graphene 2012
April 10-13, 2012 · Brussels (Belgium)

Korean Graphene Research Activities and Roadmap

April 10, 2012

Byung Hee Hong

Seoul National University

Abstract

Recently, Korean government has approved a plan for commercializing graphene technologies, including;

1) graphene-based touch panels
2) organic light-emitting diodes (OLEDs)
3) electro-chromic smart windows
4) secondary batteries for electronic vehicles
5) high-voltage high-power supercapacitors
6) ultra-light and strong composites
7) high-performance gas barrier films,
8) electro-magnetic interference shielding, and
9) environmentally friendly anti-oxidation steel plates.

These items have been carefully selected considering economic efficiency and technological feasibility. In addition, Korea is also planning a "*Korean Graphene Hub*" project that is focusing on the fundamental sciences of graphene and related 2D materials, separately.

In this talk, the brief history, recent status, and prospect of Korea's graphene projects will be introduced, and discuss how we can harmonize the world-wide graphene projects based on international collaboration rather than competition.

Contents

1

Introduction

- Korean Graphene Research Society
- Number of Research Papers/Patents
- Governmental Research Budgets
- University-Related Research Activities

Graphene
Research
Laboratory

Brief History of KGRS

- Sep. 1, 2008, First Korean Graphene Meeting hosted by Prof. B. J. Cho at KAIST
- Jun. 29-Jul. 2, 2009 1st Recent Progress in Graphene Research (RPGR) held at KIAS, organized by Y. W. Son and A. Castro Neto et al.
- Aug. 2-6, 2010, During 2nd RPGR, Korean graphene researchers planned monthly meetings at SKKU.
- Sep. 30, 2010, Seminar by H. Cheong (Sogang U.)
- Oct. 28, 2010, Seminar by H. S. Shin (UNIST)
- Nov. 25, 2010, Seminar by B. J. Cho (KAIST)
- Dec. 9, 2010, Seminar by I. Oh (KAIST) …

Conference organized by KGRS

- Nov. 10-12, Dasan Conference on Graphene, Jeju
- Jan. 21, 2011, 1st KGRS Meeting, UNIST
- Apr. 1, 2011, 2nd KGRS Meeting, KAIST
- Jun. 28, 2011, 3rd KGRS Meeting, POSTECH
- Apr. 8, 2011, National Assembly Forum on Graphene
- Oct. 3-6, 2011, 3rd RPGR, SKKU, Suwon

Korean Graphene Research Society (KGRS)

http://www.graphene.or.kr

Steering Committee

H.-J. Lee (Chair, POSTECH)
K. Cho (POSTECH)
H. Cheong (Sogang U.)
Byung Jin Cho (KAIST)
S. Y. Choi (KAIST)
S. Hong (Sejong U.)
B. Kim (Dongjin Semichem)

Secretary

B. H. Hong (SNU)
H. S. Shin (UNIST)
S. W. Jeon (KAIST)
T. Lee (POSTECH)
S. Seo (Sejong U.)
H. J. Chung (SAIT)
Y. W. Son (KIAS)

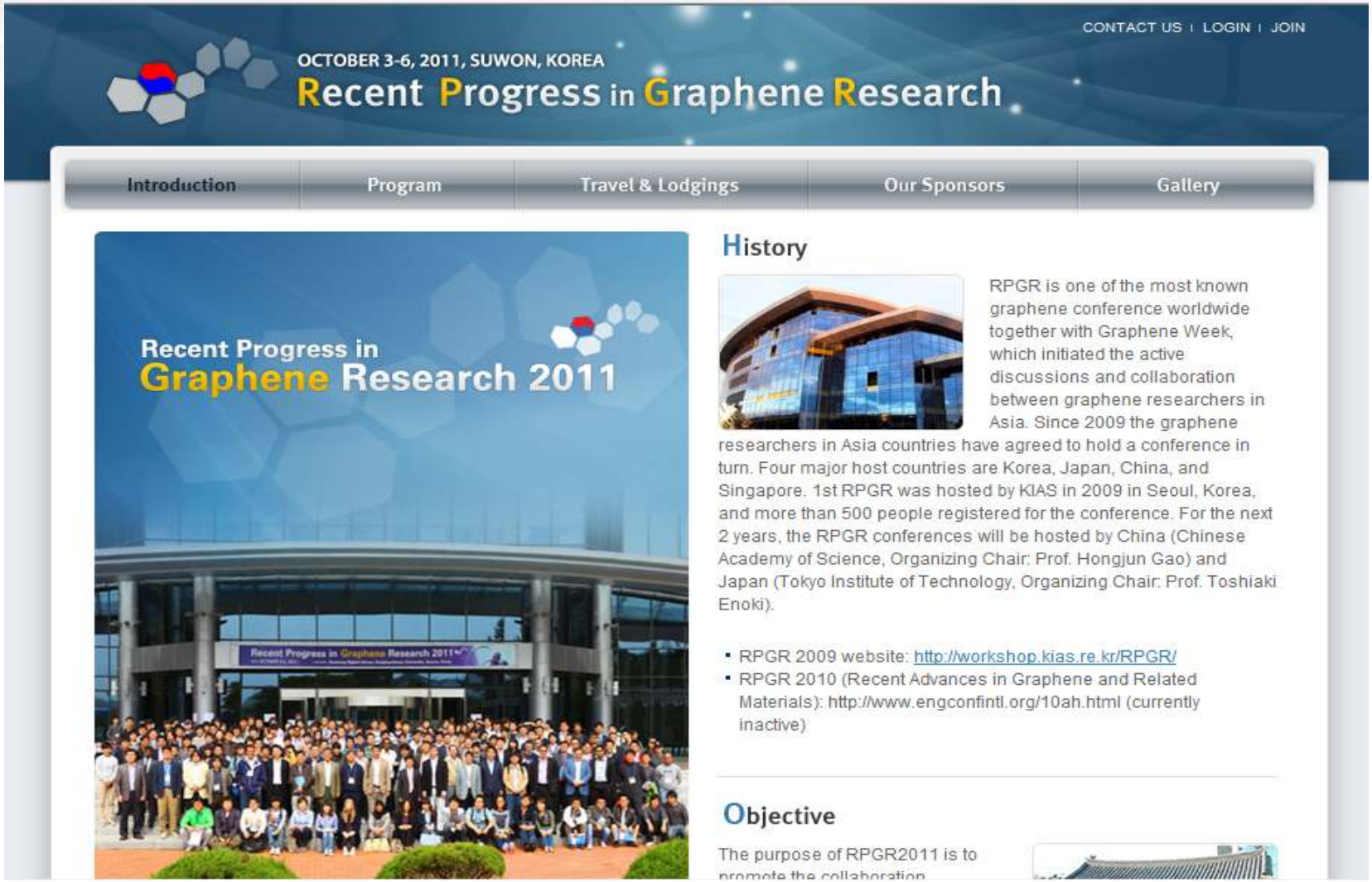
Organization Meeting of KGRS
April 1st, 2011, KAIST

National Assembly Forum on Graphene

Apr 8, 2011
National Assembly Building, Seoul

RPGR 2012, Suwon, Korea

http://www.graphene.or.kr



Oct. 3-6, 2011, SKKU, Suwon

RPGR 2012, Suwon, Korea









Oct. 3-6, 2011, SKKU, Suwon

Research Highlights from Korea

Synthesis & Patterning

- **Sejong Univ**: MBE method
- **SKKU**: Large-area graphene by CVD
- **Samsung Electronics**: Catalyst-free PECVD
- **SKKU**: Room-temperature reduction of graphene oxide
- **POSTECH**: Graphene synthesis using solid sources
- **KAIST**: Nanopatterning via block copolymer lithography
- **UNIST**: Chemical exfoliation using edge functionalization

Property Characterization

- **POSTECH**: Quantum Hall effect and nanoribbon characterization
- **Univ. of Seoul**: THz characteristics
- **SKKU**: Chemical Doping
- Sogang Univ.: Polarized Raman spectroscopy
- **Kunkuk Univ.**: Friction anisotropy in graphene domain structures
- **Sejong Univ.**: Nitrogen doping and defect structure analysis
- **KAIST**: TEM imaging of liquid samples using graphene membranes

