KOREA INSTITUTE OF ENERGY RESEARCH

CONCEPT PAPER
for KIER International Cooperation project

Personal Data	Name of PI	Min Gu Kang	Organization	Korea Institute of Energy Research
	Department	Photovoltaic Laboratory	Title	Principal Researcher
	Cell Phone #	+82-10-8030-1375	E-mail	mgkang@kier.re.kr
Title	Fabrication, loss analysis, and energy yield modelling of high efficiency shingling modules using cut bifacial n-PERT cells for minimizing cell-to-module loss			
Description	● In this project, a shingling module using bifacial cut silicon solar cells will be fabricated We will develop a physics-based simulation model to accurately predict the energy output of the developed bifacial modules. This model will also be used to optimize the cell and module structure towards optimal bifacial energy yield. ● To improve the module power generation, bifacial solar cells which can use the reflected and scattered light at the back side are studied by many groups. ● To maximize the module efficiency, a shingling module structure based on cut cells is being studied nowadays. Increasing module efficiency can be achieved because this shingling module structure allows closer packing of the cells and the cut cells lead to less resistive losses at module level due to smaller current densities. ● Thus, combining bifacial solar cells with a shingling module structure leads to a promising technology to increase the power generation of solar modules. During the day time, the incident angle of the sun light varies, and as a result the incident light intensity at the back side of the module also varies. Bifacial modules are very sensitive to this since a varying back side illumination can lead to current mismatching between cells in the module which will limit the extra power output of the module.			
Outcomes*	● A bifacial silicon mini-module consisting of cut cells with a module efficiency of 20 % @ 1 sun. ● Bifacial module power generation model that allows accurate energy yield prediction and device optimization. ● At least 1 joint publication published in a high-impact journal.			

CONCEPT PAPER
for KIER International Cooperation project

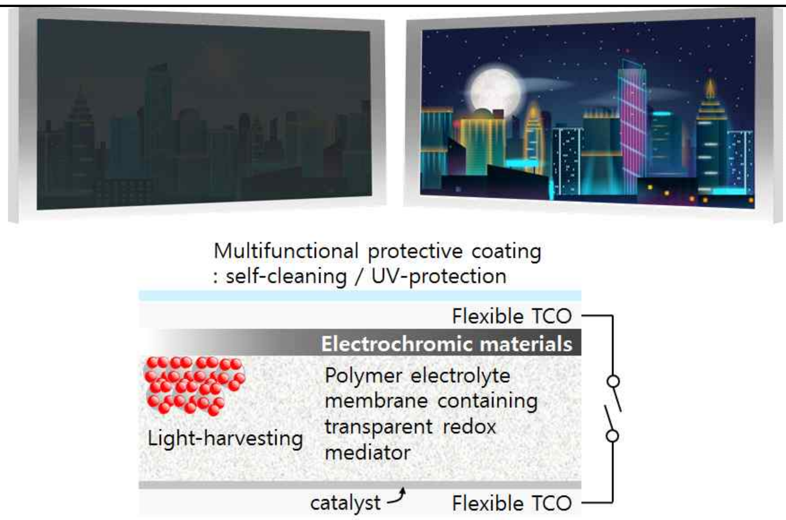
<table>
<tr><td rowspan="3">Personal Data</td><td>Name of PI</td><td>Sungjun Hong</td><td>Organization</td><td>Korea Institute of Energy Research</td></tr>
<tr><td>Department</td><td>Photovoltaic Laboratory</td><td>Title</td><td>Principle Researcher</td></tr>
<tr><td>Cell Phone #</td><td>+82-10-4703-4193</td><td>E-mail</td><td>jjunnii@kier.re.kr</td></tr>
<tr><td>Title</td><td colspan="4">Development of passive-active switchable smart window for builiding energy efficiency improvement</td></tr>
<tr><td>Description</td><td colspan="4">


