Nanostructured Materials for Next-Generation Energy Storage and Conversion

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Editors

Nanostructured Materials for Next-Generation Energy Storage and Conversion

Fuel Cells

With 255 Figures and 41 Tables

Springer

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Preface

The increase in the human population has jumped from 2.8 billion in 1955 (US President Eisenhower) to 7.5 billion in 2017 (US President Trump). This significant increase has meant that more CO_2 is generated through combustion of carbon-based fuels, which currently are the dominant fuel-mix used in transportation, heating and cooling, and electric power generation. One consequence of the continued rise of CO_2 emission is the ability of CO_2 to trap sunlight as a greenhouse gas (GHG) with subsequent worldwide redistribution of trapped heat, contributing to changes in global weather patterns. One possible approach is reducing GHG emissions and managing global warming by displacement of fossil fuels by fuel cells (FC) and FC based vehicles (FCVs), which do not generate CO_2 as a by-product but water via a redox reaction [$2H_2(g) + O_2(g) \rightarrow 2H_2O(l)$]. In addition, hydrogen when used as a fuel feedstock is a near-zero CO_2 emission source at point of use, and is available in the oxidized form in water (H_2O) or as the hydride of carbon in natural gas (methane, CH_4) that can be generated by electrolysis of water or reformation of natural gas.

The total number of electric vehicles including FCVs reached an excess of 1.25 million in 2015, of which 550,000 were new registrations. It is anticipated that by 2025, there will be 5 million FCVs with a projected FC system cost of $30–$40/kW. The gradual tightening of fuel economy and emission standards is also likely to stimulate FC development, deployment, and wide societal acceptance if the total cost of ownership can be reduced to the cost of conventional technologies.

This book focuses on the design, characteristics, and development potential of FC technologies in light of changing energy requirement and related challenges. The technological factors that influence the dynamics, flexibility, and operating costs of FC operation are highlighted. Moreover, the potential for using FC technologies in the mobility sector, stationary industrial sector, and the heat thermodynamics is discussed, as these factors determine the extent to which the future ‘value” of stationary and portable FC technology applies to other industries. This “valuation” for FC development will guide the development and direction of newer, less developed technologies, such as cost of development, ease of integration into the infrastructure, power density output, operational lifetime, and cost of operation relative to current ICEs.

The advantages of FC technologies coupled with renewable hydrogen are synergistic and offer considerable advantages over the internal combustion engine–gasoline combination. The proton exchange membrane fuel cell efficiency can be estimated as $\eta = 1 - T\Delta S/\Delta H$ and using the Gibbs free energy ($\Delta G = -237.13$ kJ/mol) and heating value of hydrogen ($\Delta H = 285.85$ kJ/mol) is around 83% efficient. The introduction of FCVs will deliver immediate benefits in air quality in large urban centers, as the usage and importance of FCs for both portable and stationary applications is expected to increase at the expense of fossil fuels.

The editors are fortunate to have renowned experts in the field contribute to this book. As a result, this book not only serves as an introduction to individuals who are new to the field, but also to individuals who are seasoned experts. All the chapters give a solid overview of the subject under discussion followed by an extension into the area of expertise of the specific author. Due to the self-contained nature of each chapter, the reader does not need to reference several chapters to get the concept, which is an advantage. The reader may see a trend in which each author presents introductory themes with their point of view.

The book is composed of three themes. The first theme is related to energy policy and electric power. In ▶ Chap. 1, the energy policy as initially proposed and actually executed is discussed between two presidencies spanning 40 years in terms of federal support in various areas deemed critical to this nation's energy security. In the second chapter, "Electric Power and Hydrogen Redox" (HREG, ▶ Chap. 2), a hydrogen redox electric power and hydrogen generation systems (HREG) are discussed, which enable electrostatic-to-chemical energy conversion in the water electrolysis for both stationary and portable applications. The third chapter (▶ Chap. 3) deals with evaluation of cell performance and durability for cathode catalysts during simulated fuel cell vehicle (FCV) operation. Specifically, cell performance and durability testing for cathode catalysts on two types of supports, carbon black and conducting ceramic nanoparticles, were discussed, including startup/shutdown cycles and load cycles.

This leads to the second theme in the book relating to optimization of FCs through design and synthesis of novel catalysts. This section begins with the design and application of metal carbonyl cluster as electrocatalyst (▶ Chap. 4) based on thermolysis or pyrolysis of osmium, ruthenium, iridium, and rhodium *n*-decacarbonyl derivatives. These materials are discussed with respect to benchmarking the oxygen reduction reaction (ORR) and hydrogen oxidation reaction (HOR) electrocatalyst reactions. The theme is continued in ▶ Chap. 5, where the use of noncarbon supports in low-temperature FCs is discussed in terms of performance. ▶ Chapter 6 focuses on the design, synthesis, and evaluation of noble metal electrocatalysts applied in polymer electrolyte fuel cells. This type of development is critical because there is insufficient worldwide Pt to meet the anticipated demand for the next 25 years in FCVs. The strategies to reduce electrocatalyst costs are a fabrication of either nonplatinum electrocatalysts with similar performance to Pt or alloying to reduce Pt loading. The electrocatalyst activity is usually increased through nanostructuring of the catalyst support that is the focus of the next chapter. In ▶ Chap. 7, low power

density and fuel utilization of catalysts in PEMFCs and/or DMFCs are discussed and expanded upon. These shortcomings are related respectively to poor reaction kinetics and methanol crossover and are overcome through the use of graphene or carbon nanotubes as newer support surfaces. The theme is concluded with a discussion of nanostructured catalysts for solid oxide fuel cells (SOFC, ▶ Chap. 8). The factors related to design and application of new nano-sized electrode catalyst to decrease the activation polarization resistance and to improve the SOFC performance are discussed.