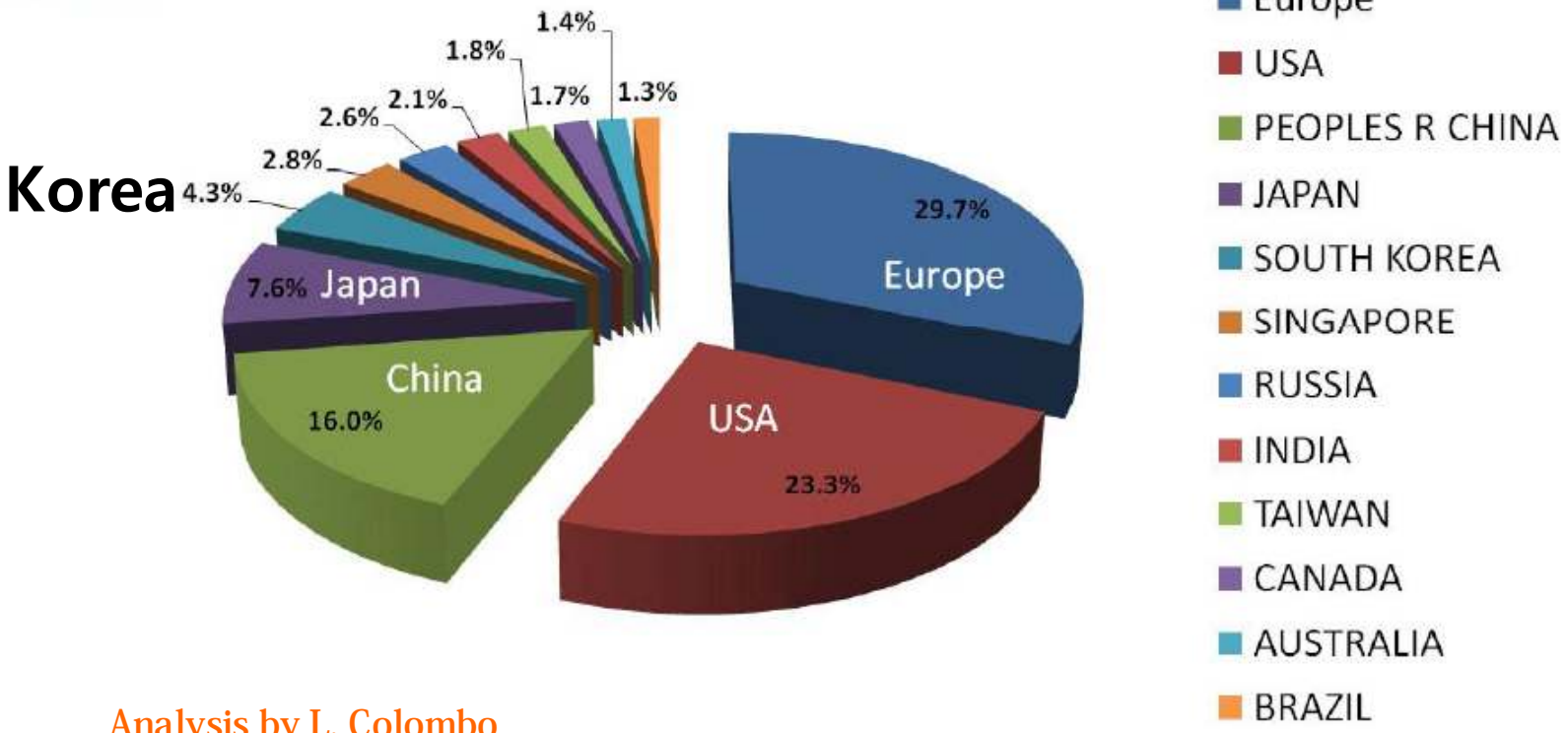
Theoretical Works

- **KIAS**: Electronic structure of graphene on SiC and Strain effect
- **POSTECH**: Giant magnetoresistance near defects in graphene
- **POSTECH:** DNA sequencing device using graphene nanoribbon
- **KIAS**: Work function of bilayer graphene under mechanical strain
- **KAIST**: Doping effect of graphene on dielectric

Device Applications

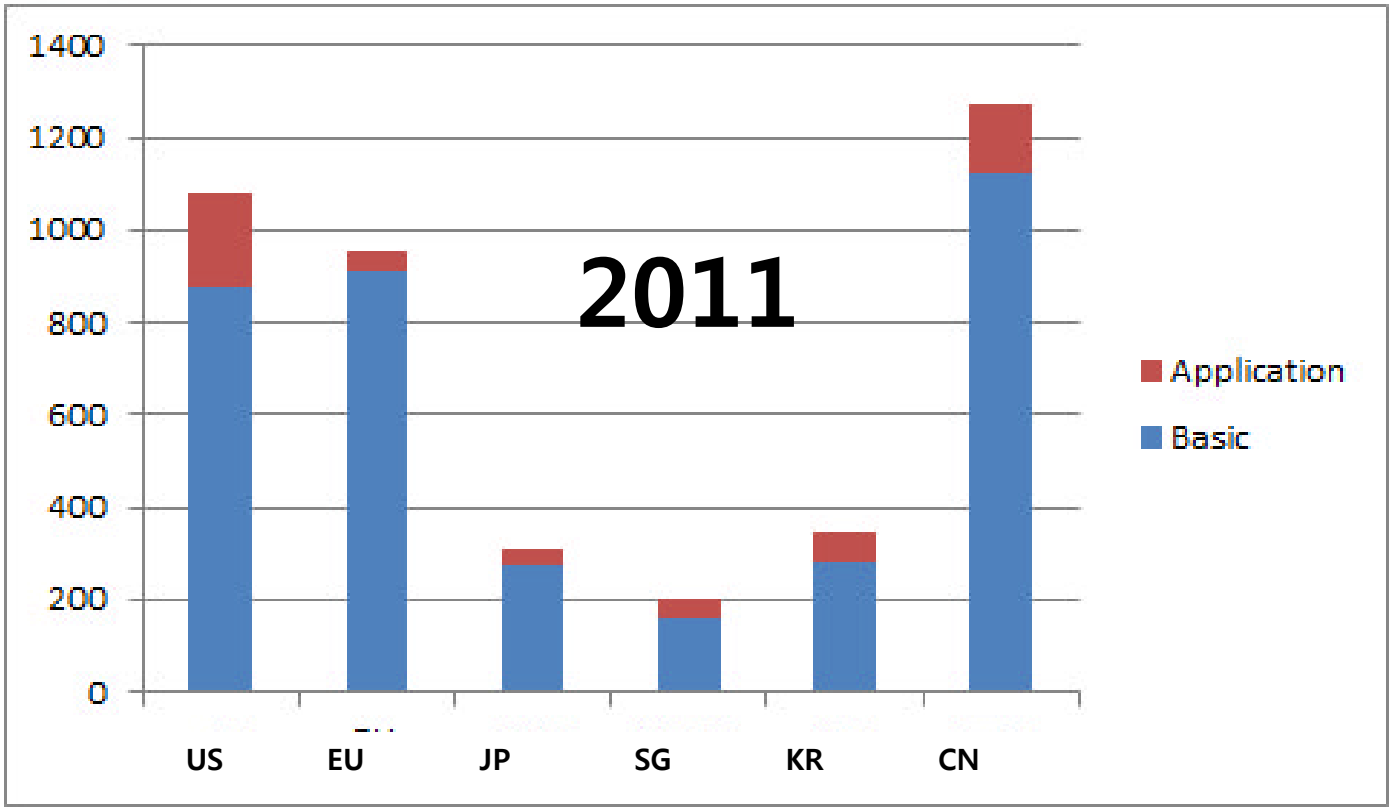
- **SKKU**: Transparent electrodes for solar cells and display
- **GIST**: Electrodes for solar cells, fuel cell, and molecular devices
- **KAIST**: Field emission from graphene-CNT hybirid material
- **SNU**: Graphene substrate for LED
- **KAIST/ETRI**: Nonvolatile flexible memory using graphene oxide
- **KAIST**: Supercapacitor using doped graphene
- **KAIST**: 20 nm flash memory using graphene

Number of Graphene-Related Papers Published in 2000~2010



Analysis by L. Colombo

Number of Graphene-Related Papers Published in 2011



"Report on Korean Graphene Hub (2011) by KGRS

Governmental Research Budget in Korea (2007~2010)