Fig1. Concept of proposed device
● Barrier(s) to tackle: electrochromic devices(EC) as one of smart windows have been installed to regulate the glare and thermal footprint of buildings by appling electrical power to them. However, the cost and complex installation of EC have retarded the wide-spread utilization of EC window.
● Strategy to solve: To develop the self-powered and passive-active switchable electrochromic films which can be adapted to both existing and new building. To do this, following materials have to be developed. low-termperature processbile electrochromic coating, highly transparent and conductive (semi) solid state electrolyte, pleasant light harvester for powering the device, multifunctional protective coating formulation, and device architecture optimization.
</td></tr>
<tr><td>Outcomes*</td><td colspan="4">
● Final goals
average visible light transmittance (70% at clear state, 30% at darken state)
device dimension: 1,000mm×1,000mm
cyclability: over 5,000
Cost down (900$/m^2 to 400$/m^2),
● Publications and/or Patents
2 publications/year
2 patents/year
</td></tr>
</table>

KOREA INSTITUTE OF ENERGY RESEARCH

CONCEPT PAPER

for KIER International Cooperation project

Personal Data	Name of PI	Kihwan Kim	Organization	Korea Institute of Energy Research
	Department	Photovoltaics Laboratory	Title	Principal Researcher
	Cell Phone #	+82-10-3105-0538	E-mail	kimkh@kier.re.kr
Title	Advanced roll-to-roll (R2R) processing for chalcopyrite-based solar cells: Designs for linear source and flexible-web control system			
Description	● The object of this work will be to provide designs for robust linear evaporation sources and highly-reliable flexible-web control system in a pilot-scale R2R (width 300 mm) co-evaporator for manufacturing flexible/light-weight CIGS solar cells. This will increase the manufacturing yield and device performance of CIGS cell by stabilizing the process and by reducing films' materials and/or mechanical imperfections that could be caused by premature source design and flexible-web handling. ● The R2R process is one of the most efficient way to manufacture flexible/light-weight CIGS solar cells (on flexible web); nevertheless, if considering an extreme deposition condition in the chamber inside, the robust/reliable evaporation sources and web (roll) handling part are critical in the R2R processing to prevent structural/compositional/mechanical failures of the deposited CIGS film on flexible web. ● First, in order to ensure the uniform supply of source-elements (i.e., Cu, In, Ga, Se) and robust operation of sources, the evaporation sources should be designed as a multi-nozzle linear source with a corrosion-resistant heating unit that may not react with highly reactive Se ions. Also, the linear evaporation sources, in the narrow chamber inside, are typically arranged in a rows, and thus the thermal interference among the sources should be suppressed. ● Second, the R2R process includes non-rigid (i.e. flexible and soft) substrate handling – particularly, winding and unwinding. Furthermore, the CIGS deposition is typically performed at the high temperature, and therefore a more delicate tension control of flexible web is necessary to prevent the permanent deformation of web. Also, a design with minimizing the friction between the deposited film and roller should be incorporated in the web handling part.			
Outcomes*	● Design of a multi-nozzle linear source for CIGS co-evaporation: 2 µm-thick CIGS growth in 5 min ● Design of a flexible-web controlling part in R2R co-evaporator: 300 mm-wide roll system with a (deposition) rolling speed of 1 m/min ● At least 1 publication in an international journal (SCI/SCIE) or 1 patent submission			

CONCEPT PAPER

for KIER International Cooperation project

Personal Data	Name of PI	Youngmin Woo	Organization	Korea Institute of Energy Research
	Department	Energy Saving Laboratory	Title	Senior researcher
	Cell Phone #	+82-10-4914-4349	E-mail	ywoo@kier.re.kr
Title	Cryocooler development for the energy storage device to utilise CO2 liquefaction			
Description	● Barrier(s) to tackle • To acquire an energy efficient cryocooler design and performance enough to apply it for carbon dioxide liquefaction • Excess electricity can be used to run a cryocooler to liquefy carbon dioxide on site at powerplants or industrial areas. • To choose best solution to utilise renewable energies to power the cryocooler • To apply the cooler technique into a variety of applications including powerplants, industrial sites, and even in vehicles ● Strategy to solve • the main exhaust from the powerplant would be carbon dioxide after the proper treatment of SOx, NOx, PM, VOC in the main exhaust gas. • liquefied carbon dioxide can be run refrigeration plant as working fluid and then liquefied again in cycle through the cryocooler operation. • liquefied carbon dioxide can run the extra gas turbine to generate electricity by the end user. • liquefied carbon can be a product as itself: the cost of bottled CO2 per kg is $0.60			
Outcomes*	● Performance of the cryocooler Heat recovery 15 % (current 10_%) CO2 emission abatement _100_% (in the sense of re-utilisation as resources) ● Publications and/or Patents More than 1 papers in the SCI journal More than 1 patents for the cooler design or applied system			