The third and final theme of the book is related to optimization of fuel cells through modeling and simulation. The section starts with a modeling analysis of water management in a PEMFC (▶ Chap. 9). The effect of relative humidity and stoichiometry of reactants on the water saturation, back-diffusion of water from the cathode to the anode, is considered and strategies to reduce possible flooding and increase FC performance and operational reliability are discussed. The chapter is followed by development of a computational thermodynamic model to better understand the cathode electrolyte in SOFCs (▶ Chap. 10). The development of density functional theory (DFT) of varying sophistications to model and evaluate with experimental data to the activity and stability of the ORR of the PEMFC electrocatalysts (▶ Chap. 11). The modeling is expanded to an entire FCV in ▶ Chap. 12. Here, the optimization strategies of hydrogen FCs as range extenders in electric vehicles are discussed. In the following chapter (▶ 13), a comprehensive treatment of a totalized hydrogen energy utilization system (THEUS) for stationary applications is introduced. The parameters for THEUS related to load leveling and cogeneration in commercial buildings from renewable energy sources such as solar photovoltaics (PVs) and wind power are explored. These two chapters tie-in a critical and often overlooked feature of the environment in which the FC operate, which is outside the finely controlled environment of the research laboratory. The influence of impurities in the air on nanostructured electrocatalysts in a PEMFC is comprehensively explored (▶ Chap. 14), and the physical or chemical hybrid materials used for hydrogen storage are discussed. In ▶ Chap. 15, hydrogen storage based on manganese oxide anchored to a polymeric matrix, as examples of solid state materials for hydrogen storage, is compared and contrasted with conventional approaches.

These types of strategies are critical to the widespread application and usage of FCVs, where the hydrogen fuel is supplied to the FCs that supply electrical energy via a power inverter to the electric motor as described in the previous chapters. The FCV could also be configured where the FC stack is channeled to the DC/DC converter and the inverter and electric motor, with an onboard auxiliary power unit. In ▶ Chap. 14, pollutants in their air and their effect on the cathode catalyst were investigated. In the following chapter (▶ 16), the effects of fabrication design on the bipolar plate and membrane electrode assembly are discussed in terms of how stresses can lead to component failure in real world settings. In many laboratory-based bench test experiments, the “purity” of the oxidant (air) and effect of actual stress and strain on the catalyst layer, or membrane electrode assembly, are often neglected. The authors of these two chapters (▶ 14 and ▶ 16) give practical

hands-on perspective coupled with research data to orientate the postdoctoral researcher or graduate student who may fabricate such components to include best practices in their FC designed tests. The design, fabrication, modeling, and evaluation of a new tubular electrode for SOFC are discussed next (▶ Chap. 17). The section concludes with a discussion of the safety aspects related to use and disposal of these electrocatalysts (▶ Chap. 18), which is not usually discussed in monographs on FC designs, development, and applications, but is an area that will gain prominence as FCs become more available and are disposed after usage. Today, we are aware of the toxicological and safety "costs" related to the disposal of aluminum or lead components and the realization of potential toxicity with aluminum or lead ion migration in soil or water after disposal. The chapter (▶ 18) outlines that nanometals, unlike their bulk counterparts, are not inert but reactive with a variety of cells.

These chapters (▶ 1 – ▶ 18) will offer the catalyst development, fuel cell design, and operation to research students, postgraduate researchers, young investigators, experienced principal investigators, and industrialists. The treatise aims to provide the current state-of-the-art information from theoretical framing of the problem to actual hands-on activities that authors have gained through their decades of experience. The expertise and knowledge are passed down to current practitioners in the field to make an informative monograph, which can serve both a reference source book and a how-to-guide.

The general aim has been to learn how to assess the technical impact of new electrocatalysts and how to improve fuel cell technology in terms of operational reliability, cost, ease of use, and safety. Lastly, the stellar contribution of the authors, their research group, and institutions are duly acknowledged. We also would like to extend our deep appreciation to our institution, colleagues, and students as well as the editorial staff at Springer publishing who has strived to deliver the best possible scholarly product. As always, errors and omission are the responsibility of the editors, for which we as preface authors ask forgiveness.

August 04, 2017

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Contents

Abbreviations

A/E	Anode/Electrolyte layer interface
AA	Acetylacetone
AC	Alternating current or Activated carbon
AE	Alkaline earth
AEC	Atomic Energy Commission
AES	Auger electron spectroscopy
AFC	Alkaline fuel cell
AFCMS	Adaptive fuel consumption minimization strategy
Ag	Argentum (silver)
ALD	Atomic layer deposition
APS	Ammonium persulfate
ARSM	Atmospheric resistive switching mechanism
AS	Air start
ATO	Antimony-doped tin oxide
Au	Auric (gold)
B	Boron
BAAEDI	Bisacetylacetoneethylenedi imine
BAWE	Bipolar alkaline water electrolyzer
BDC	Benzene-dicarboxylate
BEV	Battery electric vehicles
BN	Boron nitride
BOPs	Balance of plants
BSAEDI	Bissalicylaldehyde-ethylenediimine
BSCF	Barium strontium cobalt ferrite
BW	Bounded Warburg element
C	Carbon
C/A	Cubic/Amorphous
Ca	Calcium
CALPHAD	CALculation of PHAse Diagram
CB	Carbon black
CCM(s)	Catalyst coated membrane(s)
Cd	Cadmium

Ce	Cerium
CE	Counter electrode
CEM	Compound energy model
CFE	Carbon fiber electrode
CHP	Cogeneration of heat and power
Cl(/$^-$)	Chlorine(/chloride)
CL(s)	Catalyst layer(s)
Cm	Curium
CNLS	Complex nonlinear least squares
CNT(s)	Carbon nanotube(s)
CO	Carbon monoxide
Co	Cobalt
CO_2	Carbon dioxide
COR(s)	Carbon oxidation reaction(s)
CP	Carbon paper or Coordination polymers
CPE	Constant phase element
CPO	Coordination polymer of Oslo
Cr	Chromium
Cs	Cesium
CTE	Coefficient of thermal expansion
Cu	Cuprum (Copper)
CV	Cyclic voltammetry
CVD	Chemical vapor deposition
DARPA	Defense Advanced Research Projects Agency
DC	Direct current
DEFC	Direct ethanol fuel cell
DFAFC	Direct formic acid fuel cell
DFT	Discrete Fourier transform or Density functional theory
DHE	Dynamic hydrogen electrode
DHW	Domestic hot water
DMFC	Direct methanol fuel cell
DOE	Department of Energy
DTU	Technical University of Denmark
EC(s)	Electrochemical cell(s)
ECA	Electrochemical area
ECSA	Electrochemical surface area
EDL	Electrical double layer
EDS	Energy dispersive spectroscopy
Ee	Total cell voltage
EELS	Electron energy loss spectroscopy
EG	Ethylene glycol
EIS	Electrochemical impedance spectroscopy
EL	Water electrolyzer
EMF	Electromotive force

