honest opinion.

Dr. Yong-Taek Im

Thank you. So from the audience, do you really think they answered well or answer to that point? What do you think? Any comments or questions from the floor? I welcome, if somebody, anybody just wants to make any questions or any comments to some of these individual opinions? If not, I think, my question was not so clear to everybody. So let me make it shorter and clearer.

What is the most important factor to make mechanical engineering sustainable in your opinion? Clear? So what is the most important thing to make mechanical engineering sustainable or competitive? Is it a fair question?

Dr. Hellmut Schmücker In my personal opinion, mechanical engineering will be sustainable if the education is solid and broad and not to narrow, not too specialized and if practical training is added. During the terms, one term or two terms, practical training, the training on the job, is one of the essential points to gain experience and see if what you have learned in lessons and in the books is applicable or not. So a good and broad education, not too specialized, and practical training. Thank you.

Dr. Helmut Schift I also just want to outline this. I think the embedment in the real environment that is very important. Environment also doesn't only mean the technology. It also means some real people with knowledge about what's going on in the industry. I think that helps a lot.

Dr. Pamir Alpay I think collaboration is the key. You mentioned micro, nano, bio... so micro, nano, those are not the kind of things that mechanical engineers should take over because electrical engineering is doing micro, nano has been done in medical related fields, and micro in certain aspects in materials. So I think collaboration is one other discipline. It's key for any engineering, not just mechanical engineering.

Dr. Peter Hoffmann Collaboration, of course, is very important. But, in my opinion, the same importance applies to the way of transferring technology, the way technology transfers. And I can only repeat my talk, or I can reduce it. To know how the existing brain of people and you have to support, you have to find ways how people bring their knowledge to the industry as fast as possible.

Dr. Choong Sik Bae If I'm allowed to add one more about this sustainable mechanical engineering, I think the product of mechanical engineering, whatever it is, education, or research and development, and employment, it should be connected to the industry. It should be connected to the product. Sometimes the basic research could be long-term research, 30 years, 50 years. But still, it must aim for the product in the future. For the moment, I mentioned a compromise between the traditional technology and innovative technology development. But all of this is aiming to support the industry. That's why we need to compromise between the two. Today, Minister Joo mentioned the small and medium enterprises. But the reality is that most SMEs are not innovative technology practitioners. They are part manufacturing companies, mostly. These part manufacturing companies need very refined practice of engineering rather than innovations. The innovative things could be the theme of some startups. But that percentage is not so high. And they may deal with micro, nano, bio, and new technologies. But more than 90% of SMEs are dealing with small part manufacturing. We must keep supporting them. Education, or R&D or whatever. In that sense, by 90% of, say, 50%, we must stick to the realistic technology, the conventional things to improve the efficiencies or the accuracies or the credibility or reliability, and so on, while we attack or address the long-term innovative technologies. So again, my key word, the service for the industry. That is the basics for sustainability of mechanical engineering. Maybe that means the world market ability, which you mentioned in the new wording of KIMM. Thank you.

Dr. Hellmut Schmücker

You just mentioned the SMEs, say, SME problems. Because Minister Joo addressed this whole contribution to this field of interest, which is of course of the key to open up real development in Korea. Comparing to my country… just let me start, I remember on page 11 of his contribution, he had a nice colored pyramid. But it just shows only the numbers of companies. Large ones, middle-size, and small-size companies. And if you turn this pyramid from the tip to the toe, then you have the reality because this is the contribution to the GNP of Korea. 90% comes from the big companies, and 10 percent comes from the very small companies. And it should be vice versa to begin with, honestly. What I was missing from this contribution, and I was not ever to ask it because there was a very short amount of time, I would expect if you really assist and aid SMEs and really want to foster them to make contribution to the gross national product of Korea, you need a financial aid program which is a long-term program to make them, to give them the ability to continue their work in long-term, not in two or three years, but ten years. Because it takes a long time to accomplish the technology to the people and to the company. What I was also missing is the indication that the management assisting program is necessary. To be an entrepreneur, it's not a matter of a six-month course. But it takes more emphasis, and they should be given intensive help to understand what an entrepreneur does and what kind of future he has to expect. Thank you.

Dr. Chang Jin Kim

I remember when I was going to college, going from freshman to sophomore. I was trying to choose my major. And I still remember one of my relatives who knew something about engineering told me mechanical engineering is very good because it's very stable and it's always number two. And this is actually true, even today, in the US, and I think it's worldwide. Mechanical engineering is, in terms of the popularity for high school students to go to college, mechanical engineering now, again, is number two. Computer science is number one; it used to be electrical engineering. Electronics was number one 15 years ago, and they are actually at the bottom. So in that sense, not only in college wise, but industry wise, mechanical engineering is something like that. So when I was talking earlier that we can always go back to the fundamentals, with the collaboration in mind, we can always; the good thing is, mechanical engineering is always valuable. I don't think any of those hot topics can be obtained without having any machines. And mechanical engineering actually does make machines. In that sense, I think mechanical engineering is great. When we talk about the issues right now, it's actually about something very hot right now. AI (Artificial Intelligence), maybe, in Korea. Not that much outside. But, Korea, right now is AI. And I don't think we should go for that. We should go for ten years, not just five years or something. In that sense, mechanical engineering is, I always say, we need to go back to fundamentals. Even if it's something hot right now, we don't necessarily need to lead the hot topic. We can always be the supporting cast for any hot topics at the moment. So in that sense, I think in a way, we are fine. In terms of policy that Hellmut was trying to ask, say earlier, I have a lot of opinions, actually on those hands. However, we don't have any policymakers in the audience, so I don't think it's that useful to talk about the policymaking in Korea.