CONCEPT PAPER

for KIER International Cooperation project

Personal Data	Name of PI	Min-Soo SUH	Organization	KIER
	Department	Energy Saving Lab.	Title	Principal Researcher
	Cell Phone #	010-5142-2412	E-mail	mssuh@kier.re.kr
Title	Thermally regenerative power generation NaTEC technology			
Description	● Development of MEA for NaTEC unit cell ▪ Assembly of the ion conductivity ceramic electrolyte and the refractory metal electrode technology ▪ Ion conductivity measurement of ceramic electrolyte ▪ Current-Voltage measurement of electric conductivity property ● Development of liquid metal circulating technology ▪ Development of Sodium evaporator at high temperature regime ▪ Development of Sodium condenser at low temperature regime ▪ Development of Sodium circulative artery ● Development of novel design for NaTEC module ▪ Design of MEA assembly module ▪ Design of Circulative wick assembly ▪ Development of stand-alone fully functional NaTEC unit cell			
Outcomes*	● Novel design of NaTEC technology ● Development of NaTEC stand-alone unit cell ● Design NaTEC module (20W × 5 EA) ● Design of kW grade NaTEC generation stack module ● Publication of SCI 1 papers with IF 20% ● PCT patent of novel NaTEC technology ● Efficiency 25 % (current 8 %), Cost down (50,000 \$/kW to 10,000 \$/kW), CO2 emission abatement 20 % by utilizing Waste heat to power ● Publications 3 SCI with IF 20% and PCT patents of novel NaTEC technology			

KOREA INSTITUTE OF ENERGY RESEARCH

CONCEPT PAPER
for KIER International Cooperation project

Personal Data	Name of PI	Hana Yoon	Organization	Korea Institute of Energy Research
	Department	Separation and Conversion Materials Laboratory	Title	Senior Researcher
	Cell Phone #	+82-10-8767-8239 (+82-42-860-3201)	E-mail	hanayoon@kier.re.kr
Title	**Novel dimension-controlled materials for combined energy conversion and energy storage devices**			
Description	o *Barriers to tackle:* Integration of energy harvesting and storage devices is considered to be one of the most important energy-related technologies because of the possibility of replacing batteries or at least extending the lifetime of a battery. Moreover, in order to develop on-chip, flexible, wearable energy conversion and energy storage devices, new thin-film and especially dimension-controlled materials are desired. The energy harvesting/conversion components must also be directly integrated with energy storage modules for optimal portability. Scaling photovoltaic systems down to the low-dimensional limit while retaining efficiency requires understanding of the mechanisms of photo-induced charge separation and charge transport within semiconductor layers to conducting electrodes that deliver the charges to miniaturized storage systems like ultra-thin supercapacitors and batteries. This proposed work is aimed at synthesizing novel dimension-controlled materials (0D, 1D, 2D, and 3D), identifying their mechanisms of energy conversion and charge transport, and matching the power output of these materials to suitable charge storage devices. o *Strategy to solve:* Gas-phase and/or solution-phase synthesis approach to synthesize dimension-controlled nanomaterials will be used to fabricate on-chip and/or flexible devices for charge transport measurements. Cross-sectional transmission electron microscopy (TEM) will be used for structural characterization of the dimension-controlled nanomaterials. Variable temperature conductivity and current–voltage response in light and dark conditions will be measured to correlate composition and electronic structure with photovoltaic response. Cyclic voltammetry and in situ electrochemical transmission electron microscopy will be used to evaluate performance of a variety of electrochemical energy storage devices based on low-dimensional materials (graphene, metal oxides/chalcogenides/halides layers, carbon nanotubes, silicon nanowires etc.) and identify the system that leads to optimal impedance matching with the photovoltaic system.			
Outcomes*	o Synthesis and structural characterization of novel dimension-controlled nanomaterials o Detailed mechanistic studies of photo-induced charge separation and transport in dimension-controlled nanomaterials o Evaluation of electrochemical performance of flexible supercapacitor or battery schemes based on low-dimensional materials. o 2 publications in peer-reviewed journals and/or patents.			