EQCM	Electrochemical quartz crystal microbalance
EREV	Extended range electric vehicle
ESA	Electrochemical surface area
ESI-PSE	Electrostatic-induction potential-superposed electrolysis
EUDC	European Union Driving Cycle
EXAFS	Extended X-ray absorption fine structure
FC(s)	Fuel cell(s)
FCC	Face centered cubic
FCCJ	Fuel Cell Commercialization Conference of Japan
FCHJU	Fuel Cells and Hydrogen Joint Undertaking
FCV(s)	Fuel cell powered vehicle(s)
FCX	Fuel cell experimental (vehicle)
Fe	Ferrum (Iron or Ferrous or Ferric)
FFT	Fast Fourier transform
FIB	Focus(ed) ion beam
FRA	Frequency response analyzer
FSZ	Fully stabilized zirconia
FT	Fourier transform
FUN(s)	Functional unit(s)
FWHM	Full-width-at-half-maximum
GA(s)	Graphene aerogel or Genetic algorithm(s)
GCB	Graphitized carbon black
Gd	Gadolinium
GDC	Gadolinium doped ceria
GDE(s)	Gas diffusion electrode(s)
GDL(s)	Gas diffusion layer(s)
GDQ	Generalized differential quadrature
GGA	Generalized gradient approximation
GHG(s)	Greenhouse gas(es)
GIXD	Glancing incidence X-ray diffraction
GNT(s)	Graphene nanotube(s)
GO	Graphene oxide
GOA	Graphene oxide aerogel
H_2	Hydrogen
HA	*Hygrophila auriculata* plant extract
HAADF	High-angle angular dark-field
HAXPES	Hard X-ray photoelectron spectroscopy
HCP	Hexagonal close pack
HF	High frequency
HFAA	Hexafluoro acetylacetone
HFR	High-frequency resistance
Hg	Hydrargyrum (Mercury)
HKUST	Hong Kong University of Science and Technology
HLG	HOMO-LUMO gap

HOMO	Highest occupied molecular orbital
HOR(s)	Hydrogen oxidation reaction(s)
HREG(s)	Hydrogen generation system(s)
HRTEM	High resolution transmission electron microscope
HT	Heat treated/treatment
IAE	Ionized air reference electrode
ICE(s)	Internal combustion engine(s)
I-E(s)	Current-potential curve(s)
IFP(s)	Imidazolate framework(s) Potsdam
In	Indium
INT(s)	Interface(s)
IR	Internal reforming or Infrared spectroscopy
IRMOF(s)	Isoreticular metal organic framework(s)
ITO(s)	Indium oxide(s)
JUC	Jilin University China
K	Kalium (Potassium)
KCL	Kirchhoff's current law
K–K	Kramers–Kronig
KMC(s)	Kinetic Monte Carlo simulation(s)
KVL	Kirchhoff's voltage law
La	Lanthanum
LANL	Los Alamos National Laboratory
LCA	Life cycle assessment
LDA	Local density approximation
Li	Lithium
LSC	Lanthanum strontium cobaltite
LSCF	Lanthanum strontium cobalt ferrite
LSCM	Lanthanum strontium chromium manganite
LSGM	Lanthanum strontium gallium magnesium oxide
LSM	Lanthanum strontium manganite
LST	Lanthanum strontium gallium or Linear systems theory
LUMO	Lowest unoccupied molecular orbital
LZO	Lanthanum zirconium oxide
M/T	Monoclinic/Tetragonal
MCFC(s)	Molten carbonate fuel cell(s)
MEA	Membrane electrode assembly
MEMS	Micro electro mechanical system
MFC	Mass flow controller
MFFCS	Multifunctional fuel cell system
MFU	Metal-Organic Framework Ulm University
Mg	Magnesium
MHT	Metal hydride tank
MIEC	Mixed ionic and electronic conductor
MIL	Materials of Institut Lavoisier

Mn	Manganese
MNP(s)	Magnetic nanoparticle(s)
Mo	Molybdenum
MO(s)	Metal oxide(s)
MOF(s)	Metal-organic framework(s)
MOR(s)	Methanol oxidation reaction(s)
Mpc(s)	Metallic phthalocyanine(s)
MPGe	Miles per gallon equivalent
MWNT(s)	Multi-walled carbon nanotube(s)
N_2	Nitrogen
NASA	National Aeronautics and Space Administration
Nb	Niobium
NCL	Nitrogen-doped carbon layer
NCP(s)	Nanoscale coordination polymer(s)
NEDC	New European Driving Cycle
NHE	Normal hydrogen electrode
NI	Necking index
Ni	Nickel
NL(s)	Normal liter(s)
NLLS	Nonlinear least squares
NM(s)	Nanomaterial(s)
NO	Nitric oxide
NOTT	University of Nottingham
NP(s)	Nanoparticle(s)
NSF	National Science Foundation
NU	Northwestern University
O	Atomic oxygen
O_2	Molecular oxygen
OCV	Open circuit voltage
ODA	Oxygen depleted air
OER(s)	Oxygen evolution reaction(s)
OP	Optimization problem
ORR(s)	Oxygen reduction reaction(s)
Os	Osmium
Ox	Oxidant
P	Phosphorus
PAFC(s)	Phosphoric acid fuel cell(s)
PAH(s)	Polycyclic aromatic hydrocarbon(s)
PANI	Polyaniline
PBCO	Praseodymium barium cobaltite oxide
PBFM	Praseodymium barium ferrite magnesium oxide
PBFM(s)	Praseodymium barium ferrite magnesium oxide(s)
PBI	Polybenzimidazole
PBMO(s)	Praseodymium barium magnesium oxide(s)