Institution		2007	2008	2009	2010	Total
Ministry of Education, Sci. & Tech.	No. Projects	8	20	58	75	161
	Budget (USD)	**495k**	**1,416k**	**15,769k**	**20,416k**	**35,096k**
Ministry of Knowledge & Economy	No. Projects	-	-	3	9	12
	Budget (USD)	**-**	**-**	**942k**	**2,081k**	**3,023k**
Ministry of Environment	No. Projects	-	-	1	1	2
	Budget (USD)	**-**	**-**	**85k**	**95k**	**180k**

"Report on Korean Graphene Hub (2011) by KGRS

Governmental Research Budget in KR/US/EU (2006~2010)

Country	Year	~2006	2007	2008	2009	2010	2011	Total
S. Korea	No. Projects	1	8	13	88	148	145	403
	Amount (mil USD)	0.7	1.0	0.6	18.0	28.5	15.7	64.6
US	No. Projects	3	11	26	52	69	7	168
	Amount (mil USD)	3.3	4.3	25.5	17.9	21.8	17.2	74.6
EU	No. Projects	1	2	6	14	20	4	47
	Amount (mil Euro)	2.1	2.3	8.1	12.2	29.5	14.4	68.8
Source http://rndgate.ntis.go.kr, http://www.nsf.gov, http://cordis.europa.eu/								

"Report on Korean Graphene Hub (2011) by KGRS

University-related research activities in Korea

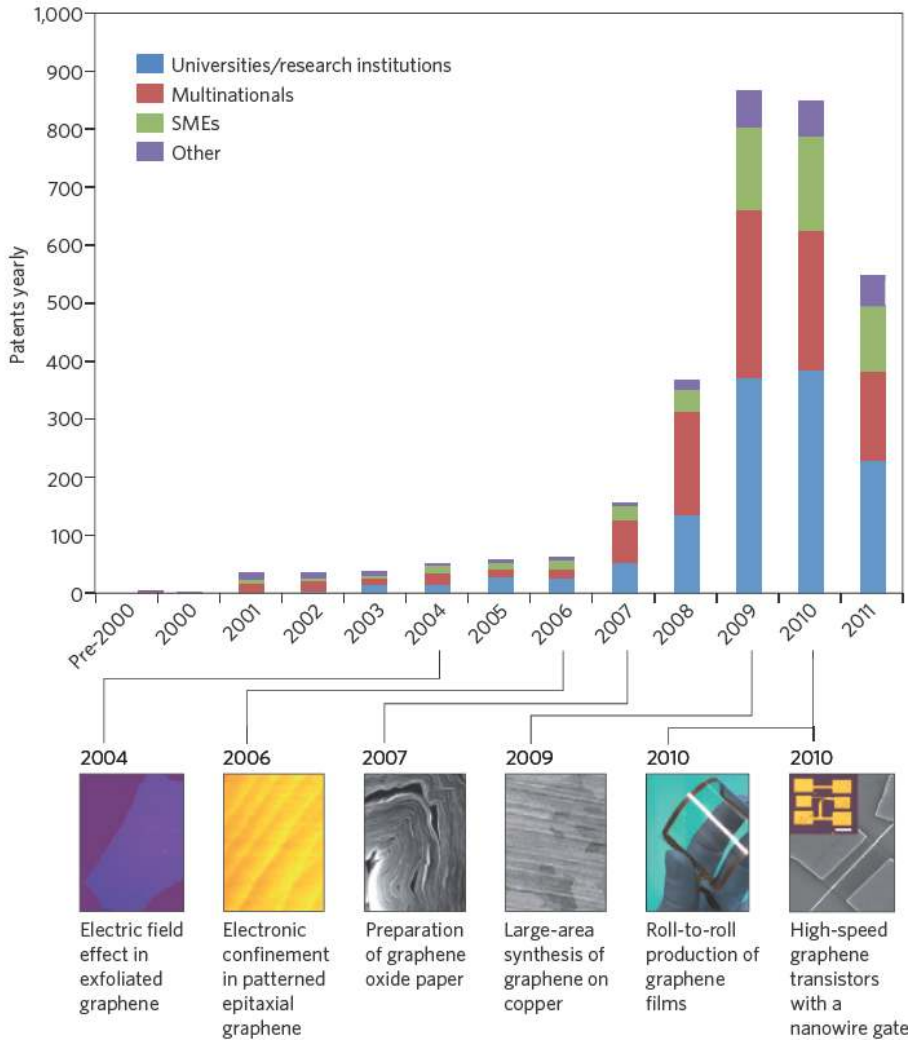
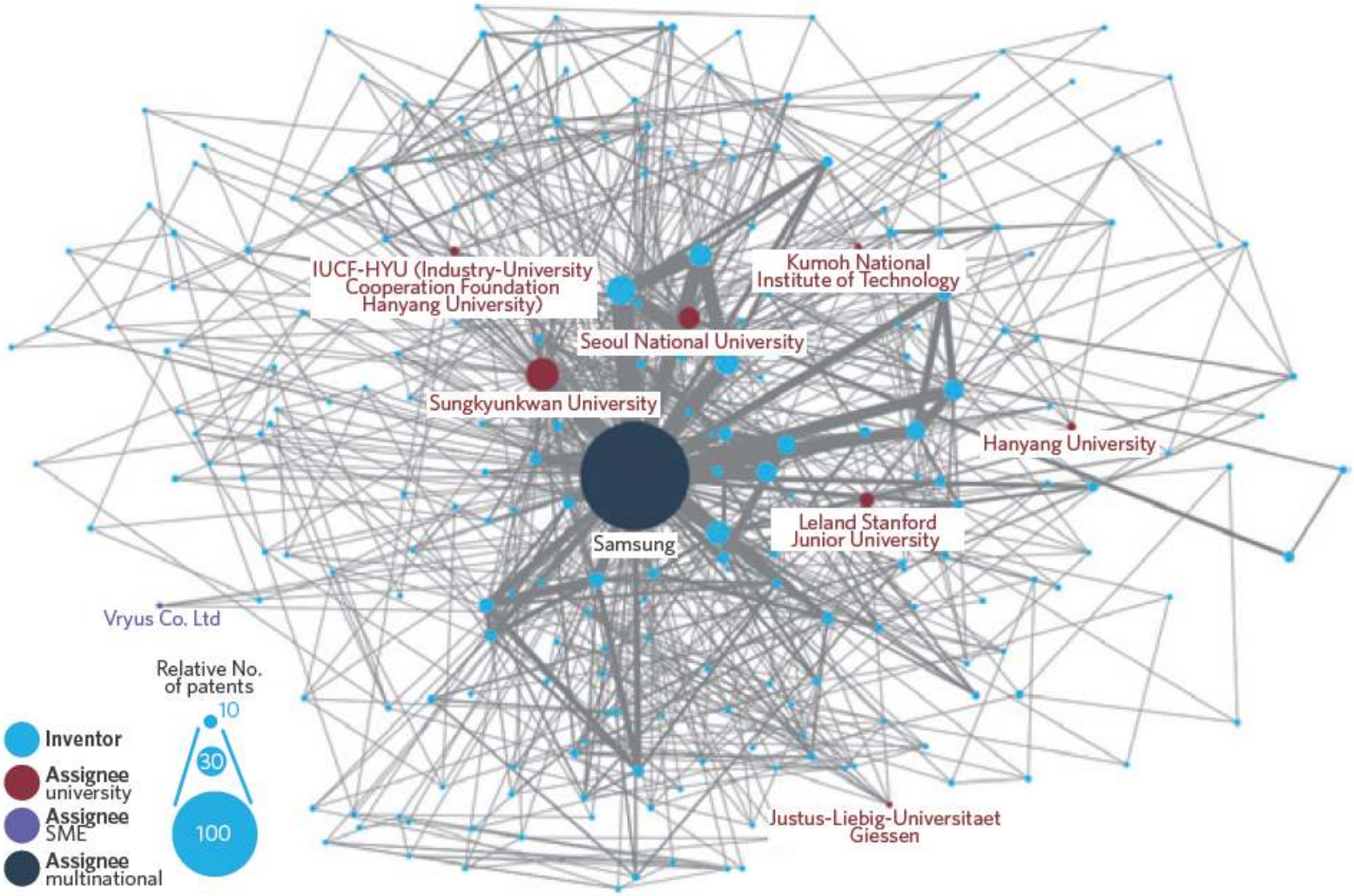