CONCEPT PAPER
for KIER International Cooperation project

Personal Data	Name of PI	Heeyeon Kim	Organization	Korea Institute of Energy Research
	Department	Energy Materials Research Laboratory	Title	Principal Researcher
	Phone #	+82 42 860 3613	E-mail	heeyeon@kier.re.kr
Title	Development of the multi-dimensional nanostructured catalyst to overcome the thermodynamic limit of a chemical reaction by atomic-scale modeling and characterization techniques			
Description	• **Barrier(s) to tackle:** Various heterogeneous catalysts have been developed to improve the performance and durability of energy devices and chemical processes. However, the catalyst development process has been inefficient since catalysts are mainly developed by experimental trial and error, which is costly and time-consuming. In addition, the compositions and structures of developed catalysts are often not fully optimized. We must substantially accelerate the development process of fully optimized catalysts guided by atomic scale modeling and characterizations in order to overcome the thermodynamic limit of the catalysts to date and quickly commercialize them. The synthesized catalyst would be applied to direct methane coupling (DMC), hydrogen fuel cells, electrode for reverse electrodialysis (RED) system and renewable hydrogen production by CH_4 reforming. • **Strategy to solve:** KIER will identify promising candidate compositions and structures of metal hybrid, metal-ceramic or metal-carbon hybrid catalysts for various energy devices and chemical processes mentioned above. Through the international collaboration, the catalyst model will be optimized and the performance of the catalyst will be tested. Each catalyst need to be characterized based on atomic scale analysis such as AC-TEM, STEM, and EELS. The deactivation mechanism can be investigated by using in-situ characterization technique. By investigating the activation and deactivation mechanisms, we will also work on improving the durability of the catalysts. The partner group is encouraged to draw up additional grant from their country based on KIER's funding as a seed.				
Outcomes*	**Through the collaboration with KIER, the following outcomes will be obtained:** • At least 1 hybrid catalyst model or sample for the suggested energy devices (DMC, FC, CH_4 reforming, RED etc.) • Atomic scale characterization results of hybrid catalysts with mechanistic study • Publications and/or Patents: 2 publications in SCI journals and 1 patent				

KOREA INSTITUTE OF ENERGY RESEARCH

CONCEPT PAPER
for KIER International Cooperation project

Personal Data	Name of PI	Chan Young Park	Organization	Korea Institute of Energy Research
	Department	Greenhouse Gas Research Laboratory	Title	Principal Research Scientist
	Cell Phone #	+81-10-5520-9202	E-mail	cpark@kier.re.kr
Title	Development of Indoor CO_2 Abatement Technology Applicable to Crowded Places			
Description	**Barrier(s) to tackle** There are very few studies reporting indoor CO_2 capture based on adsorption technology in the literature. The level of CO_2 concentrations in indoor crowded places can go up to 3,000 ppm or more. Most studies have been reported for CO_2 capture from industrial sites such as post-combustion sources (~10-15%) or ambient air (~400 ppm). Indoor air quality (IAQ) has studied intensively on VOCs, mainly CO and formaldehyde. The feasibility of such a CO_2 capture system based on a techno-economic analysis has not been reported in the literature, either. Therefore, there is a strong need for developing a cost-effective CO_2 adsorbent and an adsorption system that can bring down high indoor CO_2 concentration to an acceptable level (e.g., from 3,000 ppm to <1,000 ppm). **Strategy to solve** First, a pool of adsorbent candidates will need to be identified and selected after rigorous evaluations. Some of the desired properties of such candidates will include low adsorbent cost, low regeneration cost, high regenerability, long shelf life, high durability against other indoor gases, and environmentally benign waste disposal for spent adsorbent. Then, the selected adsorbents will be examined to obtain key design information on a CO_2 adsorption system to be installed indoors. Currently it is deemed to reasonable to design an adsorption system in a form of a fixed-bed reactor (e.g. cartridge), which will be operated by introducing indoor air to the system. The parameters to be considered for the design of such a system will include adsorption capacity, adsorption kinetics, CO_2 capture performance, pressure drop, gas flow rate, etc. Second, the improvement of adsorbent performance and CO_2 desorption for the regeneration of the adsorbent will mainly be investigated. Currently, it is thought to be most practical to regenerate the spent adsorbent off site. An ideal desorption process will require low energy cost, fast desorption kinetics, high CO_2 recovery from spent adsorbent, minimum degradation of adsorbent, etc. To separate CO_2 from spent adsorbent, temperature swing and temperature vacuum swing will be compared in terms of the aforementioned desorption criteria. Then the performance of a finalized adsorbent will be demonstrated through multiple adsorption and desorption cyclic tests. KIER will focus on designing a CO_2 adsorption/desorption system and evaluating the system through long-term cyclic tests for commercialization. A partner will focus on developing novel CO_2 adsorbent materials through lab-scale evaluations.				
Outcomes*	CO_2 emission abatement: from 3,000~5,000 ppm to <1,000 ppm CO_2 capture efficiency >80% (current: not reported), Cost down (not reported), 2~3 Publications and/or Patents				