PC(s)	Phthalocyanine(s)
PCI	Pressure-concentration isotherm
PCN(s)	Porous coordination network(s)
Pd	Palladium
PD	Polydopamine
PDFV	Polyvinylidene fluoride
PDU	Power distributor unit
PEC	Predictive environmental concentration
PEEK	Poly-ether-ether-ketone
PEFC(s)	Polymer electrolyte fuel cell(s)
PEM	Proton exchange membrane
PEMFC(s)	Polymer electrolyte membrane fuel cell(s)
PEO	Polyethylene oxide
PFSA	Perfluorosulfonic acid
PGM(s)	Platinum group metal(s)
PHEV(s)	Plug-in hybrid electric vehicle(s)
PIM	Intrinsic microporosity
PLD	Pulsed laser deposition
POP(s)	Porous organic polymer(s)
PPy	Polypyrrole
PPY-PSS	Polypyrrole polystyrene sulfonate
PSCFN(s)	Praseodymium strontium cobalt iron niobium oxide(s)
PSZ	Partially stabilized zirconia
Pt	Platinum
PTFE	Polytetrafluoroethylene
PV(s)	Photovoltaic(s)
PVDF	Polyvinylidene fluoride
Q-HQ	Quinone-hydroquinone
RA(s)	Risk assessment(s)
RC	Resistor-capacitor
RCL	Resistor-capacitor-inductor
Rd	Reductant
RDE(s)	Rotating disk electrode(s)
RDS	Rate-determining step
RE	Reference electrode
RES	Renewable energy sources
RF	Radio frequency
rGO(s)	Reduced graphene oxide(s)
Rh	Rhodium
RH(/s)	Relative humidity (/humidities)
RHE	Reversible hydrogen electrode
RL	Resistor-inductor
ROS	Reactive oxygen species
RPE	Retinal pigment epithelium
RPM(s)	Robust porphyrinic material(s)

RRDE	Rotating ring-disk electrode
RS	Red seed extract of *Hydrophilia auriculata*
RT	Room temperature
Ru	Ruthenium
S	Sulfur
SBA	Santa Barbara amorphous type mesoporous silica
SBU(s)	Second building unit(s)
Sc	Scandium
SCE	Saturated calomel electrode
SEM	Scanning electron microscope
SFM	Strontium ferrite molybdate
SGTE	Scientific Group Thermodata Europe
SHE	Standard hydrogen reference electrode
Si	Silicon
Sm	Samarium
SMMO(s)	Strontium magnesium molybdenum oxide(s)
SMSI	Strong metal-support interaction
Sn	Tin
SNU	Seoul National University
SoC	State of charge
SOFC(s)	Solid oxide fuel cell(s)
Sr	Strontium
SSC	Samaria strontium cobaltite
SSE	Single voltage source electrolysis
SSFF	Stainless steel fiber felt
STEM	Scanning transmission electron microscopy
SU/SD	Start-up/Shutdown
SWCNT(s)	Single-walled carbon nanotube(s)
SZO	Strontium zirconate
T/C	Tetragonal/Cubic
Ta	Tantalum
TAA	Dibenzotetraaza anulenes
TaC	Tantalum carbide
TDS	Thermal desorption spectroscopy
TEM	Transmission electron microscope
TGA	Thermogravimetric analysis
THEUS	Totalized hydrogen energy utilization system
Ti	Titanium
TiB	Titanium boride(s)
TiC(s)	Titanium carbide(s)
TiN(s)	Titanium nitride(s)
TiO	Titanium oxide or Titania
TMC(s)	Transition metal carbide(s)
TMPP(s)	Tetrametoxiphenyl porphyrin(s)
TOE(s)	Tonne of oil equivalent(s)

TPB	Triple phase boundary
TPP	Tetraphenyl porphine
TPR	Temperature-programmed reduction
TXRF	Total reflection X-ray fluorescence
UiO	University of Oslo
UMCM	University of Michigan Crystalline Material
URFC(s)	Unitized reversible fuel cell(s)
USP	Ultrasonic spray pyrolysis
UTSA	University of Texas at San Antonio
UV	Ultraviolet
V	Vanadium
W	Tungsten
WC(s)	Tungsten carbide(s)
WE	Working electrode
WGSR(s)	Water gas shift reaction(s)
WWII	Second World War
XAS	X-ray absorption spectroscopy
XPS	X-ray photoelectron spectroscopy
XRD	X-ray diffraction
Y	Yttrium
YST	Yttrium-stabilized titania
YSZ	Yttria-stabilized zirconia
ZIF(s)	Zeolite imidazolate framework(s)
Zn	Zinc
Zr	Zirconium
ZTC	Zeolite template carbon

About the Authors

Fan Li received his Ph.D. in Materials Science and Engineering from Royal Institute of Technology (KTH), Sweden, 2007, and Physical Chemistry in Metallurgy from the University of Science and Technology Beijing in 2008. He is an Associate Professor at Beijing University of Technology. He has directed and participated in (>10) projects supported by National Natural Science Foundation of China (NSFC), Beijing Natural Science Foundation, Ministry of Education, and Ministry of Science and Technology of P.R. China. Dr. Li is focused on electrochemical properties of the transition metal oxides with mixed valence states and applied them in polymer electrolyte membrane fuel cell. The preparation and characterization of nano-structured electro-catalyst with low content noble metals is his main study field. Dr. Li has authored and coauthored textbook, book, and book chapters and peer-reviewed journal articles (>50). During the past 9 years, he taught over 500 students and trained more than 100 undergraduate and postgraduate students.

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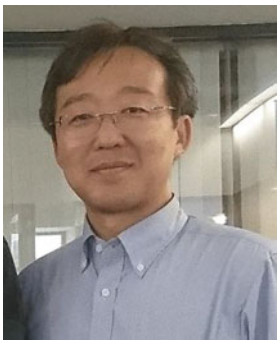
Chartered Scientist. During his service in TAMUK, he trained more than 3,000 students on both undergraduate and graduate levels. He created online courses and established safety training protocols in conjunction with the risk management. Currently, he collaborated with the local law enforcement as a consultant.

Jingbo Louise Liu received her Ph.D. in Materials Science and Engineering from the University of Science and Technology Beijing in 2001. She is a Full Professor at Texas A&M University – Kingsville (TAMUK) and focused on materials preparation, characterization, and applications. She is the DEBI Faculty Fellow at the US Air Force Research Laboratory. She has authored and coauthored, books, book chapters, and peer-reviewed journal articles (>90). During her 11-year services in TAMUK, she taught >7,000 students and trained to conduct leading edge research. She directed and/or participated in the projects (>40) supported by the NSF (USA and China), NSERC (Canada), ACS Petroleum Research Funds, and Department of Education as PI, Co-PI, and senior personnel.

