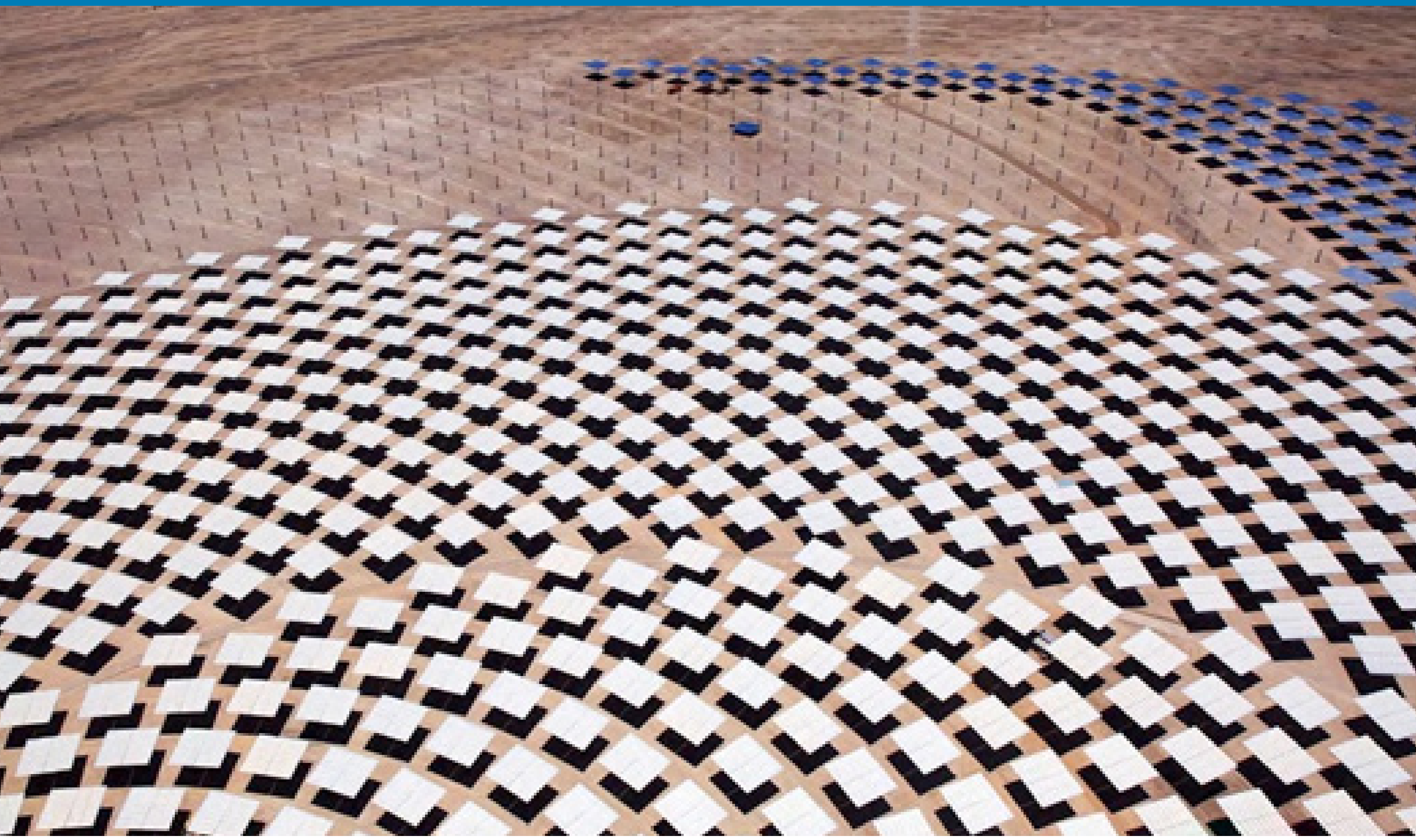
VI WORLD MATERIALS SUMMIT

MATERIALS INNOVATION FOR THE GLOBAL CIRCULAR ECONOMY AND SUSTAINABLE SOCIETY

Council of Europe, Strasbourg — 20th & 21st November 2017



INCLUDING

THE FORUM FOR NEXT GENERATION RESEARCHERS

Council of Europe – European Youth Centre, Strasbourg, France
18–19 November 2017

E-MRS

UNESCO
Organisation
des Nations Unies
pour l'éducation,
la science et la culture

uniTwin
Chaire UNESCO
« Sciences et Ingénierie des matériaux:
énergie environnement santé »

UNIVERSITÉ DE STRASBOURG

MRS

MATERIALS INNOVATION FOR THE GLOBAL CIRCULAR ECONOMY AND SUSTAINABLE SOCIETY

Council of Europe, Strasbourg – 20th & 21st November 2017

Organisation des Nations Unies pour l'éducation, la science et la culture

Chaire UNESCO «Sciences et Ingénierie des matériaux: énergie environnement santé»

VI WORLD MATERIALS SUMMIT

Including

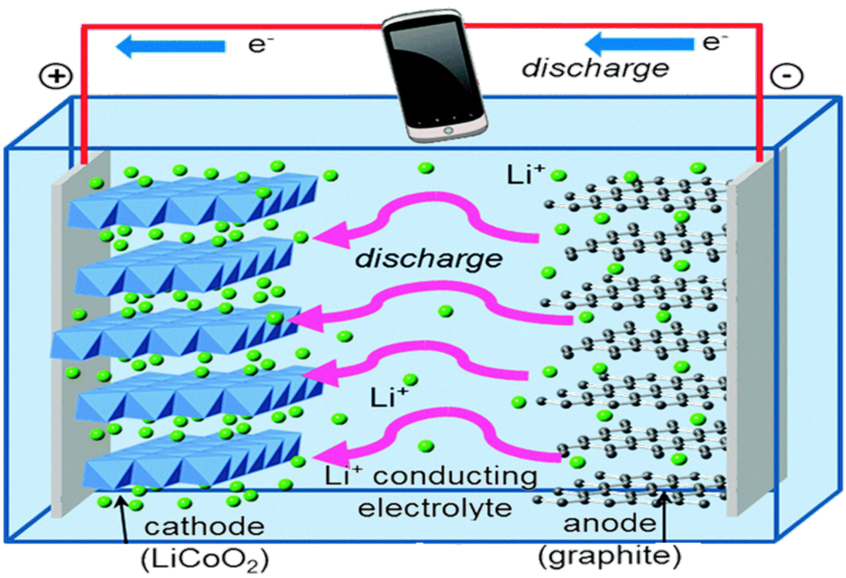
The Forum for Next Generation Researchers