Dr. Yong-Taek Im That reminds me that, when I just visited the Technical University of Berlin, they just showed me the future work to develop, to replace the machining people by robots. So they want to develop this machining robot. So that's a very simple idea, but we, in the Korean robot society, nobody was talking about, many people, they were talking about building robots, but nobody is talking about machining robots. So, in Korea, we are talking about this dancing robot or robot that does soccer games, and, like this AI; they are talking about AI. But in reality, I think, in the AI field, the microprocessor is, the speed of the microprocessor is also important to make compared to any software algorithm or shell of AI. So from that point, do you have any recommendation to our research program of KIMM to improve our research productivity?

Dr. Hellmut Schmücker First of all, I have a bad news for you. The number one company, Kooka in Oxford was sold to the Chinese. They have a stakeholder of over 50% now. So I didn't understand the deal because I was wondering, "Where is the German automotive industry?" They should have grabbed it, but they didn't. Robot for production is maybe not as sensational as robot for dancing or serving elderly people, but I think this is in progress. We have a lot of robots already for machining and the process we already started here. I think Korea has an obligation not only to start it but to emphasize this because, from what I've shown this morning, from the shortage of manpower, from the shortage of engineers, which will come particular vocational training, that's what I missed this morning. Vocational training is so important because, before robots come, you need to have excellent vocationally-trained people to operate these machines so that the robots can learn it. So this is the field, simply the must for Korea because you will have a shortage of people later in the production process.

Dr. Peter Hoffmann I think to make production efficient, you need automation solutions. And robots are part of automation. Robots were introduced in production, I think, in the 60's. And it started during the Industrial Revolution to use robots for production. And now we are going to have the 4th Industrial Revolution. And for that, I think it's important or necessary to make, to improve software how to operate such systems. How to operate together in multi-move systems for example. How to get machines more flexible in terms of being used for different products. The same technology, the same system technology to produce different products. And using high automated systems does not mean to have fewer jobs. If you have more efficient production, you can have more administration, and besides, the quality of working can be raised.

Dr. Yong-Taek Im What time is the end of this panel? Ok, we are on track. And as a senior research scientist, please give us a recommendation to improve our productivity for young research scientists.

Dr. Hellmut Schmücker The research scientists should be encouraged to develop products which can be implemented in the industrial processes. Now, this is a simple sentence, but, it's hard work. To implement into the production, particularly into these SME enterprises, which we were talking about, it requires, of course, SME enterprises are capable and able to understand and are fit to go into production and to have vision that this is the selling product. So it's supposed to work on both sides. That's why I was so happy to see that SME problem is really addressed because it has to be developed. Because they are the customers of KIMM today and tomorrow. Even I hope more for tomorrow than today. So I'd like to encourage those excellent engineers and clever researchers at KIMM to find out if their product, their development as real applications, they normally know but, to find out a company which is able, capable of, made capable to produce this item for the benefit of the market. Thank you.

Dr. Pamir Alpay Ok, so, adding to Hellmut's point is teamwork. That's also one of the key aspects. Building on teams working on goals together. That's the only thing I wanted to add there.

Dr. Helmut Schift We are very often talking about Germany, which is a good example of how things are working. I've been in Denmark for a sabbatical. Well, I have to tell you Danish people learn to work in groups very early. I think even in the kindergarten already. And I think that a collaborative approach, teaching a collaborative approach, small projects, not for a big purpose in school in the beginning, that is something where maybe you can see later. I would say, for future, involvements and collaborations. I do not exactly know how the education system in Korea is, but not only working together in the same level but also being able to ask the superiors as early as possible without any fear of being criticized. This is a very important thing. I was amazed at young Ph.D. students who are already little bit older had no fear to ask me as a visitor there about my opinion. They immediately discussed with me, and I think, in Switzerland, I was not used to that. Therefore, you have to really lower, I would say, the thresholds into action.

Dr. Chang Jin Kim I think the question was how to improve the productivity of KIMM, and I have an opinion. But I think everybody already knows. Also, I don't know that would be the solution or not. But I think number one, when I observe over the years how KIMM researches work, it's actually the same everywhere in Korea, though. I think researchers should spend more time doing research. I do teach; I do research. So I do have to write proposals, make reports. I have to go to meet people and meetings. Yes. But compared to Korea, it's nothing. Korea is in a way pretty extreme to ask for researchers to do the paperwork. And I think everybody knows it; everybody complains about it. I don't think it's just KIMM but anywhere, everywhere else in Korea is the same. So I think the problem starts from the government. That's why I was complaining earlier that there is nobody listening for policymaking viewpoints. So, in a way, it's kind of strange, but, that is my opinion. If there is anything you can do, Dr. Im, as a director, make researchers spend more time doing research. That's the number one observation I have always.