Katsutoshi Ono received B. Eng. Degree from Kyoto University, Japan, in 1961 and degree of Dr. Sci. from Faculté des sciences, Université de Paris in 1967. He was researcher at Ecole des Mines de Paris, 1965–1967, Professor of Materials Science, Kyoto University, 1982–1997, Energy Science and Technology, 1997–2001. He is currently a Professor Emeritus. He taught Chemical Thermodynamic Thermodynamics for under graduate course, and Thermal Chemistry and Chemistry and Statistical Mechanics for graduate course. As the laboratory experiments, he conducted the measurements of free energy and the equilibrium phase diagrams of the binary and ternary metal-oxide systems at high temperatures, 1983–1990. He focused his works on the industrial field of metallurgy, 1990–2001: Application of vacuum metallurgy to the steelmaking and the electron-

beam melting of high-melting-point metals and alloys. From 2001 to 2010, he was engaged in the development of a new process for titanium production (OS process). He published "Design, Test and Theoretical Assessments for Reduction of Titanium Oxide to Produce Titanium in Molten Salt" in 2016. He is now working on the hydrogen energy. It is basically a study of how to achieve self-sustainable electrical power generation. Recently, he proposed the theoretical concept of hydrogen redox electric power and hydrogen energy generators.

Makoto Uchida received his Ph.D. in Engineering Science from the University of Yamanashi (UoY) in 1999. He was attached in Panasonic Corporation from 1987 to 2008. He established a basic design of the fuel cell stack and membrane electrode assembly (MEA) for Panasonic Fuel Cell co-generation system (ENE-FARM), and promoted the product planning and the business project. He was related to the decision of the Japan Industrial Standard of the polymer electrolyte fuel cell (PEFC) power system as the chief member of The Japan Electrical Manufacturers' Association. In 2008, he moved from Panasonic to UoY and was inducted to a Professor and a manager of Metals Research Division, Fuel Cell Nanomaterials Center, which was established at that time, and promoted the "Research on Nanotechnology for High Performance Fuel Cells (HiPer-FC)" project which was founded from the New Energy and Industrial Technology Development Organization (NEDO) of Japan. Currently, he is also promoting the next "Superlative, Stable, and Scalable Performance Fuel Cell" (S-Per-FC) project founded by NEDO from 2015 and other collaboration researches with many companies. He is establishing MEA to advance performance and durability of PEFCs and directs researches of new fabrication methods for MEAs. He has authored and coauthored textbook, book, and book chapters and peer reviewed journal articles (>70). During his 9-year services in UoY, he trained >100 graduate students to conduct leading edge research. He received the Technical Development Award of the Electrochemical Society of Japan in 2006.



Katsuyoshi Kakinuma received his Ph.D. in Engineering Science from the Tokyo University of Science in 1998. He joined Kanagawa University as a Research Associate and invented the new oxide-ion conductor for solid oxide fuel cells (SOFC). In 2008, he moved from Kanagawa University to University of Yamanashi as an Associate Professor at Fuel cell nanomaterials center and was then promoted as a Professor of the center in 2011. He also promoted "HiPer-FC" from 2008 to 2014 and "S-Per-FC" project from 2015 founded from NEDO. He is establishing invention of high durable and high active catalysts supported on conducting ceramics nanoparticles for PEFC. He has authored and coauthored textbook, book, book chapters, and peer-reviewed journal articles (>90). He was in charge of the editorial board of *Electrochemistry* (The Electrochemical Society of Japan, 2010–2012). His awards include the Young Researcher Award of the Electrochemical Society of Japan (Sano Award) in 2005.

Akihiro IIYAMA received his Ph.D in Mechanical Engineering from the University of Tokyo (UoT) in 1991. He joined Nissan Motor Co., Ltd. in 1982 and worked for the R&D of the diesel engines and gasoline engines. In April 2008, he was appointed the General Manager, Fuel Cell Laboratory, Nissan Research Center, Nissan Motor Co., LTD.; in April 2010, he was appointed the General Manager, EV System Laboratory, Nissan Research Center, Nissan Motor Co., LTD.; and in April 2011: Expert Leader, EV System Laboratory, Nissan Research Center, Nissan Motor Co., LTD. During these periods, he led the R&D activity on the MEA degradation mechanism analysis, their mitigation technology, fuel stack and its system development, and prototype FCV development in Nissan Motor Co., LTD. In February 2015, he moved to the University of Yamanashi as a Project Professor and became the Director of Fuel Cell Nanomaterials Center, University of Yamanashi in April 2015, to manage the "SPer-FC" project funded by the NEDO, Japan, a position he still occupies. He has authored and coauthored textbook, book, and book chapters and peer-reviewed journal

articles (>30). He received the 2013 FY Thermal Engineering Award, Distinguished Engineers, from the Japan Society of Mechanical Engineers.

Jorge Uribe Godínez received his Ph.D. in Materials Science from the Research and Advanced Studies Center of the National Polytechnique Institute (CINVESTAV, Campus Queretaro), Mexico, 2011. He was also a postdoctoral research fellow at Institute of Chemistry of the National Autonomous University of Mexico (UNAM) to conduct research in the field of electrocatalysis and PEM fuel cells (2014). Currently, he works at National Center of Metrology of Mexico (CENAM) as researcher. He is directing the re-establishment of the Primary National System for Measurement of Electrolytic Conductivity in Mexico. In addition, he keeps collaboration with colleagues from UNAM and CINVESTAV, to develop new electrocatalysts and to evaluate them in hydrogen PEM fuel cells. Dr. Uribe has authored some journal articles, and he is co-inventor of a patent about mono- and polymetallic electrocatalysts and its application in hydrogen fuel cells. He also peer reviewed some journal articles and presented more than 40 research works at different scientific congress. Since 2012, he has trained seven undergraduate students and six graduate students and he has participated as Professor of courses to both undergraduate and graduate levels. Dr. Uribe has received more than ten awards for his research work.

Xuecheng Cao received his B.E. degree in New Energy Materials and Devices at Soochow University in 2014. He is currently a Ph.D. student in Prof. Ruizhi Yang's research group. His research interests focus on the design and understanding of nanostructured carbon-free cathode materials for lithium-oxygen batteries (LOBs), transition metal oxide based electrocatalysts for oxygen reduction reaction (ORR) and oxygen evolution reaction (OER). He aims to develop materials with tunable structure and improve the energy conversion efficiency of LOBs.