18-19 November 2017

Council of Europe – European Youth Centre, Strasbourg, France

Africa Australia Brazil India Japan Korea

Mexico Russia Singapore Taiwan



Published by: European Materials Research Society
23 Rue du Loess
BP 20 – 67037 Strasbourg Cedex 02, France
emrs@european-mrs.com
Production management: Cycloid Fathom Technical Publishing, Illinois, USA
M. Nelson (graphic design), S. Zillman (copy editing)
Printed in: Strasbourg, France
Printer: Éclair Reproduction
First Printing, 2018

CONTRIBUTING EDITORS

John Blizzard	European Materials Research Society
George Crabtree	Argonne National Laboratory
Osvaldo N. Oliveira, Jr.	Universidade de São Paulo
Rod Ewing	Stanford University
Lan Fu	Australian National University
Andrew B. Holmes	University of Melbourne
Martin Hynes	European Science Foundation
Elton Kaufmann	Argonne National Laboratory
George Kiriakidis	University of Crete
José Manuel Martínez-Duart	Universidad Autónoma de Madrid
Baldev Raj	National Institute of Advanced Studies (Bengarulu)
Sharath Sriram	Royal Melbourne Institute of Technology
Alan Taub	University of Michigan
Peter Wellmann	Friedrich Alexander Universität

COMMON ABBREVIATIONS

AHSS	advanced high-strength steels
CCS	carbon capture and sequestration (or storage)
CNG	compressed natural gas
CNT	carbon nanotube
CSP	concentrated solar power
CST	concentrated solar thermal
CTE	coefficient of thermal expansion
EHS	electricity home systems
ELV	end-of-life vehicle
GHG	greenhouse gases
ICT	information and communications technology
PCE	power conversion efficiency
PAM	polyacrylamide
PV	photovoltaic
RES	renewable energy source(s)
SAR	synthetic aperture radar

ON THE COVER

View of an array of heliostats taken from the power collector tower at Chile's Atacama1 Concentrated Solar (Thermal) Power Plant.

DISCLAIMER

REMARKS FROM THE COUNCIL OF EUROPE

Excerpts from remarks delivered to the Summit from Gabriella Battaini-Dragoni, Deputy Secretary General of the Council of Europe.

We live in an era of extraordinary scientific and technological advance.

Not since the industrial revolution has so much change come so quickly or been so profound.

New technologies and electronic data, environmental matters, reproductive rights and end-of-life issues: Each of these and more are pertinent to the work that we do.

The European Court of Human Rights has found that the positive obligation on States to protect the right to life applies in the context of toxic emissions and waste-collection sites, including where these are the responsibility of private companies.

The Council of Europe is the first international organization to include examination of the implications of artificial intelligence for human rights and the rule of law in its work program.

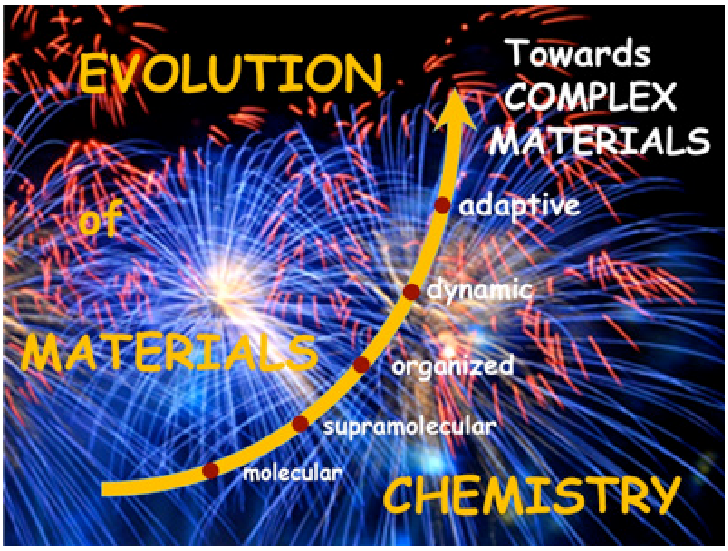
In a fast-changing field, it is important to take stock of the issues, and recommend courses of action that will have a positive benefit for society and mitigate the problems that arise.

Paraphrasing recent remarks of Patricia Espinosa Cantellano, Executive Secretary of the United Nations Framework Convention on Climate Change,

'…[there are] two faces of climate change: firstly positive, resolute, inspiring momentum by so many governments and a growing array of cities and states to business, civil society leaders and UN agencies aligning to the Paris Agreement's aims and goals…[but] secondly, the reality check. The thermometer of risk is rising; the pulse of the planet is racing; people are hurting; the window of opportunity is closing and we must go further and faster together to lift ambition and action to the next defining level'. [5 November 2017, *in re* COP23]


SUPER TYPHOON
RENEWABLE ENERGY
EXTREME WEATHER
METHANE
STORMS
COMBUSTION
GLOBAL WARMING
MITIGATION
GREENHOUSE EFFECT
CARBON DIOXIDE
CLIMATE
CHANGE
EMISSIONS
ENERGY EFFICIENCY
HEAT WAVES
DEFORESTATION
SEA LEVEL RISE
DEATH
DISASTER
GLACIERS
FOSSIL FUEL
HUMAN INFLUENCE
GLOBAL AVERAGE TEMPERATURE
TEMPERATURE ANOMALIES
GREENHOUSE GAS
OZONE
DISASTER


THE FUTURE HAS AN ANCIENT HEART (Carlo Levi)


EVOLUTION
of
MATERIALS
Towards COMPLEX MATERIALS
adaptive
dynamic
organized
supramolecular
molecular
CHEMISTRY

PREFACE

The purpose of the Sixth World Materials Summit, as was true of its five predecessors, is to bring together policy- and decision-makers, experts in markets and industrial technologies, and leaders from the science research community. They assess the status of the many global challenges we face today, identify the best paths forward, and recommend actions that will get us moving along those paths. This year's program focuses on Materials Innovation for the Global Circular Economy and Sustainable Society. The economic model that focuses on eliminating waste and inefficiency and promotes greater resource productivity — what we call the 'circular economy'—has been discussed in many forums. Sustainability is part and parcel of that concept.