Table 1 | Top 10 ranking of university-related inventors by number of patents

Rank	Name	Number of patents	Organizational affiliations in inventor's graphene patents
1	Jae-young Choi	62	Kumoh National Institute of Technology; Samsung; Sungkyunkwan University
2	Hyeon-jin Shin	43	Samsung; Sungkyunkwan University
3	Seon-mi Yoon	39	Samsung; Sungkyunkwan University
4	Ilhan A. Aksay	35	Battelle Memorial Institute; Princeton University; Vorbeck Materials Corporation
5	Hyun-jong Chung	34	Samsung; Seoul National University; Sungkyunkwan University
6	Sun-ae Seo	33	Samsung; Seoul National University; Sungkyunkwan University; Leland Stanford Junior University
7	Byung Hee Hong	28	Samsung; Sungkyunkwan University
8	Yun-sung Woo	21	Samsung; Seoul National University; Sungkyunkwan University
9	Robert K. Prudhomme	21	Princeton University; Vorbeck Materials Corporation
10	Rodney S. Ruoff	20	Graphene Energy; Northwestern University; Texas Instruments; University of Texas
11	James M. Tour	20	University of Texas; William Marsh Rice University
12	John S. Lettow	18	Princeton University; Vorbeck Materials Corporation

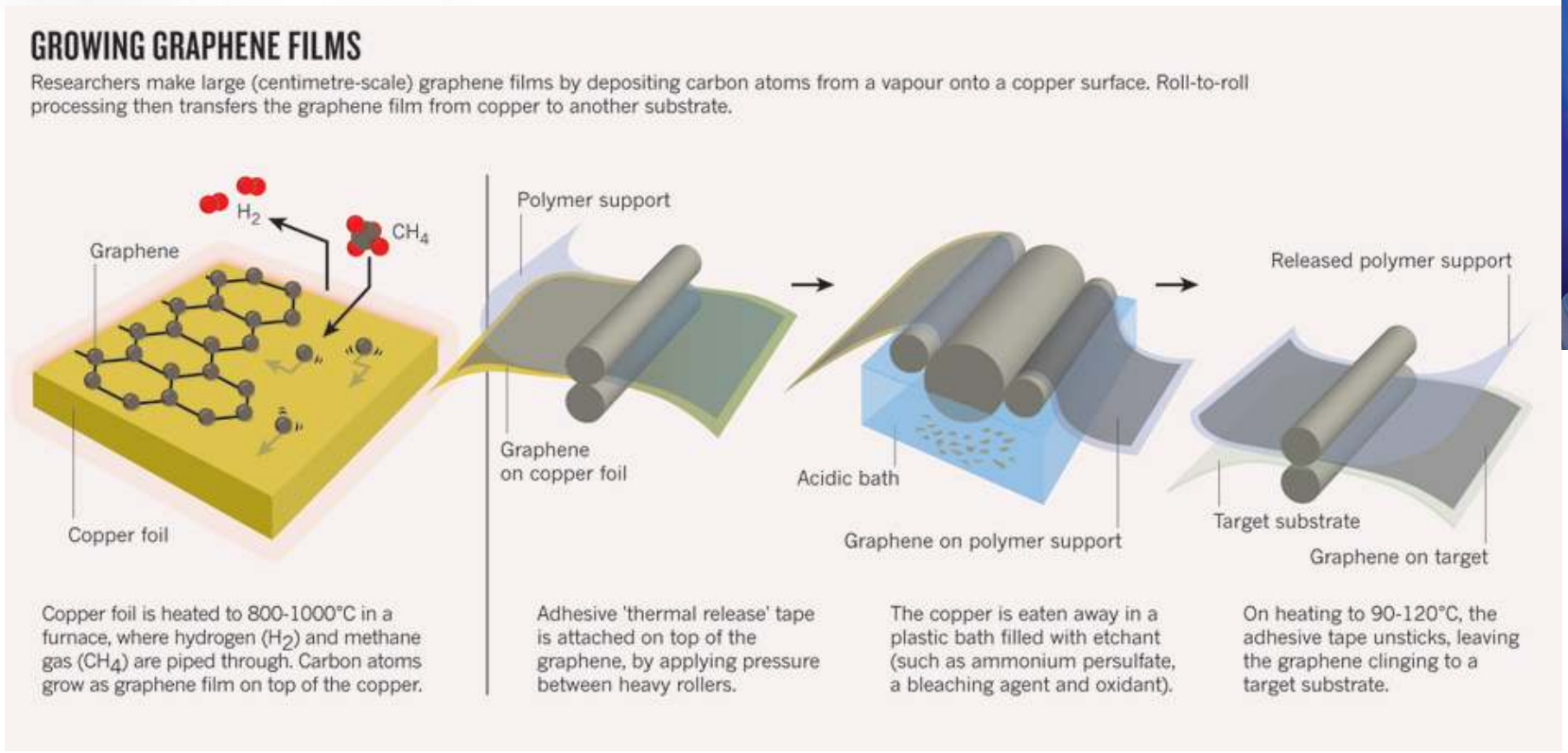
Nature Mat. 11 (2012)

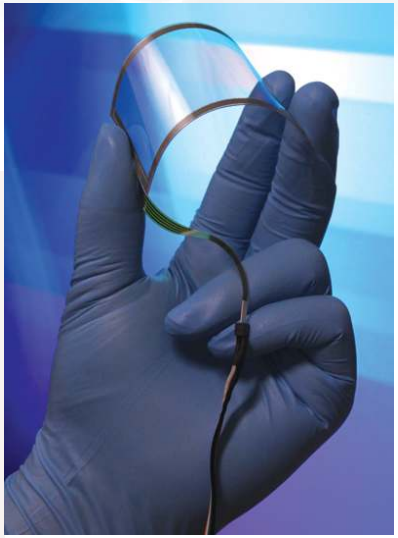
University-Company Cooperative Research Activities in Korea

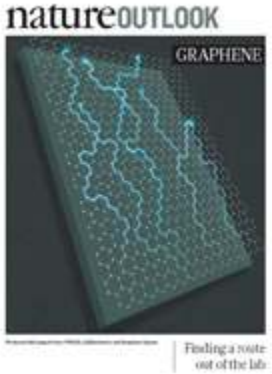


Nature Mat. 11 (2012)

Nature Outlook Special Issue on Graphene







Nature 483 S29-42 (15 March 2012)

2

Korean Graphene Research Hub

by Ministry of Edu. Sci. & Tech.

- Background
- Purpose
- Organization
- Budget

Backgrounds

- There is a nation-wide criticism that Korea has been too much focus on near-term application and commercialization.
- Korea is one of the countries paying the most royalties for the use of fundamental technologies. (ex. CDMA technology by Qualcomm, 6 billion USD a year).
- Korea is No. 1 in display industry, but 90% of transparent electrodes are imported from Japan.
- The competitiveness of final set products are strong, but fundamental technologies for materials and components are very weak.