Ruizhi Yang received her Ph.D. in Condensed Matter Physics from the Institute of Physics, Chinese Academy of Sciences in 2005. She was a Postdoctoral Fellow at Dalhousie University (2005–2008) and Research Associate at Stanford University (2008–2011). She is a Professor at Soochow University. Her research interests mainly focus on the development of advanced electrode materials for fuel cells, lithium-air batteries, and other metal-air batteries at an atomic scale; the fundamental understanding of electrocatalysis in fuel cells and metal-air batteries; and also understanding of the structural dynamics of nanoparticles, thin films, and single crystals in electrocatalytic processes. Prof. Yang has directed and participated in more than 10 projects supported by National Natural Science Foundation of China (NSFC), the National Key Research and Development Program of China, Natural Science Foundation of Jiangsu Province, etc. She has authored and coauthored book chapters and peer-reviewed journal articles (>60) and held patents (>20). She received the Electrochemistry Award for Young Talent, China, in 2013. During her service in Soochow University, she taught over 300 students and trained more than 50 graduate students to conduct leading edge research.

Dr. Surbhi Sharma completed her B.Sc. (Hons) in Physics, University of Delhi, followed by MSc. in Nanoscience from Amity University, India. She received her Ph.D. degree from Ulster University, UK, 2011, where her work was conferred with the Best Thesis Award. She joined the University of Birmingham as a Teaching Fellow in fuel cells in 2011. She taught and trained students at the undergraduate and postgraduate level for carrying out systematic and innovative research and also attained professional teaching qualifications and is a Fellow of Higher Education Academy since 2013. She has also co-supervised doctoral students' studies to completion. As the Work Package Leader for the multi-partner project STAMPEM (2012–2015), funded by the European Union's Fuel Cells and Hydrogen Joint Undertaking (FCH-JU), 7th Framework Program, she delivered hybrid polymer-metal NP conductive, corrosion protection coatings for stainless

steel. She has research interests in the field of energy materials and novel energy applications with a focus on exploring graphene oxide and its oxygen functional group interactions with metal nanoparticles and reduced graphene based materials along with metal nanoparticles for CO-tolerant electrocatalyst-support systems, composite and multilayer proton conducting membranes, electrochemical sensors/biosensors, and corrosion protection coatings. She has reviewed research articles and book proposals and is on the editorial board for a number of journals. She has authored and published 29 peer-reviewed articles and book chapters along with a patent on nitrogenated graphene. She has been awarded research funds from Defence Science and Technology Laboratories (DSTL), Royal Academy of Engineering (RAE), and Materials Research Society (MRS).

Carolina Musse Branco graduated in Material Engineering at Universidade Federal do Rio Grande do Sul (Brazil) in 2011. There she continued her masters on electrolyte polymer/cellulose membranes for PEMFC with hydrogen at the Laboratory of Polymeric Materials. In 2013, she joined the Centre for Hydrogen and Fuel Cell Research at the University of Birmingham, UK, as a Ph.D. student, which was finalized in July of 2017. During the Ph.D., she investigated multilayer membranes for intermediate temperature PEFC.

Yufeng Zhang received his Ph.D. in Microelectronics and Solid State Electronics from Harbin Institute of Technology China, 2004. He was also a postgraduate research associate at Harbin Institute of Technology to conduct research in the field of power MEMS. As a Professor at Harbin Institute of Technology, he has directed and participated in (>10) projects supported by the Chinese National Natural Science Foundation, 863 Program, 973 Program, Doctoral Fund in Universities, etc. He has coauthored book chapters and peer-reviewed journal articles and delivered more than a dozen presentations at various scientific conferences.

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Shadi Darvish is a final year Ph.D. candidate in Materials Science and Engineering and will be graduating in December 2017 from Florida International University. She has started her Ph.D. in Integrated Materials and Processes Design (IMPD) group on spring 2014. During her Ph.D., she has carried out research on several topics, including thermodynamic investigation of defect chemistry inside the perovskites, thermodynamic predictions of electronic and thermomechanical properties of perovskites, and the impact of atmosphere impurities on solid oxide fuel cells' (SOFC) cathode. She is also collaborated in several industrial projects while she worked as an intern at QuesTek Innovation LLC. Her efforts during her Ph.D. study resulted in publishing several articles for ceramic-based membranes and SOFCs.

Mohammad Asadikiya is a Ph.D. candidate in the Department of Mechanical and Materials Engineering of Florida International University (FIU). He received his M. Sc. from Sharif University of Technology (2009) in corrosion and protection of materials. He spent several years in various industrial sections, mainly to control corrosion and protect different types of materials. He was the manager of R&D section of Maham imensaz Co. until 2013, working to develop new corrosion inhibitors and scale removers.

Mr. Asadikiya has published several peer-reviewed journal and conference papers and presented in various scientific conferences. He has also published one book chapter and holds one patent. He is currently working on the reassessment of thermodynamic database of yttria-stabilized zirconia as the electrolyte in solid oxide fuel cells (SOFCs). He is also investigating the sintering behavior of boron carbide by applying the CALPHAD approach.

Dr. Mei Yang is currently working in Worcester Polytechnic Institute (WPI) as Assistant Research Professor and Associate Technical Director of Center for Heat Treating Excellence (CHTE) following her position as a Senior R&D Engineer in H.C. Starck, where she was in charge of the alloy development for various niobium, tantalum, and molybdenum alloys. Her expertise is integrated materials and processes development for both metals and ceramics by combining modeling and experimental investigation. Her current research is focused on advanced heat treatment techniques.