What is unique to our series of Summits is our recognition of the crucial and ubiquitous enabling role played by advanced engineering materials — present in almost every aspect of the challenges the world faces, yet formerly taken for granted or ignored. It is now widely appreciated that materials development and innovation are key to meeting and overcoming virtually all the challenges facing the world, if the sustainable circular economy is ever to be achieved.

The list of global challenges is long and complex. Adding to the complexity of these issues is their extreme interconnectedness. With population growth as a driving force (world population is estimated to increase more than 30% by 2050), we can see regionally non-uniform deficiencies becoming more severe in food, potable water, energy, and critical materials, as well as degradation and disruption of the environment — land, water and air.

Obvious examples of multifaceted interdependence are seen among food supply, water for irrigation of arable land, and fertilizers and pesticides that increase food production but potentially contaminate the ground water that would otherwise supply potable water in many regions. Finding new sources of clean fresh water, as well as efficient 'green' desalinization technologies for sea water, is an urgent need. In addition, the energy required for agriculture itself and for subsequent preservation and distribution of its produce can, as a side effect depending on its means of generation, increase greenhouse gases (GHG) such as carbon dioxide (CO_2) in the atmosphere, thus contributing to global warming and a consequent impact on climate change.

An exhaustive analysis must include tertiary connections and beyond. For example, the human health consequences of vital resource shortages and of contaminated food chains add stress to a resource-dependent medical infrastructure that is already burdened, due to growing average life expectancy and the resulting greater percentage of the aged in the population.

Finding new sources of clean fresh water, as well as efficient 'green' desalinization technologies for sea water, is an urgent need.

Participants in the Summit's deliberative process immediately recognize the difficult task confronting them. For example, there is a great tension between the vast benefits we derive from our industrialized society, with ever-increasing technological power to improve the quality of life for an ever-increasing fraction of the planet's population, and the largely unintended negative consequences of that extraordinarily rapid progress: the anthropogenic impact on what some will claim is an easily disrupted and delicate ecological balance. In the marketplace, the very automation and growing digital economy that make our lives easier work against a 'sustainable society' through the erosion of job markets at the same time that populations grow, especially in developing regions. History has taught us that these circumstances often lead to political unrest and conflict, especially when exacerbated by endemic cultural factors. The public at large sees and is sensitive to such flare-ups of conflict and discord, but is much less aware of the slower and less dramatic, but nevertheless dangerous, abuse of our one and only home.

Summit participants, in contrast, are intensely aware of the challenges of sustainability. We can only theorize about the Earth system's elasticity — its forgiveness of the insults we inflict and its ability to self-correct. Similarly, whether, how, and for how long populations can absorb hardships and remain viable can only be surmised from past experience —and these days also from agent-based modelling using simulation codes on supercomputers. Perhaps one way to enunciate our Summit's goal is that we strive to identify mitigation strategies in as many sectors of human activity as we can. Such strategies will require an acceptable level of economic and social sacrifice while still helping us avoid potential tipping points in climate, in resource scarcity, in a befouled environment, and, ultimately, in the habitability of the Earth.

... we strive to identify mitigation strategies in as many sectors of human activity as we can.

Sustainability issues are, of course, not new. Many specific areas are now being addressed through leading-edge innovative technologies. Human health is benefitting from remote access to digitized medical records, from new treatment modalities ranging from lasers to energetic particle beams to encapsulated drugs, and from tests that now reach into our own personal genetic codes and make 'personalized medicine' a realistic opportunity.

As technical alternatives and economic incentives attempt to decrease generation of CO_2 and to slow its inexorable build-up in our atmosphere, technologies for carbon capture and storage and, beyond that, for re-use and conversion of waste CO_2 are being developed. In fact, a number of pilot plants have successfully converted CO_2 into methane, methanol, and higher molecular weight hydrocarbons or polymers. Although fossil fuels remain the GHG generating culprit, such back-end mitigation of emissions with sufficient technical advances might extend their use while limiting damage to the environment.

A massive increase in demand for electrical energy will test all aspects of our generation, transmission, utilization, and storage systems. In addition to population growth, the impetus for greater demand arises from new and more power-consuming devices, not the least of which will be the electric vehicle. With the inevitable eventual reduction in fossil fuel usage, questions mount concerning the ultimate realizable capacity of renewable sources like wind power and solar radiation to meet demand. The often unpredictable and intermittent nature of such sources makes energy storage, and batteries in particular, a vital component of any smart electric grid. Of course, the battery is also the power source for any mobile device. The grid must not only manage load-levelling strategies through the use of batteries, but also be substantially redesigned to handle recharging of the battery-powered vehicles of the future. Much progress in battery technology has been seen, and much more is needed. Similarly, there is ongoing development of more efficient means of transmission (including superconductors) and more energy efficient homes, offices and factories.

Nuclear power has the advantage of carbon-free and continuously available energy generation, but its association with nuclear weaponry and a widely separated series of notorious containment failures has turned public, and often political, opinion against it. As next-generation reactor designs are proven and the need for a stable and much less polluting energy source increases, nuclear may take on a more prominent role.

This brings us to the realization that access to adequate supplies of certain critical materials is necessary for greatly expanded and sustainable development. The most common approach to electricity production from fissile fuels requires uranium, of which the known reserves are limited. Current and expected future versions of batteries require lithium. Lithium is a relatively abundant element (0.0017% in the Earth's crust), but can the rate of extraction from salts and ores keep pace with the demand for vehicles and electronics while competing successfully with its other uses? The rare earth metals, of limited availability even today, play a central role as components in our electronic devices. This last case best illustrates why there is an ongoing search both for substitute materials and for efficient methods of recycling discarded electronic equipment for recovery of these elements.

All the challenges to the circular economy and a sustainable society cannot be called out in a short introduction. The recognized ecological impact of single-use plastics in our waste streams is an example of where materials advances could have an impact — both in biodegradability and in potential recycling from waste to resource. Many other symptoms of profligate use of resources might be addressed by science and by innovative materials science in particular. On the other hand, the impact of human infrastructure* covering more than 50% of Earth's land, as well as vast areas of 'unnatural' land use, present problems that go well beyond science solutions alone. These issues will demand societal adjustments to mitigate their consequences.