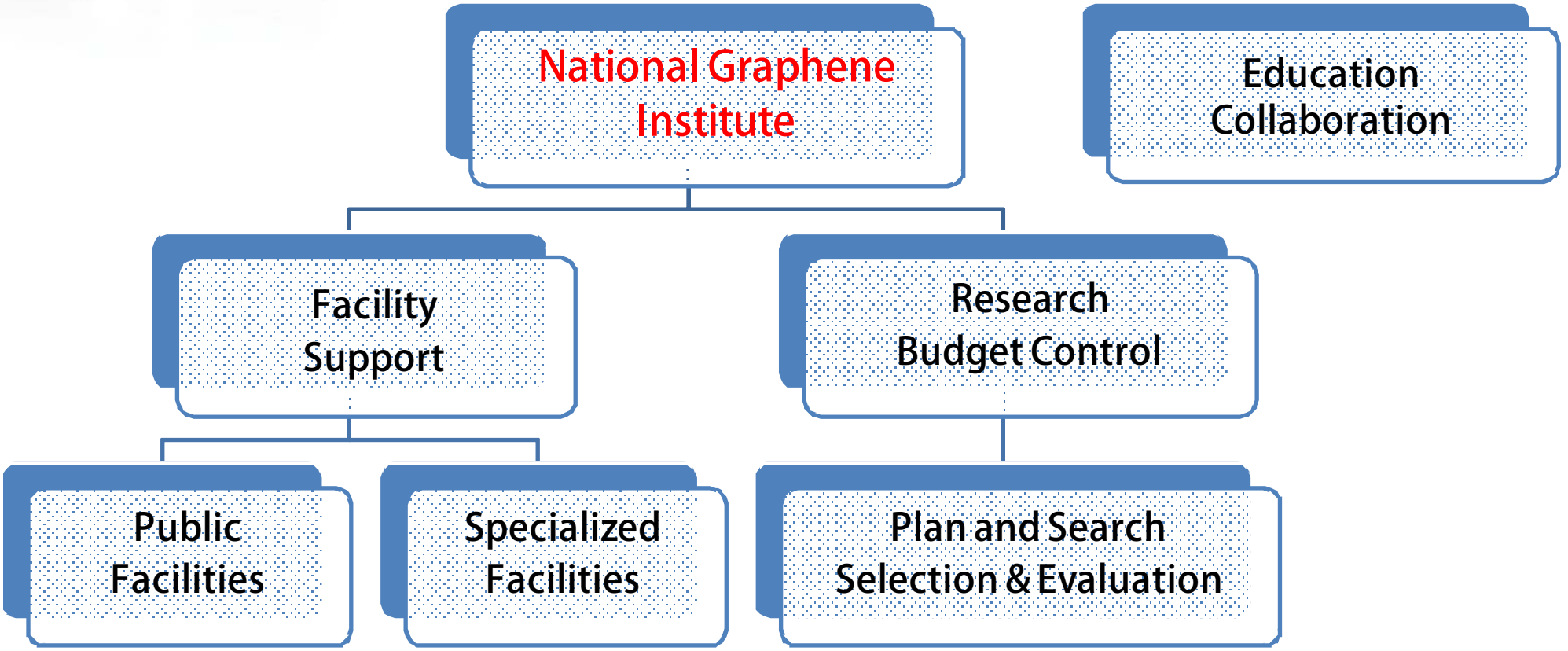
Purpose

- To support individual researchers by providing the most advanced research facilities dedicated to graphene and related 2D materials researches.
- To minimize duplicated investment and internal competitions.
- Fair distribution of governmental research budgets
- To educate general people to understand the importance of graphene researches
- To promote the international and company-university collaborations.

Demand Analysis & Planning Project by KGRS (2011)

- Option 1. Independent Governmental Institute (200~300 mil USD/year)
  - ✓ Takes long time for legalization process
  - ✓ Good for many researchers
- Option 2. (A branch of) Institute of Basic Science (~100 mil USD/year)
  - ✓ Budget has been already secured at least for 10 years.
  - ✓ Director-oriented program (~ Max-Plank Institute).
  - ✓ Good for only 4~5 PIs
- Option 3. Central Fab. Facility & Funding controlled by KGRS
  - ✓ Limited budget
  - ✓ Duplication with existing Fabs.

Organization

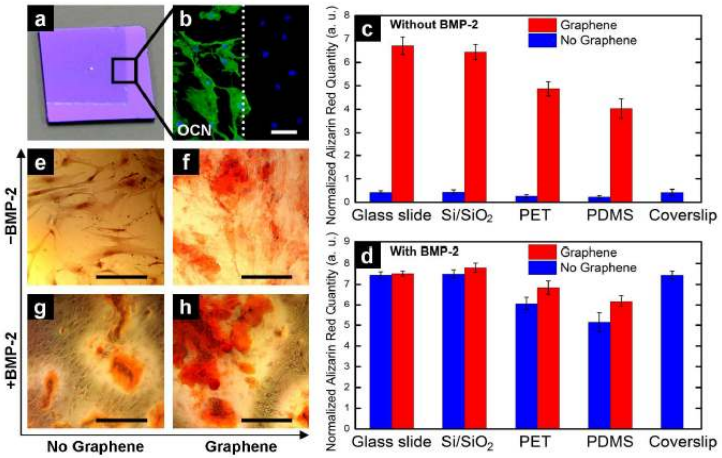


Examples

Specialized Facility

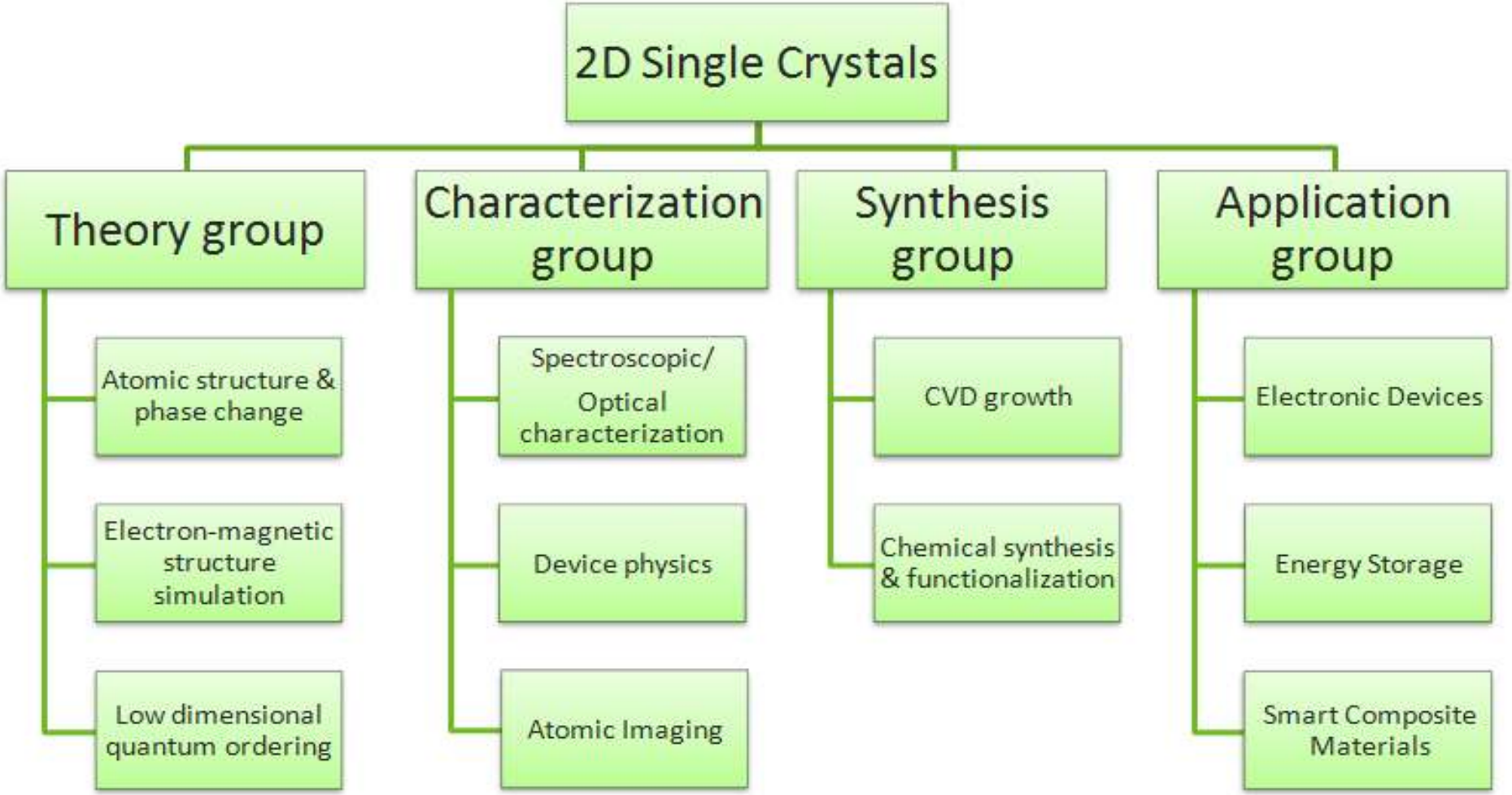
Ultrahigh Magnetism Facility

Finding and Supporting New Research Topics



Biological Applications of Graphene

Research Areas



Research Budget (mil USD)

Category	Years						비고
	1st Stage					2nd	
	2013	2014	2015	2016	2017	2018	
1. Construction	4	18	18	0	0	0	40.0
Site	0	0	0	0	0	0	
Building	4	18	18	0	0	0	
2. Facility	0	0	15	10	0	0	25.0
3. R&D	0	6.7	18	20	20.5	21	86.2
Labor Cost	0	2.8	7.5	8.4	8.6	9.0	
Direct Cost	0	2.8	7.5	8.4	8.6	9.0	
Overhead	0	1.1	3.0	3.2	3.3	3.5	
4. Management	0	0.5	2.5	3.5	4	4	14.5
Sum	8.0	25.2	53.5	33.5	24.5	25.0	169.7

3

Graphene Materials and Components Commercialization Project

by Ministry of Knowledge and Economy

Graphene
Research
Laboratory

Backgrounds

- Many companies are interested in graphene materials, but suffering from the lack of information.
- More and more graphene researches are moving toward applications. However, they don't exactly know the demand and the technological details to be used in real applications.
- Even big companies don't want to take the initial risks of investing on graphene materials.