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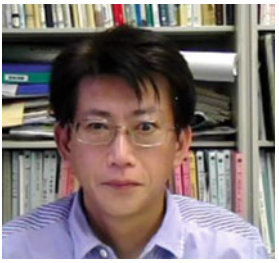

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Rolando Pedicini is a researcher with permanent position at CNR – Institute for Advanced Energy and Technologies "Nicola Giordano" of Messina, Italy. He obtained a Master Degree in Chemistry, on March 2000, at the University of Messina (Italy). Its scientific activity includes: nonperfuorosulfonic polymers functionalization like PEEK, PSF, etc.; development of different kinds of polymeric membranes; chemical-physical characterization; and materials development for solid state H_2 storage applications (metallic oxides anchored to a polymeric

matrix; coverage of metallic alanate; and study and characterization of natural material for H_2). Actually, Dr. Pedicini is the person in charge of the research unit "Hydrogen storage: materials and applications" pertaining to the "Fuel Cells for Polymer Electrolyte (PEFC) and Hydrogen Storage." Since 2011, he is a member of the "COST ACTION MP1103 – WG1 Session." From 2013 until now he is a member of the Editorial Board of the following scientific journals: *The Scientific World Journal: Energy*, *Energy Research Journal*, *MAYFEB Journal of Energy*, *SCIREA Journal of Energy*. Since 2015, he is a member of "New European Research Grouping on Fuel Cells and Hydrogen" (N-ERGHY). Since 2015, he is Technical Coordinator of two MoU with the Instituto Tecnológico de Chetumal (Mexico) and Universidad de Quintana Roo (Mexico). Currently, Dr. Pedicini is involved in several research projects (14) on national and European funds serving as a part of the ITAE research. In 2014, he worked as an evaluator for national projects banned from the Ministry of Education, University and Research. Dr. Pedicini performs regularly as a "Reviewer" for different scientific international journals. He is author/coauthor of 26 papers on international scientific journals, 62 congress communications, and 29 scientific reports for EU and national projects and for industrial contractors.

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hydrogen storage. She is involved in various research programs related to the previously mentioned topics. She was the scientist responsible of CNR-ITAE unit in the 7th Framework Programme Collaborative Project No. 303452, "Improved Lifetime of Automotive Application Fuel Cells with Ultra-Low Pt-Loading (IMPACT)." She published about 148 articles (more than 783 citations and H-index: 15 from SCOPUS Database) – 47 in international journals, one book chapter (Springer), and she had about 101 contributions in national and international conferences. She is a reviewer for several international scientific journals. She was member of the scientific committee of conferences.

Dr. Enza Passalacqua is graduated in Industrial Chemistry and specialized in Chemistry and Catalysis Technology at University of Messina. She is a researcher at Institute for advanced energy technologies "Nicola Giordano" (ITAE) of CNR since 1988 and a Research Manager since 2010. From 1993 to 2012 she has coordinated the research activity "Polymer electrolyte fuel cells (PEFC) and hydrogen storage" at CNR-ITAE, and currently is research manager and collaborates with the same research group. She has been technical leader of several national and European projects addressed to the development and characterization of components (gas diffusion electrodes, membranes, membrane/electrodes assembly) and to the realization of small size PEFC stack and systems. She is author of 97 papers for international journals and more than 200 for international congresses. In 2008, she was teacher in the II level Master in "Systems for Production and Transport of Hydrogen and Fuel Cell" of the University of Messina-Department of Industrial Chemistry and Materials Engineering. From 2009–2011 she was a component of the Female Researchers in Europe Window (FRIEND) of CNR to help and push female researchers to participate in the project. From 2011–2013 she has carried out technical and scientific activity in the Joint Programme of European Energy Research Alliance (EERA) as expert for CNR. From 2016 she is in the Panel Transport as CNR expert to evaluate MiSE Projects.

Javier de la Cruz received his Ph.D. in Electrical Engineering from the CINVESTAV, Mexico, 2014. He has been a Lecturer since 2010 in three Mexican universities, including UNAM. He is a CONACYT Researcher at the INEEL since 2014. He has participated in more than five projects supported by CONACYT. Now he is leading a national project on small wind turbine technology with international collaborations. He has published journal conference and journal papers in fuel cell technology.

Dr. T. Romero received her Ph.D. in Transport Phenomena in Proton Exchange Membrane Fuel Cells from the University of British Columbia in 2008. She has expertise in electrocatalysts, membranes and membrane electrode assembly fabrication, and integration of nanomaterials for improving fuel cells performance. At the Institute for Fuel Cell Innovations (IFCI), Dr. Romero worked developing new methodologies and designing novel testing apparatus for fuel cell transport phenomena studies. From 2000 onwards, she has worked at the Instituto Nacional de Electricidad y Energías Limpias (INEEL) where she works on fuel cell systems development, coordinating multidisciplinary national and international teams. Dr. Romero graduated *summa cum laude* with a MASc. in Electrocatalysts for Fuel Cells from the Universidad Nacional Autónoma de México (UNAM). In 2001, she took an appointment in the National Research Energy Laboratory (NREL), in Colorado, where she developed a MEA fabrication methodology. Dr. Romero has authored more than 20 peer-reviewed papers and has two patents granted.

Dr. U. Cano-Castillo carried out his D.Phil. in Materials Science at the University of Oxford working on environmentally assisted corrosion cracking of composite materials. Since then, he has been working on electrochemistry applied to energy systems including membrane fuel cells, automotive batteries, and electrolysis. He is founder of the Hydrogen and Fuel Cells group at the Electricity Research Institute in Mexico where he has led several applied projects, including fuel cell systems for transportation applications. He has several patents granted on that technology. Dr. Cano-Castillo is

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Hilmi Mohamed is currently enrolled as a Ph.D. student in Gas Engineering in Universiti Teknologi Malaysia since 2014. His major research area is triple layer hollow fiber applied for the solid oxide fuel cells (SOFCs). His research goals are to develop fibers with unique structure to enhance the stability and mechanics of the SOFCs. He has authored and coauthored peer-reviewed journal papers with high impact factors. He had also presented his research discoveries in national and international conferences.

Dr. Siti Munira Jamil received her Ph.D. in Gas Engineering from Universiti Teknologi Malaysia, Malaysia, 2017. She was promoted to a Postdoctoral Researcher at Universiti Teknologi Malaysia due to her outstanding achievement in her Ph.D. study. She has authored and coauthored peer-reviewed journal articles and book chapters and delivered a few presentations at various international and national conferences. Currently, she is an active researcher in bringing the new technology of microtubular solid oxide fuel cell (MT-SOFC) in Malaysia.

Siti Halimah Ahmad received her Master in Gas Engineering from Universiti Teknologi Malaysia in 2016. Her research interests emphasize the nanoparticles for solid oxide fuel cells (SOFCs). Her future research will focus on the development series of nanoparticles with different tunable structures and advancement of the robustness of the SOFCs. She has authored and coauthored peer-reviewed journal publications with high impact factors.