The materials science and engineering community recognizes its responsibility to our planet and its people. The Sixth World Materials Summit, bringing together experts in the several relevant fields from around the world to focus on these topics, provides a forum for discussion and a call for action that both informs and appeals to the world's policy- and decision-makers.

Nota bene: You will find in the following report that the same general topics arise repeatedly in different contexts, a direct consequence of the interconnectedness and overlap of energy, environment, raw materials, waste, CO_2 emissions, recycling, economic, and climate factors. One critical factor cited throughout is the need for public understanding and support of the technological solutions proposed in each region of the globe.

GSA Today*, **22, No. 12 (December 2012).

DECLARATION & KEY RECOMMENDATIONS

Materials Innovation for the Global Circular Economy and Sustainable Society

{*We deeply regret the unexpected loss of our colleague Professor Baldev Raj, who was of immense help in organizing both the Summit and the Forum and who contributed to this report before his untimely passing away.*}

More than 80 senior materials scientists, leading industrialists, and policy leaders from many parts of the world attended the VI World Materials Summit held in Strasbourg, France on 20-21 November, 2017. The Summit was hosted by the European Materials Research Society (E-MRS), the Chinese Materials Research Society (C-MRS), and the International Union of Materials Research Societies (IUMRS), representing the entire world. The topic of the 2017 Summit was *Materials Innovation for the Global Circular Economy and a Sustainable Society.*

In addition, 26 young researchers selected from around the world participated in the Summit and expressed their views on the world's needs and their solutions.

As the population continues to grow, the world faces the challenges of varying deficiencies in energy, potable water, nutrition and food, critical materials, degradation and disruption of the environment, climate change, inequalities, increasing desertification, and more. Delegates examined possible strategies for a circular economy and sustainable development offered by new materials, with case studies and examples from various countries being presented. Specifically, innovative technologies for recycling, energy supply for end-use applications, energy storage, renewable energy (solar, wind, etc.) and more, were discussed in detail. These technologies require new and improved materials and manufacturing processes, as well as innovative action to increase efficiency and reliability, to decrease greenhouse gas emissions, to reduce capital costs, to extend operational lifetimes and ensure that essential products and services are available for all citizens of the world.

Key conclusions on the five themes of the Summit are summarized as follows:

1. FUTURE ENERGY SUPPLY FOR MEGACITIES

- In the megacities of industrialized countries, a drive toward renewable energy emphasizes generating low-carbon solar photovoltaic (PV), solar thermal, wind energy, and other renewables. Stability considerations suggest that renewables not exceed 50% of the energy mix until a massive energy storage capability becomes available. Storage will make renewable energy competitive with the current conventional sources of our large electricity supply, such as natural gas and nuclear.

Nuclear power can back up the variability of wind

- The challenges ahead for nuclear energy are its public acceptance, cost competitiveness among clean energy options, and policy frameworks for achieving targeted outcomes. For most large cities and mega-users, nuclear energy with the safer and more sustainable Generation IV reactors, including small modular reactors, could emerge as the optimal carbon-free solution.
- Significant energy efficiency improvements in turbines are possible with new materials and configurations that facilitate high-temperature operation.
- New bio-inspired processes, for example, those based on nanocatalysts or artificial photosynthesis, need to be developed for higher energy efficiency. Harnessing micro-bacteria is the new direction for processing refuse such as solid waste and sewage from megacities.

2. FUTURE ENERGY SUPPLY FOR DEVELOPING COMMUNITIES

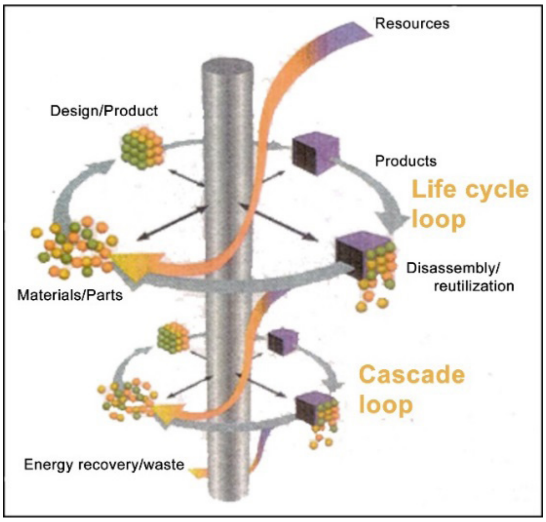
- Rural or decentralised economies need a diversity of energy technologies, and renewable energy will play an essential role. With minimizing the use of carbon a priority, solar PV and solar thermal are becoming the viable option.
- New technologies at a competitive cost are essential to increase the efficiency of capturing CO_2 emission and converting it to valuable chemical products and liquid fuels.

- Clean energy using hydrogen is another solution, but the production and storage of H_2 needs to be further developed.

3. CIRCULAR ECONOMY ENHANCEMENT

Recycling Li-ion batteries, rare-earth-rich products at end-of-life, and other materials is a problem for science and technology, as well as having social and cultural implications.

- Recycling is a country's responsibility and thus a policy obligation. Education on the need for recycling is essential. Current recycling technologies that are cost-uncompetitive, inefficient, and create environmental problems need to be improved.
- Electric vehicle development has been slowed by the limited availability and high price of certain elements, particularly lithium and cobalt. Electric, hybrid or fuel-cell cars are definitely the future modes of personal transport, but energy densities must increase while charging times decrease, safety must be enhanced, and the capital cost of Li and Co lowered. A low- or no-cobalt battery is now a viable option.
- Recycling of all materials currently used in production processes must be considered when designing new products.



4. FROM MATERIALS TO SYSTEMS FOR AN INFORMATION AND COMMUNICATIONS TECHNOLOGY (ICT) SOCIETY

- New materials and sensor devices will enable a smart electric grid to safely distribute a high percentage of renewable energy. A new era of efficient and reliable smart grid systems will transform the electric power industry.
- Flexible electronics are developing rapidly. With their large area, low cost, and good performance and functionality for wearables, security, smart packages and health monitoring/diagnostics, they are destined to be the next generation of technologies.