Dr. Yong-Taek Im I think the time is up. So, well, I'm doing very good, right, to control the time? It's 6:10. So, I just want to wrap up this panel discussion. And I really appreciate your active participation to share your opinion and comments on some of those abstract things. And when I think about the last comment of working together on some topics which are really important for the future, I think everybody knows it's very important. And also, the comment of Prof. Kim, yes, we know what you are talking about. And it's a very complicated issue everywhere, even in the United States. You have to travel Washington D.C. to get the funding. So the same thing, everywhere. But the thing is, yesterday, I was discussing with some of the visitors, and I found out at the Fraunhofer Institute, they don't have any order from the government for setting up the direction of their research. So that's very good. And I really hope we can achieve that kind of research environment here in Korea. So, again, I just want to conclude this session. And thank you for your participation and contribution.

CLOSING REMARKS

Yong-Taek Im
Chair of IFAME and President, Korea Institute of Machinery and Materials, Korea

I believe that today has been a great experience and another important step to stimulate technological innovation and create a fertile environment for convergence for manufacturing.

I would like to thank all the speakers and session chairs for their contributions, and the steering and organizing committees for their sincere dedication to planning and coordinating the Forum. Your professionalism, strong commitment, and excellent collaboration resulted in an illuminating event.

I also appreciate all the support and help from international office and other colleagues. As you have already noticed, we just had new rising stars of two MCs running today's event. Let's give a round of applause to Dr. Ji Hyeon Lee and Mr. Gwang Bum Seo.

And I really appreciate your participation until this last moment. A lot of times, when we have this kind of meeting, it's not easy to stay late. I am really thankful for all of your participation from abroad and from within Korea.

Let's enjoy final event, the Gala Dinner tonight.

Thank you very much.

MEMORIES OF THE FORUM

Speakers of the forum visited KIMM's labs before the forum.

Speakers and former presidents of KIMM had dinner before IFAME 2016.

Opening Remarks by Dr. Yong-Taek Im, President of KIMM

Congratulatory Remarks by Mr. Jae Moon Park,
Deputy Minister of Ministry of Science, ICT and Future Planning

Congratulatory Remarks by Dr. Sang Chun Lee,
Chairman of National Research Council of Science and Technology

Congratulatory Remarks by Mr. Eun Kwon Lee, Member of National Assembly of Korea


Congratulatory Remarks by Mr. Sang Min Lee, Member of National Assembly of Korea

Dr. Chang-Jin (CJ) Kim, Professor of Mechanical and Aerospace Engineering at UCLA, giving a talk entitled “Superhydrophobic Surfaces for Reducing Frictional Drag: Dream or Reality?”

DR. Helmut Schift, Head of Polymer Nanotechnology Group of Paul Scherrer Institute, giving a talk entitled “Back to Mechanics – How Nanoimprint Lithography Changed the Way How We are Thinking about Nanomanufacturing?”

Dr. Hellmut Schmücker, retired Head of Technical Division, Max Planck Institute for Physics, giving a talk entitled “KIMM – Birth, Growth, and Impact”

Dr. Jeong-Soo Lee, Vice President of Materials & Devices Advanced Research Institute at LG Electronics, giving a talk entitled “Innovative MEMS, Opto, and Nano Technologies in LG Electronics”

Dr. Peter Hoffmann, Managing Director of Erlanger Lasertechnik GmbH, giving a talk entitled “Laser Welding in High Volume Production”

Dr. Pamir Alpay, Professor and Department Head of Materials Science & Engineering at University of Connecticut, giving a talk entitled "Accelerating Materials Deployment and Manufacturing via Multi-Scale Modeling and Genomics"

Dr. Man-Been Moon, Vice President of Hyundai Steel Company, giving a talk entitled "Hyundai Steel's Challenge toward Automotive Steel Specialized Steelworks"

Dr. Jack Wang, Director of Metal Processing R&D Department at MIRDC, giving a talk entitled "The R&D Prospects of Additive Manufacturing (AM) Technology at MIRDC"

Dr. Choong-Sik Bae, Professor and Chair of School of Mechanical & Aerospace Engineering at KAIST, giving a talk entitled "Vision of Energy Sustainability"

Dr. Young-Sup Joo, SME Minister at Small and Medium Business Administration, giving a talk entitled “Korean SME Policy Innovation for Creative Economy”

Dr. Yong-Taek Im, President of KIMM, giving a talk entitled “KIMM for Creative Economy”

At the opening ceremony: host, speakers and VIPs


Participants enjoying luncheon

Panel Discussion

Participants

Participants enjoying dinner

Opera singing during the gala dinner


Speakers and Steering Committee members


Steering/Organizing Committee members &
Mr. Mik Fanguy, Visiting Professor of Scientific Writing at KAIST

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Mechanical Engineering & Global Sustainability

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