KIER KOREA INSTITUTE OF ENERGY RESEARCH

CONCEPT PAPER
for KIER International Cooperation project

<table>
<tr><td rowspan="3">Personal Data</td><td>Name of PI</td><td>Jung-Je Woo</td><td>Organization</td><td>Korea Institute of Energy Research</td></tr>
<tr><td>Department</td><td>Gwangju Bio/Energy R&D Center</td><td>Title</td><td>Senior Researcher</td></tr>
<tr><td>Cell Phone #</td><td>+82-10-2340-7981
(+82-62-717-2402)</td><td>E-mail</td><td>wooj@kier.re.kr</td></tr>
<tr><td>Title</td><td colspan="4">LBL-assembled, structurally graded 3D-framework as a dendrite-free electrode for high energy storage systems</td></tr>
<tr><td>Description</td><td colspan="4">o Barriers to tackle: High energy electrochemical storage systems are urgently needed to meet the considerably increasing demands in mobile devices, electric vehicles and energy storage system for grid support. Unfortunately, the energy density of commercialized lithium (Li)-ion battery remains insufficient in newly emerging applications that would require high-energy battery. Among all elements, Li metal is regarded as the ‘Holy grail’ material due to its extra-high capacity and the lowest negative electrochemical potential. However, the uncontrolled Li dendrite growth and low Coulombic efficiency during Li plating/stripping have limited its widespread use and application in rechargeable battery system. Recently, the use of conductive micro/nanostructured framework electrode has been considered as the most promising strategy to control Li plating/stripping process and inhibit Li dendrite growth in Li metal batteries, since the diffusion, distribution, nucleation and growth reactions of Li would be highly dependent on the surface properties and architecture of the conductive framework. This proposed work is aimed at designing and fabricating the novel conductive 3D-framework electrode with unique spatial structure, elucidating reaction mechanisms for metal plating/stripping during repeated battery cycling, and providing the technical solution for the dendrite-free electrode with high Coulombic efficiency, which is suitable for not only Li metal- but also other metal-based (Na, Zn, Al etc.) energy storage systems with high energy density.
o Strategy to solve: Layer-by-layer (LBL) assembly approach will be used to design and fabricate the structurally and functionally graded 3D-framework, which serves as a dendrite-free electrode in alkali metal (Li and/or Na) batteries. For this purpose, the quantitative relationships between the structural (active surface area, material composition, porosity, tortuosity, etc.) and electrochemical parameters (current density, electric field, ion concentration, ion diffusion, etc.) will be revealed through the electrochemical modeling, and the reaction mechanism as well as the dynamic of metal plating/stripping on the graded 3D-framework will be also examined. Based on the optimized electrode design, LBL assembly process will be developed for demonstrating the concept of the graded 3D-framework where the structural parameters such as the porosity and material composition can be gradually changed in the direction of electrode thickness. Detailed structural and compositional information for the graded electrode will be obtained by using various analytical tools, and then its electrochemical performances in terms of Coulombic efficiency, rate-capability and cyclability will be evaluated by constructing the half- and full-cells assembled with the graded 3D-framework electrode.</td></tr>
<tr><td>Outcomes*</td><td colspan="4">o Design and fabrication of structurally and functionally graded 3D-framework via LBL assembly approach
o Structural characterization of the graded framework and detailed mechanistic studies for the metal plating/stripping on that electrode
o Electrochemical performance evaluation of the graded 3D-framework and feasibility demonstration as a dendrite-free electrode in metal-based batteries with high energy density
o 2 publications in peer-reviewed journals and/or patents</td></tr>
</table>