5. DISRUPTIVE MATERIALS FOR THE FUTURE

- 3D additive manufacturing technology can produce objects of almost any shape or geometry, with elements and phases that to date have been difficult or impossible to combine. Advanced materials and processes with lifecycle management using digital platforms are emerging as new frontiers. Materials genome and integrated computation materials engineering are new possibilities having immense potential applications. Material additive manufacturing technology has a wide spectrum of applications in spacecraft, consumer products, defence equipment, and other fields.
- Nano-scale materials and technologies have many applications in health, such as diagnosis, control, prevention, and treatment of diseases, and progress in computing and materials modelling has enormous potential for developing new materials. The nanomedicine market will expand rapidly, but ethical issues must not be neglected.
- Disruptive materials such as nanoalloys and nanomaterials, high entropy alloys, and advanced composites are only some examples of areas in which additional research funds are needed. Materials like silicon nitride (SiN), gallium nitride (GaN), and diamond and coatings for power electronics are also finding substantial research funds for the global economy and sustainable society.

The Summit's participants emphasised that planet Earth is searching for the next paradigm shift in the world's ecosystems in order to meet aspirations and responsibilities, to ensure sustainability, to combat the world's current inequalities — but perhaps this goes beyond what is appropriate to cover in this Declaration.

The circular economy, with efficiency and effectiveness in various segments of the value chain, is one answer to the search for a new paradigm — one that requires focus, continued dialogue with stakeholders, prioritisation, funding and collaboration.

Whatever the solutions are, materials are at the core of future sustainability and quality of life. A new generation of young research leaders to enhance international understanding, who have the ability to collaborate and communicate with all levels of society about materials research and development, is the foundation on which the future depends. Such was the final echo of the Summit.

CONTENTS

THE SUMMIT

FORUM FOR NEXT GENERATION RESEARCHERS

THE SUMMIT

APPENDICES


australian
environmental
environment
transmission
sustainability
infrastructure
transition
engineering
performance
technological
government
australia's
photovoltaic
implementation
nanotechnology
challenge
industrial
electricity
countries
investments
innovation
electronic
generation
production
international
manufacturing
quality
technology
distribution
management
president
recycling
carbon-free
hydrogels
transportation
fundamental
hydrocarbon
market
devices
transport
renewables
electronics
nanocomposites
desertification
material
world
hydro
health
producing
decarbonizing
metering
end-of-life
sources
integrated
batteries
communities
decarbonize
customer
advanced
regions
american
metallic
security
electric
vehicles
additive
carbon-based
traditional
decarbonized
wind
taiwan
dioxide
german
electrochemical
researchers
diamond
nanomedicine
demands
e-mobility
lifetime
syngas
uranium
distributed
australia
radiation
generated
e-waste
policies
source
coal
geologic
treatment
environmentally
plant
scientists
catalysis
photothermal
india's
sensor
political
challenges
european
ethanol
innovative
potable
paris
state
reduce
abundant
earth
brazil
megacities
cells
technical
sensors
laser
diversity
people
supply
emerging
cobalt
scale
disposal
geothermal
aluminium
order
steel
society
drugs
fields
charging
europe
waste
temperature
sense
synthesis
advances
solar
gases
growth
properties
lithium
soc
electrical
reactor
microgrid
differences
alloys
progress
efficient
engine
air
fuels
korean
editor
development
toxicity
mobility
policy
heat
sustainable
automation
chinese
mobile
vehicle
reduction
wearable
therapeutic
co2
lead
nano
asia
technologies
global
coatings
greenhouse
emrs
company
biosensors
silicon
conventional
electrification
collaboration
germany
systems
molecular
funding
chemistry
element
implementing
new
li-ion
efficiency
films
irrigation
copper
polymers
areas
cycle
grid
gasoline
equipment
resistance
elements
future
economic
decarbonization
individual
public
agency
cell
nanocomposite
lithium-ion
plants
emissions
methodologies
products
machines
perspectives
life
power
biomedical
combustion
human
societies
renewable
solutions
sciences
safety
science
solution
societal
water
switching
fossil
medicine
microgrids
data
forum
cancer
consumers
capture
variability
silver
bacteria
capacity
food
nanoscale
composite
world's
industries
cultural
metals
rooftop
climate
fuel
industry
applied
land
nuclear
oxide
commercial
reactors
nanocarriers
grids
generate
composites
voltage
emission
system
weight
thermal
density
battery
integration
failure
automotive
economy
mitigate
meter
polymer
mix
oil
summit
africa
smart
mining
models
catalytic
planet
carbon
recycle
research
national
india
methane
warming
demand
resource
nanotubes
consumer
korea
remanufacture
country
processing
china
organic
circular
release
energy
scientific
automobile
institute
liquid
america
developing
education
turbines
economically
regulatory
potential
markets
catalysts
generating
hydrogen
population
e-mrs
mechanical
components
fibre
nanomaterials
worldwide
processes
hydrogel
photovoltaics
consumption
therapy
reducing
nanoparticles
meters
atmosphere
conversion
storage
delivery
chemical
developed
energies
applications
materials
resources
iumrs
metal

INTRODUCTORY COMMENTS (Obiter Dicta)

To set the stage for the wide variety of topics to be addressed throughout the two-day Summit, insights and aspirations were provided by high-level representatives of several institutions, including the European Commission, the European Parliament, the University of Strasbourg, the Chinese Academy of Science, the EUREKA network, the European Materials Forum, and the European Community on Computational Methods in Applied Sciences.

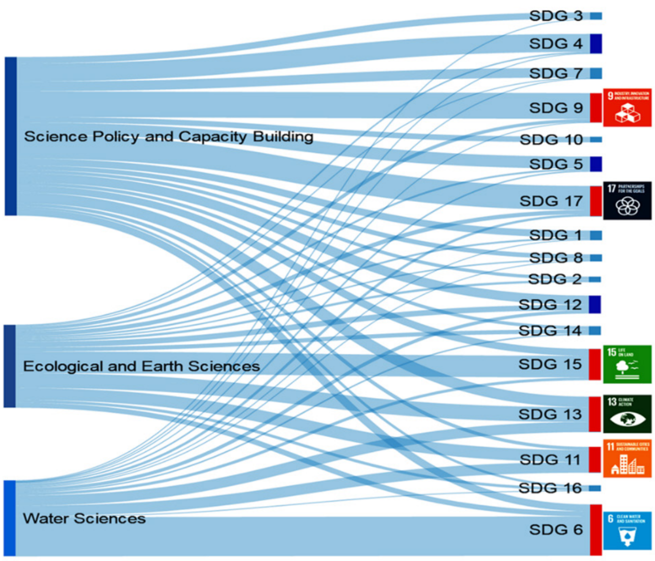
- The Court of Human Rights' rulings on the protection of life provide binding legal instruments regarding the biomedical field, but such matters as toxic waste, disaster response and human dignity also require attention.
- Data mining for the circular economy may lead to discovery of 'disruptive materials'.
- Those who determine policy require independent science advice.
- In today's context of achieving sustainable development goals by 2030, as well as Future Earth efforts, big data, and climate challenges, it is worth reflecting on the increasing importance of materials and the expansion of the materials field over the past 30 years.
- Promoting collaborative R&D programs with shared instrumentation that include small and medium size enterprises (SMEs), as well as the participation of large industries, will advance innovation.
- Materials are an important component of our research. Advanced computation and simulation tools do not replace but complement advanced materials theory and experiment.
- Access to raw materials is critical, not just for industrial competitiveness but also for global security. Legislation attempts to tackle this problem, which includes recycle and reuse.