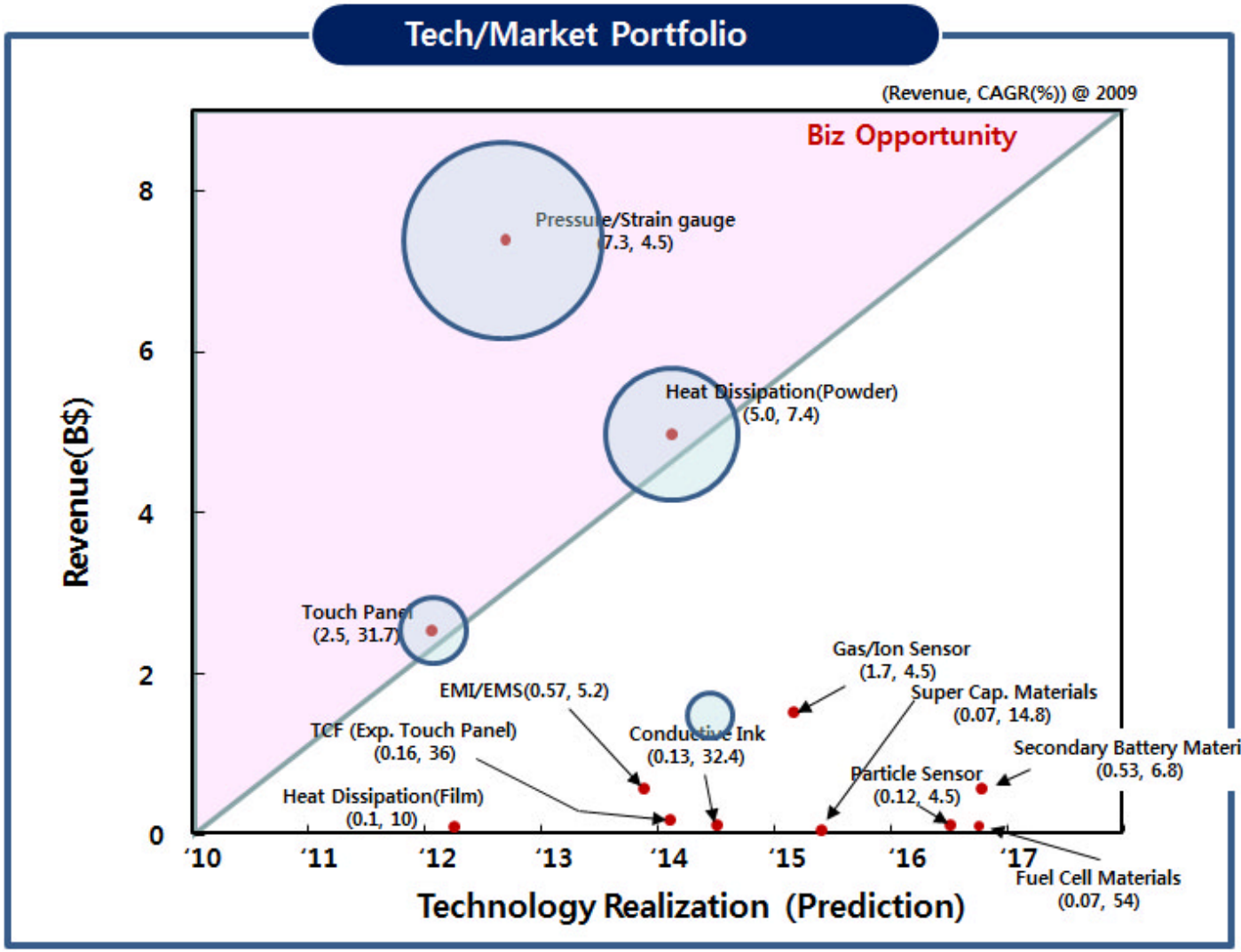
Purpose

- To promote the collaboration between big, medium sized companies and university/institution researchers.
- To minimize duplicated investment and internal competitions.
- Government takes the risk of initial investment, and draws more investments from non-governmental institutes and companies.

Mass production

Company	Items	Status
Samsung Techwin	Large-are CVD Graphene	2nd generation pilot plant to be completed in 2012
POSCO, Hanwha Chemial	Graphene Nanoplatelets For energy electrodes and composites	Co-investment with XG Science 200 tons / year in 2014
Envirotech.	Graphene Nanoplatelets For energy electrodes and composites	1 Kg/day 70 tons / year in 2014
SSCP	Graphene Nanoplatelets For Heat Dissipation	300 tons /year

mass production



TCF : Transparent Conductive Film

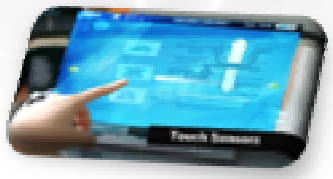
mass production

1st generation pilot line of Samsung Techwin

Recent R&D status: mass production

Pilot plant, Envirotech.

Investment to XG Science
POSCO & Hanwha Chemical



Flexible Display Touch Screen

Transparent electrodes

Nano-inks

Conductive Ink EMI

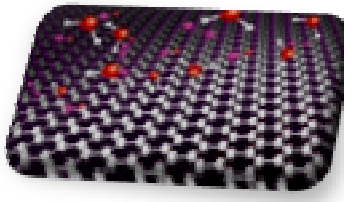
High-speed Transistors RFIC, Sensor

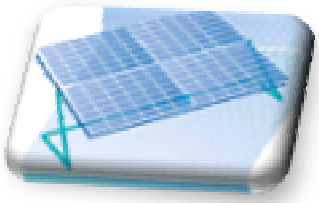
Next Generation Semiconductors

CVD Graphene & Graphene Nanoplatelets

Barriers

Gas barriers For displays packaging



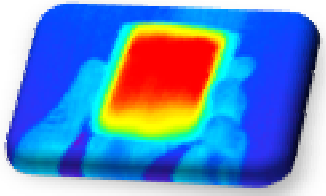


Solar-Secondary-Fuel cells Supercap.