Dr. Mohd Hafiz Dzarfan Othman is an Associate Professor in Department of Energy Engineering, Faculty of Chemical and Energy Engineering, Deputy Director of Advanced Membrane Technology Research Centre (AMTEC), and also Head of Renewable Energy Research Group. He received his Bachelor's and Master's degrees from Universiti Teknologi Malaysia, Malaysia, and Ph.D. from Imperial College London, United Kingdom. Up to May 2017, he has supervised 23 Ph.D. students and 18 master's students, with research interests in ceramic/polymeric membranes for energy generation, gas separation, and water reclamation. He has published more than 80 articles in Scopus-indexed journals with h-index of 13. He has led 18 research/consultancy projects, including recently received international grants *Kurita Water and Environment Foundation* and *Nippon Sheet Glass Foundation for Materials Science and Engineering*, besides co-researcher of another 50 projects, which in total worth RM16 million (about USD 4 million). Through these projects, his research team has successfully developed sustainable membranes for the treatment of various pollutants in water as well as an economical fuel cell for efficient electricity generation and has been granted two patents (four more are currently being examined). Some of the research products have also been recognized in the national and international level by winning several awards, for instance Asian Invention Excellence Award in *28th International Invention, Innovation and Technology Exhibition* (ITEX'17), Best Invention Award in *18th Industrial Art and Technology Exhibition (INATEX2016)*, Jury Award in *17th Industrial Art and Technology Exhibition (INATEX2015)*, Most Distinguish Award in *Persidangan Dan Eskpo Ciptaan Institusi Pengajian Tinggi Antarabangsa (PECIPTA) 2013*, Double Gold Medal in *British Invention Show (BIS) 2008*, and Best of the Best Award in *Malaysia Technology Expo (MTE) 2008*.

Dr. Mukhlis A. Rahman graduated with B. Eng. (Chemical Engineering) in 2003. He was involved in research activities since 2004 when he became a master's student at Universiti Teknologi Malaysia. He worked on the preparation of polymer precursor for the development of carbon fiber locally, in collaboration with SIRIM and other public universities. He published two ISI research articles and one patent has been granted. Dr. Mukhlis A. Rahman later received his M. Eng. (Gas Engineering) in 2006. He started his academic career when he was appointed as a Lecturer in 2007 in the Department of Gas Engineering, Faculty of Chemical and Energy Engineering. Shortly after that, he was granted with a scholarship from Ministry of Higher Education to further his Ph.D. study in Chemical Engineering at Imperial College London, focusing his scope on ceramic membrane for microreactor incorporated with palladium membrane for hydrogen separation. Through his works, seven ISI research articles were published in the area. He was able to complete his Ph.D. study in 3 years and 8 months before coming back to UTM on August 2011 to continue his academic career. Due to excellent achievement during his Ph.D. study, he was awarded an Excellent Service Award 2011 from UTM. Dr. Mukhlis A. Rahman has great passion in "research and innovation" fields. He and his research group have developed ceramic and glass membranes locally to be used for water purification. Until now, he has supervised four Ph.D. students and six master's students, with research interests in ceramic membranes incorporated with porous materials for water reclamation. He has published more than 40 articles in Scopus-indexed journals with h-index of 13. He has led 10 research projects, besides coresearcher of more than 50 projects, which in total worth more than RM10 million.

Dr. Juhana Jaafar graduated with a B.Eng. (Chemical Engineering) from Universiti Teknologi Malaysia in 2004. She was then granted with National Science Fellowship under Ministry of Higher Education (MOHE) to pursue her M.Sc. in Gas Engineering from Universiti Teknologi Malaysia. In 2011, she graduated with a Ph.D. in Gas Engineering from the same university specializing in advanced membrane manufacturing for energy application. She has started her academic career

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Ahmad Fauzi Ismail is Professor at Faculty of Chemical and Energy Engineering, UTM. His research interests are in the development of polymeric, inorganic, and novel mixed matrix membranes for water desalination, waste water treatment, gas separation processes; membrane for palm oil refining; photocatalytic membrane for removal of emerging contaminants; and development of hemodialysis membrane and polymer electrolyte membrane for fuel cell applications. He obtained his Ph.D. in Chemical and Process Engineering in 1997 from University of Strathclyde and M.Sc. and B.Sc. from Universiti Teknologi Malaysia in 1992 and 1989, respectively. He is the author and coauthor of over 500 refereed journals. He has authored 6 books, 45 book chapters, and 4 edited books, 4 Patents granted, and 16 Patents pending. His h-index is 50 with cumulative citation of over 10112. He has won more than 120 awards nationally and internationally. He is a Fellow of The Academy of Sciences Malaysia, Chartered Engineer in the UK, and a Fellow of the Institution of Chemical Engineers. Ahmad Fauzi also served as the Editorial Board Member of *Journal of Membrane Water Treatment*, *Jurnal Teknologi*, *Journal of Membrane Science and Research*, and *Journal of Membrane and Separation Technology* and the Advisory Editorial Board Member of *Journal of Chemical Technology and*

Biotechnology. He involved extensively in R&D&C for national and multinational companies related to membrane-based processes for industrial application. He is the founder of Advanced Membrane Technology Research Center, which is now known as Higher Education Center of Excellence. Currently, Ahmad Fauzi is the Deputy Vice Chancellor of Research and Innovation, UTM.

Dr. Nancy KingSanders' background in higher education spans more than 27 years to include a current appointment as Associate Vice-President for Student Success at Texas A&M University-Kingsville, a position she has held since 2011. Prior appointments include Associate Dean for Graduate Studies, Administrative Intern for Academic Affairs, Graduate Music Education Coordinator, as well as attaining tenure and the rank of Full Professor in the Music Department at Texas A&M University-Kingsville. Under her administrative leadership at TAMUK, she established the Center for Student Success to include AVID (Advancement Via Individual Determination) for Higher Education, the First-Year Experience, a two-semester First-Year Seminar Course, Centralized Academic Advising, the Graduation Pathway Success Mentoring Center, the Pathway Academic Assistance Tutoring Center, Freshman Interest Groups, Academic Career Literacy, Mapping First-Year Seminar Curriculum to General Education Component Area Options, and Javelina Common Read Program, resulting in a 15.9% increase in First-Time in College retention at Texas A&M University-Kingsville. She was also selected as a National First-Year Student Advocate by Cengage and the National Resource Center for the First-Year Experience and Students in Transition. Dr. KingSanders' other responsibilities include all academic support for undergraduate students and Co-Principal Investigator for a Title V Individual $2.625 Million Hispanic Serving Institution Grant to embed research into undergraduate courses.

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