CHALLENGES

Materials Challenges, Circular Economy, Energy Challenges, and Solutions for Industry

Global Materials Challenges

(contributing editor A. B. Holmes, Melbourne)



One well-known and effective international organization that pursues a wide-ranging set of activities, including basic science and engineering for sustainable development, is the UNESCO agency of the United Nations. Through multiple institutes, centres, partnerships, networks, and UNESCO 'chairs', the Natural Science sector of UNESCO promotes relevant education, research and improved social-ecological systems globally.

*Sustainability science has emerged as a new academic discipline in the last decade. It provides a new approach to dealing with complex, long-term global issues, such as human-induced climate and ecosystem changes, from broad perspectives. Guidelines have been developed to help Member States harness the potential of sustainability science in their sustainable development strategies.**

*From: *https://en.unesco.org/sustainability-science*

PERSPECTIVES IN CHEMISTRY – COMPLEX MATERIALS

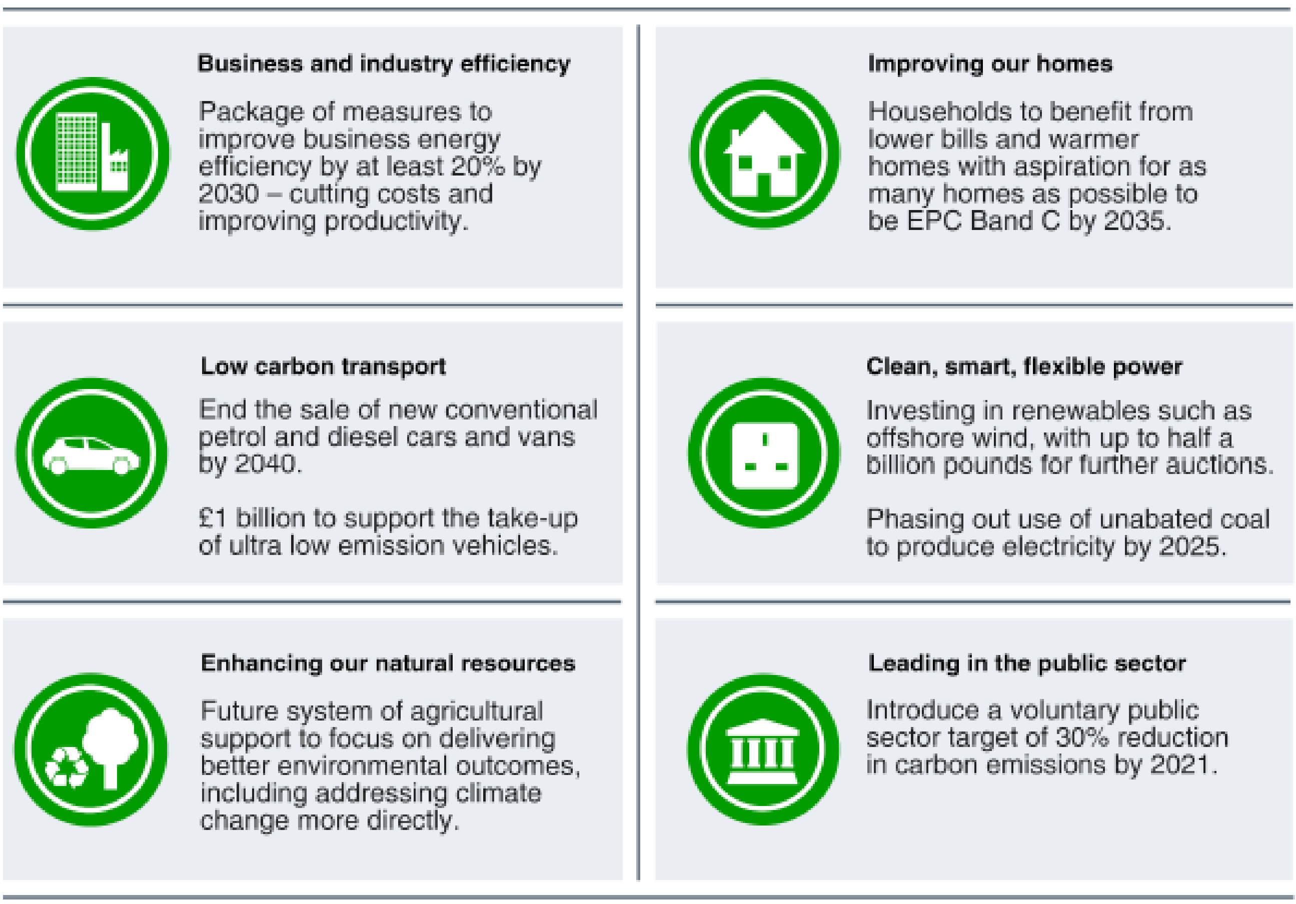
'Innovation' usually refers to new applied technological solutions and products, but it also may mean new and creative approaches to basic science, most particularly to the chemistry of complex materials. Nobel laureate Jean-Marie Lehn (Strasbourg) provided such a perspective to Summit participants. The field of supramolecular chemistry that involves non-covalent bonding holds promise for advanced polymers. What are called 'constitutional dynamic materials' can be formed via reversible connections, i.e., reversible combinations of complementary building blocks to form 'dynamers' that can have self-healing, responsive, and adaptive properties. Control of reaction products can be achieved through additives that act as agonists or antagonists for particular favoured or unfavoured reaction paths.