Energy Electrodes

Heat Dissipation

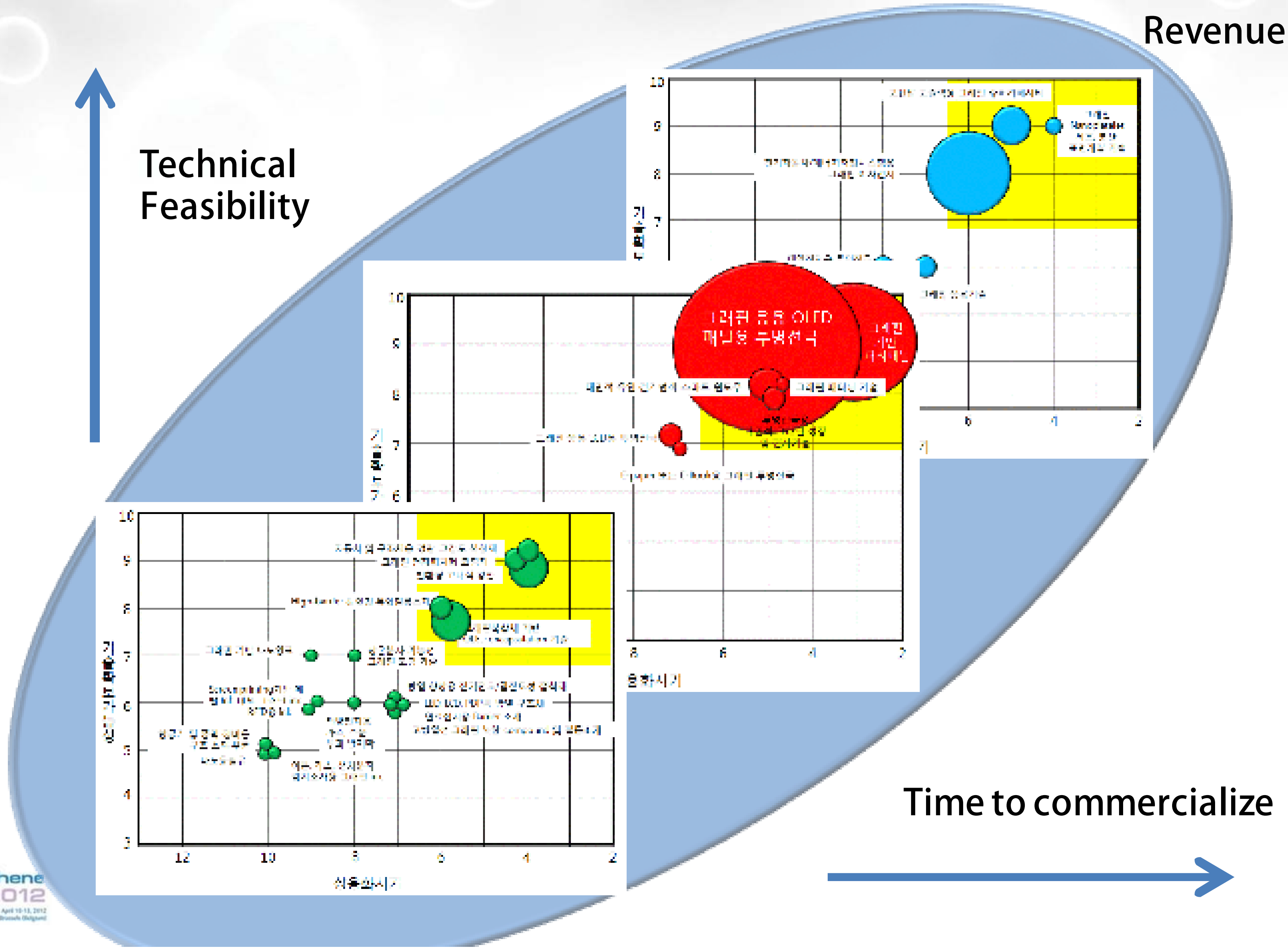
LED lighting ECU units



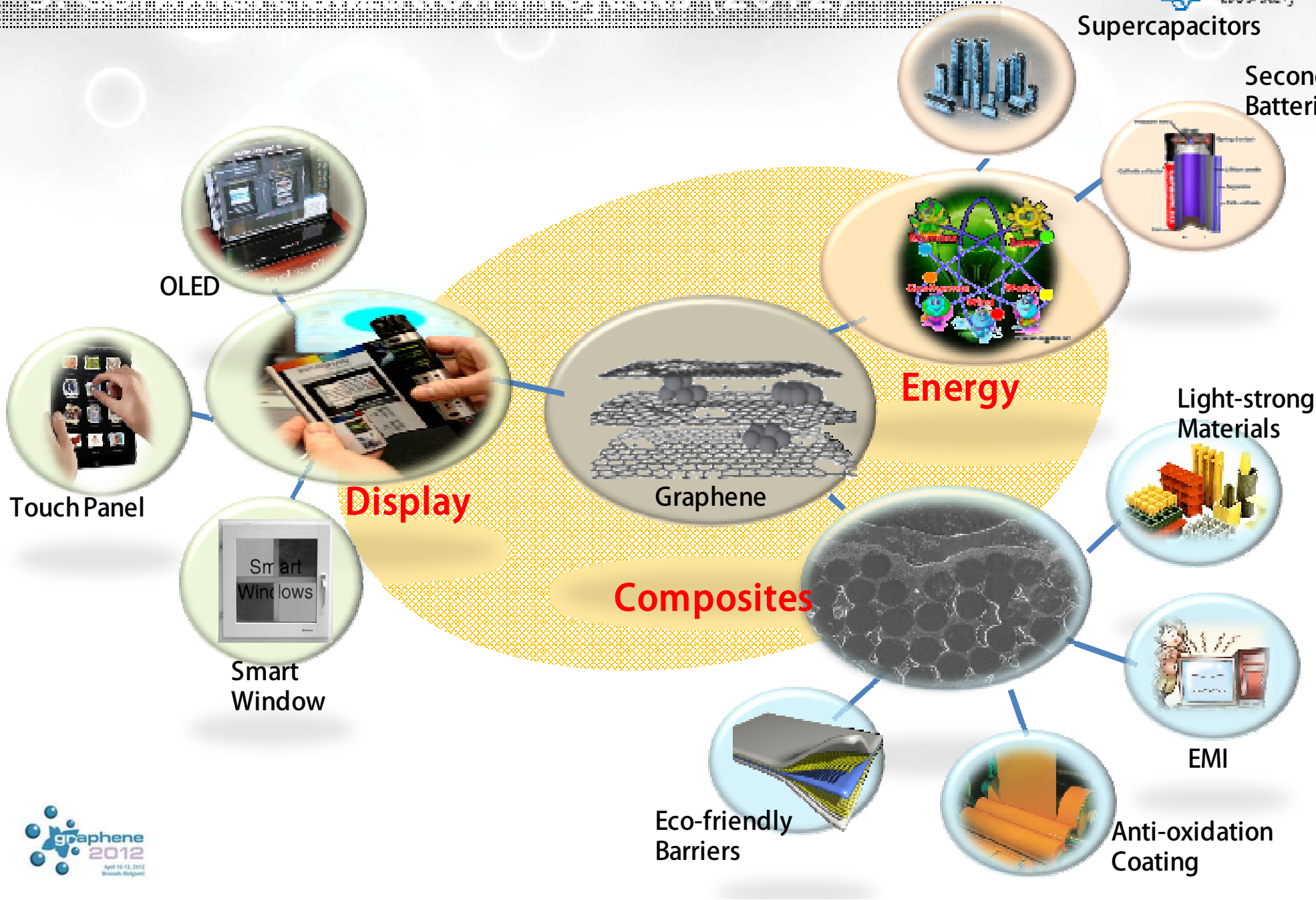
Ultra-light Strong composite

Cars Aerospace

3. Commercialization Projects (2011)



3. Commercialization Projects(2012)



3. Commercialization Projects (2012)

Category		2019	2020	2021	2022	2023	2024	2025
Toch Panels	World (100k USD)	289.8	319.2	351.5	387.1	426.3	469.4	517.0
OLED	World (100k USD))	114.0	170.0	224.8	297.4	393.3	520.2	688.1
	Encapsulation (100k KRW)	1,000	1,500	1,500	1,800	1,800	2,000	2,000
Smart Windows	Passive (100k USD)	39.4	44.5	50.1	56.6	63.8	72.0	81.2
	Active_BIPV (100k USD)	203.4	237.7	277.9	324.9	379.8	444.0	519.0
Secondary Cells for EV/ESS	ESS용 LIB (100k USD)	130.8	159.7900	194.1	235.7	286.3	347.7	422.3
	EV용 LIB (100k KRW)	831,841	848,832	877,846	907,852	938,883	970,975	1,004,164
Supercap.	100k USD	2.0	3.4	5.7	9.5	15.9	26.6	44.4
Composites	Car Body (100k KRW)	49,247	53,075	57,200	61,646	66,437	71,601	77,167
High Barriers	High end (100k USD)	155.6	161.3	167.1	173.2	179.4	185.9	192.7
	Packaging (100k KRW)	25,598	26,750	27,953	29,211	30,526	31,900	33,335
EMI Coating	Electronics (100k USD)	1.6	2.2	3.1	4.3	6.0	8.4	11.8
	EMI/RFI (100k USD)	56.6	58.2	59.9	61.6	63.3	65.1	67.0
Antioxidation Coating	Domestic (100k KRW)	109,370	118,742	128,918	139,966	151,960	164,982	179,120

National Projects (2012)

Budget: 200 mil USD for 6 years (Gov. 83.4 mil USD, Non-Gov. Matching 127. USD)

Category	'13	'14	'15	'16	'17	'18	Sum
Gov.	25.3	24.0	13.1	7.6	6.9	65.	83.4
Non-Gov.	10.8	10.3	22.0	30.4	27.6	26.0	127.2
Sum	36.1	34.3	35.1	38.0	34.5	32.5	210.6

구 분		'13	'14	'15	'16	'17	'18	Sum
Display	Gov.	10.5	9.5	3.0	3.0	2.3	2.3	30.6
	Non-Gov.	4.5	4.1	12.0	12.0	9.2	9.2	51.0
Energy	Gov.	5.5	5.5	5.5	2.4	2.4	2.0	23.3
	Non-Gov.	2.4	2.4	2.4	9.6	9.6	8.0	34.3
Composites	Gov.	9.3	9.0	4.6	2.2	2.2	2.2	29.5
	Non-Gov.	4.0	3.9	7.7	8.8	8.8	88	41..9