There are many current examples. At a paediatric cardiac centre in Budapest, supramolecular biomaterials have been used to repair congenital heart defects. [*Xeltis*] The biodegradability of polymers in water has been tailored through insertion of molecular imine groups while retaining processability and mechanical properties. Covalent dynamers have transformed soft, stretchy films into tough ones and controlled the optical properties of polymer films. Dynamic constitutional variation by selecting appropriate components can engineer adaptive chemical systems that respond to environment, media, phase changes, physical and chemical effectors, and morphological changes. [*Mitsui Chemicals*]

These developments illustrate the long evolutionary process for these approaches to molecular manipulation, from early 1990s basic research to today's transition from basic to applied research, as well as the long lead time to realise commercial applications.

The possible initiatives by governments and industry that address energy and environmental challenges are many. Activities in the United Kingdom offer some examples.

Elements of UK Strategy*



***UK Department for Business, Energy & Industrial Strategy**

A projection of investment in energy sources shows that most activity will depend on new technologies, such as electricity and hydrogen with their opportunities for emissions reduction and carbon capture.

Outstanding questions remain: How can the research community be encouraged to engage in effective employment of new discoveries?

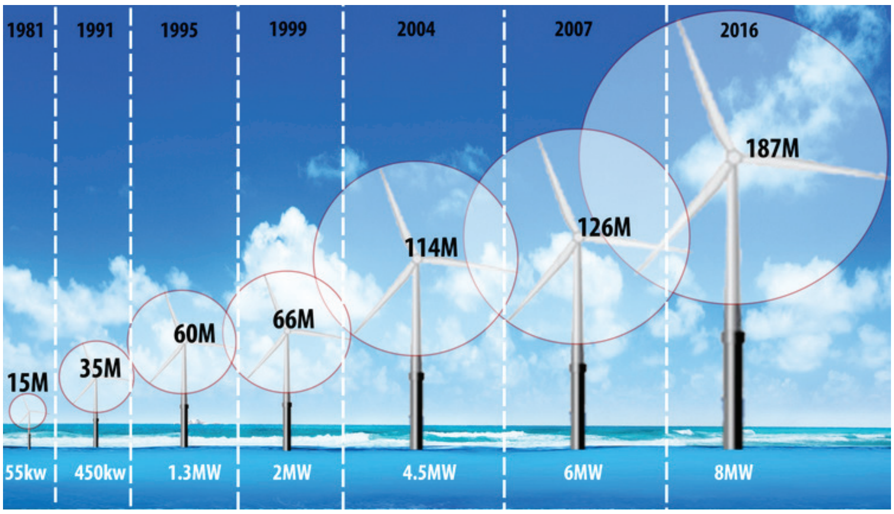
Many individual improvements in common, everyday areas are also possible and are being pursued. For example, reducing weight by replacing metal and wood with recycled plastic in seat composite materials can save billions of euros in air and train transport. [*Cecence*] To protect an aircraft from lightning, graphene integrated into carbon fibre structures increases conductivity and reduces weight, compared to traditional copper mesh, and can save fuel and enable a greater passenger load. [*Haydale*]

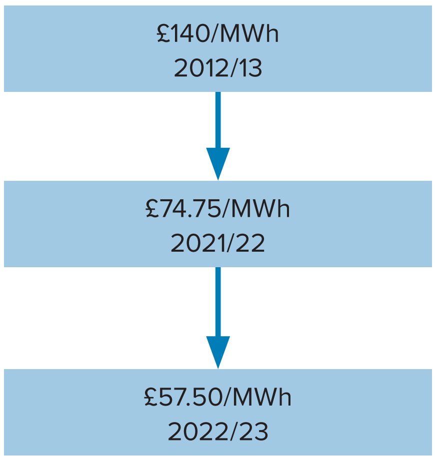
Re-use of materials that would otherwise be disposed of as waste is a major objective in the UK and elsewhere. One option reduces weight by incorporating from 30% to 50% carbon fibre production waste into carbon fibre-based fabrics for automotive and sports materials. [*Sigmatex*]

Outstanding questions remain: How can the research community be encouraged to engage in effective employment of new discoveries? How is carbon emissions capture in basic manufacturing technologies to be realised? What are the optimal 'clean growth' scenarios that maintain economic growth while implementing clean and energy efficient technologies?

An improvement of only 5% in a large-scale technology can have a significant effect. Mid- and long-term technology-based advances currently being pursued include the following:

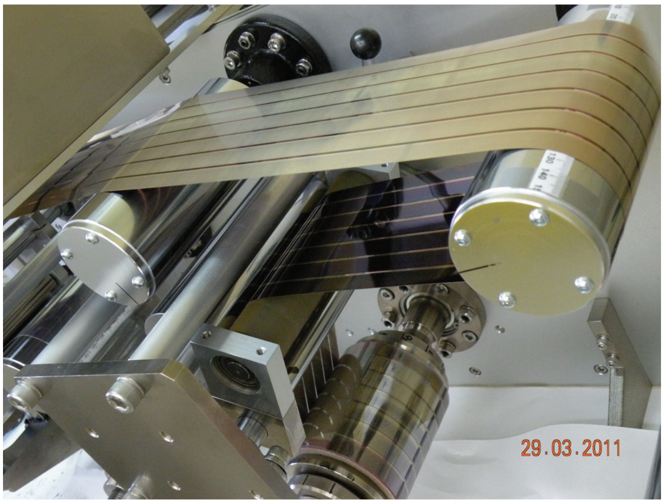
- Low carbon transport. A hydrogen-fuelled vehicle has greater range than a battery-powered vehicle, and hydrogen is more flexible. The UK is looking at transferring an entire city to a hydrogen gas infrastructure.
- Collection materials for removing greenhouse gases from the atmosphere.
- Larger and cheaper rotor blades for wind turbine power generation. At the current scale of £57.5/MWh, maintenance costs remain a problem.
- New materials alternatives to retrofit buildings for energy efficiency without the need for costly, high-skills investments.
- Improvements at all length scales of the solid oxide fuel cell (SOFC) for automotive use — from the microscopic behaviour of electrode surfaces and ion transport to the design of full systems.