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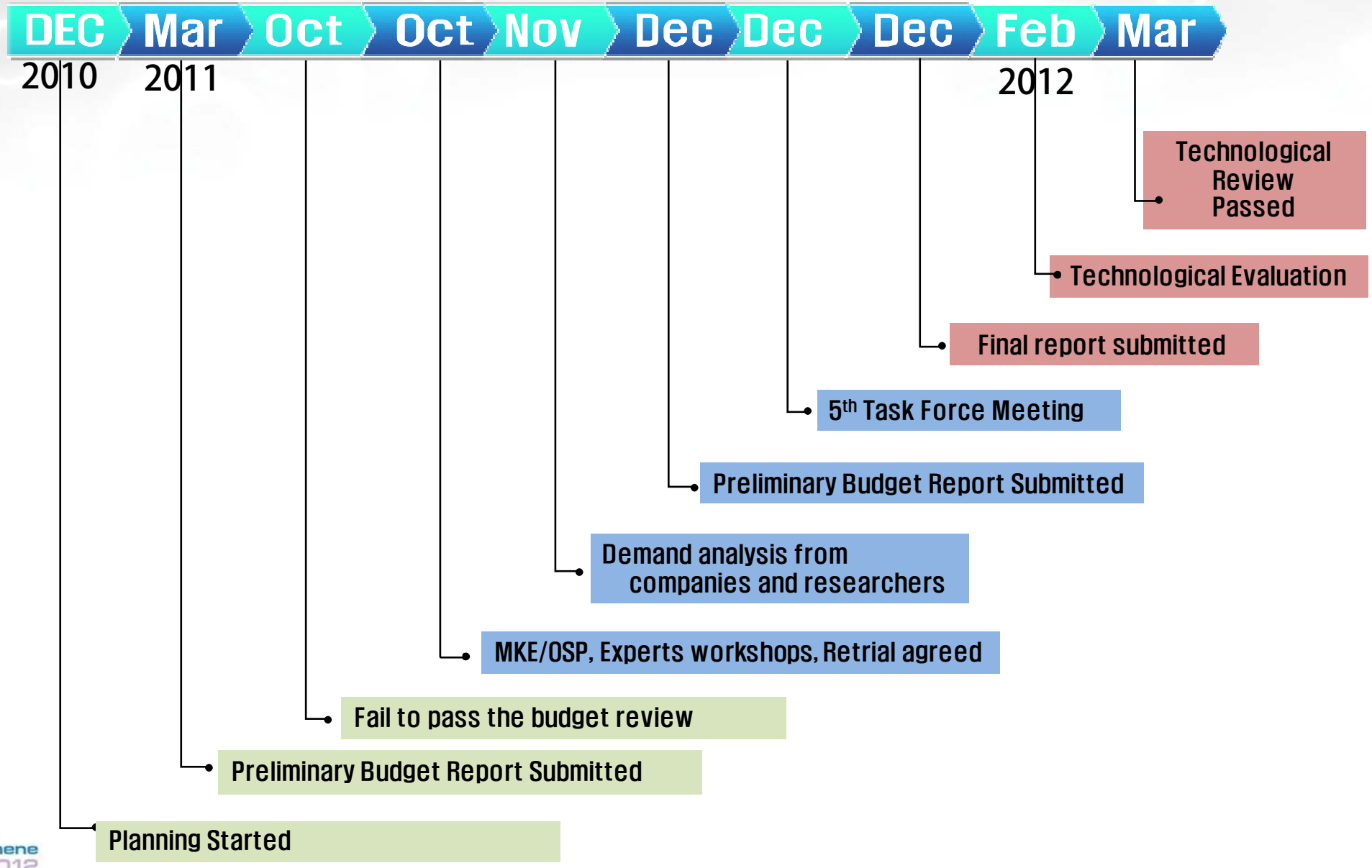
DEC
Mar
Oct
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Feb
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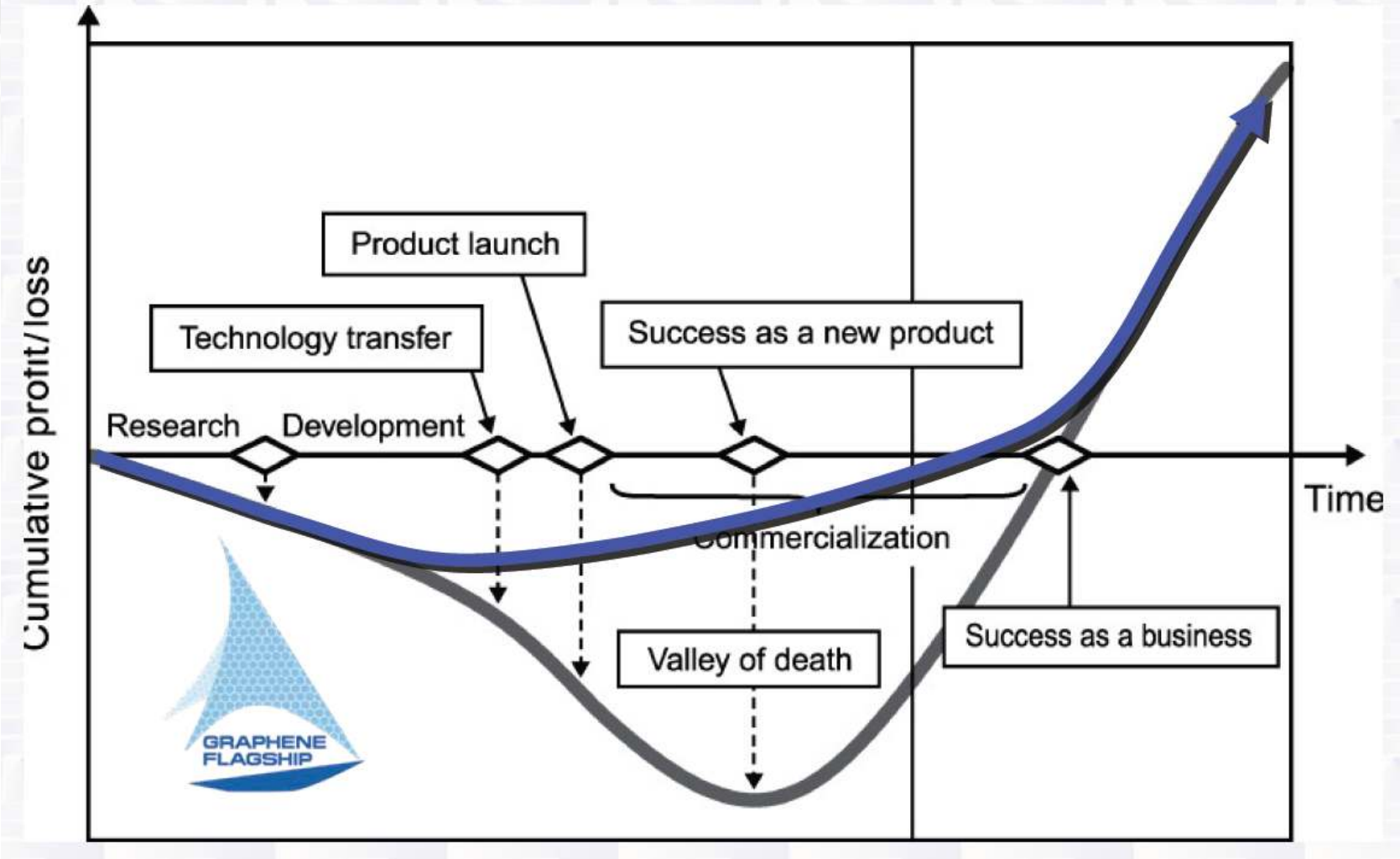
2010
2011
2012
Technological Review Passed
Technological Evaluation
Final report submitted
5th Task Force Meeting
Preliminary Budget Report Submitted
Demand analysis from companies and researchers
MKE/OSP, Experts workshops, Retrial agreed
Fail to pass the budget review
Preliminary Budget Report Submitted
Planning Started

Commercialization projects (2012)



Acknowledgements

Special Thanks To Dr. Soon Hyung Hong,
Managing Director of
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Ministry of Knowledge Economy (MKE)
&
KGRS Members

Industrial Collaborators

SAMSUNG — Samsung Techwin, Electronics, Mobile Display, LED

SK energy — Substrate Films

posco — Composites

LS Cable

LG — Wire Applications
Energy Applications

GRAPHENE SQUARE
www.graphenesquare.com