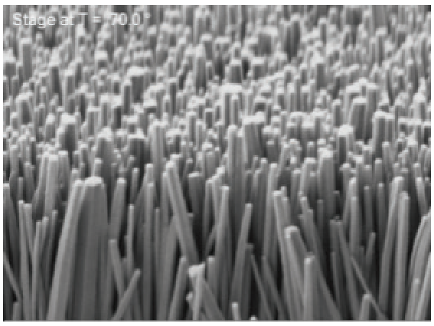
UK Department for Business, Energy & Industrial Strategy

Transparent bus



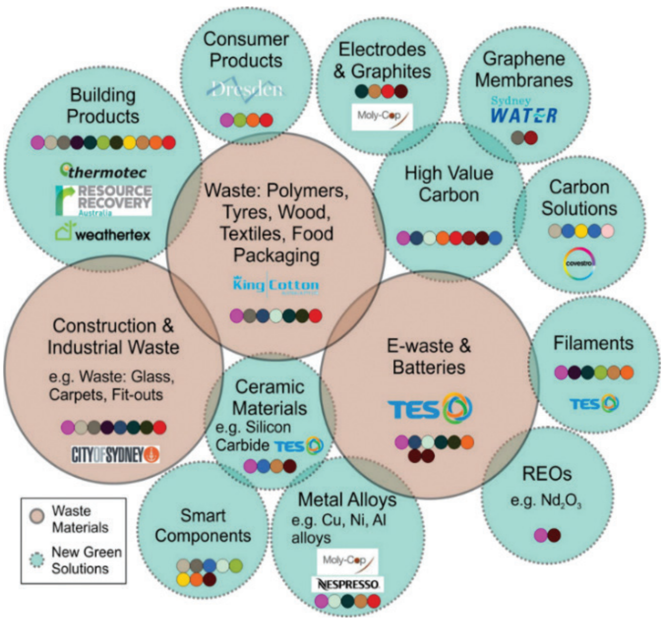
Roll to roll gravure printing [*CSIRO*]

A couple of current materials advancement projects are instructive to recognise here: flexible, transparent and sustainable electronics based on oxide thin films (for displays and wearable devices), and organic semiconductors and phosphorescent metal-containing polymers for electronic devices (organic photovoltaics [PV] and light emitting diodes [LEDs]). In both cases, new fabrication methods, such as environmentally friendly solution processing, and spin-coating at lower than traditional temperatures, are being employed. These methods will save on costs and can be scaled to mass production.



DUV (deep ultraviolet)-assisted processing of thin film transistors based on zinc tin oxide with aluminium oxide dielectric layers has been developed, and ways to replace or augment conventional oxide thin films in devices with semiconducting and conducting aligned nanowires are being researched. Other novel materials are making their way into devices: Bulk heterojunction polymer and molecular devices with fullerenes have been fabricated with 10% energy conversion efficiency.

Printed solar cells incorporating perovskite layers have been made that show up to ~10% power conversion efficiency (PCE). Larger area solution deposited perovskite cells with up to 15% efficiency have been reported. Only time will tell if organic PV will show sufficiently high efficiency, lifetimes, and economy to compete with silicon devices.



The concept of 'micro-factories' that apply new innovative waste processing solutions locally. Local companies associated with each product are indicated. (From the Sustainable Materials Research & Technology (SMaRT@UNSW) program at the University of New South Wales, Sydney.)

The list of possible applications of flexible cellulose-based (paper) devices in fields of electronics (ultra-low power, touch surfaces, RFID, and antennas), energy (batteries, supercapacitors, and wireless), and biomedical (microfluidics in point-of-care diagnostics and biosensors) is long indeed.

Rethinking the nature of waste [...] has led to the idea of 'green micro-factories' that make products from waste.

Beyond new and more efficient energy solutions and the associated innovative materials advances, the management of the world's waste stream is an essential component of a sustainable circular economy.

Rethinking the nature of waste, working with industry partners, and putting potential end-users in touch with 'waste sources' has led to the idea of 'green micro-factories' that make products from waste. As discussed further below, there is a need for innovation here too, because like-for-like waste-to-product simply doesn't work for complex materials.

Circular Economy

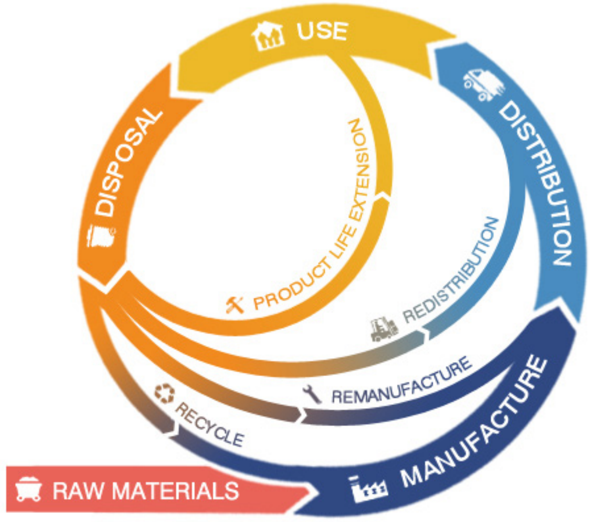
(contributing editor G. Kiriakidis, Heraklion)

A 'circular economy' in materials is a closed loop system in which resource input and output (waste, emissions, energy) are minimized by narrowing material and energy loops.

In a circular economy, we look for better ways to recover products from waste and make waste a 'raw material', transforming waste not only into its own kind — i.e., glass into glass or plastic to plastic — but going beyond by breaking and reforming the bonds between the elements in a complex waste mix that would otherwise go to a landfill. The aim is to produce previously unimaginable value-added new 'green' materials and products. In this vision, recyclability needs to be extended to include manufacturability, so that waste becomes a feedstock for new material manufacturing. New concepts like the micro-factory, a custom-designed, flexible, small-scale unit capable of transforming waste into valuable resources, are creating a new paradigm. It offers opportunities to utilize waste to generate income and jobs at the local community level, while contributing to solutions to global environmental problems. Carefully planned recycling efforts are needed within a continent like Europe that has exhausted almost all its raw material resources. Realizing the 4Rs concept (reduce, reuse, recycle, remanufacture) is imperative for ensuring that the resulting value-added products are commercially relevant and have access to markets.

Electronic waste (e-waste) is a complex mixture that contains a range of different materials — incompatible polymers (8 to 12 basic polymers and flame retardant polymers), metals and oxides (more than 30 types of metal and 20 types of oxides). The amount of e-waste produced around the globe is increasing at an alarming rate. E-waste in 2012 was on the order of 50 million tons; the chart below shows the distribution per country.

The Circular Economy*



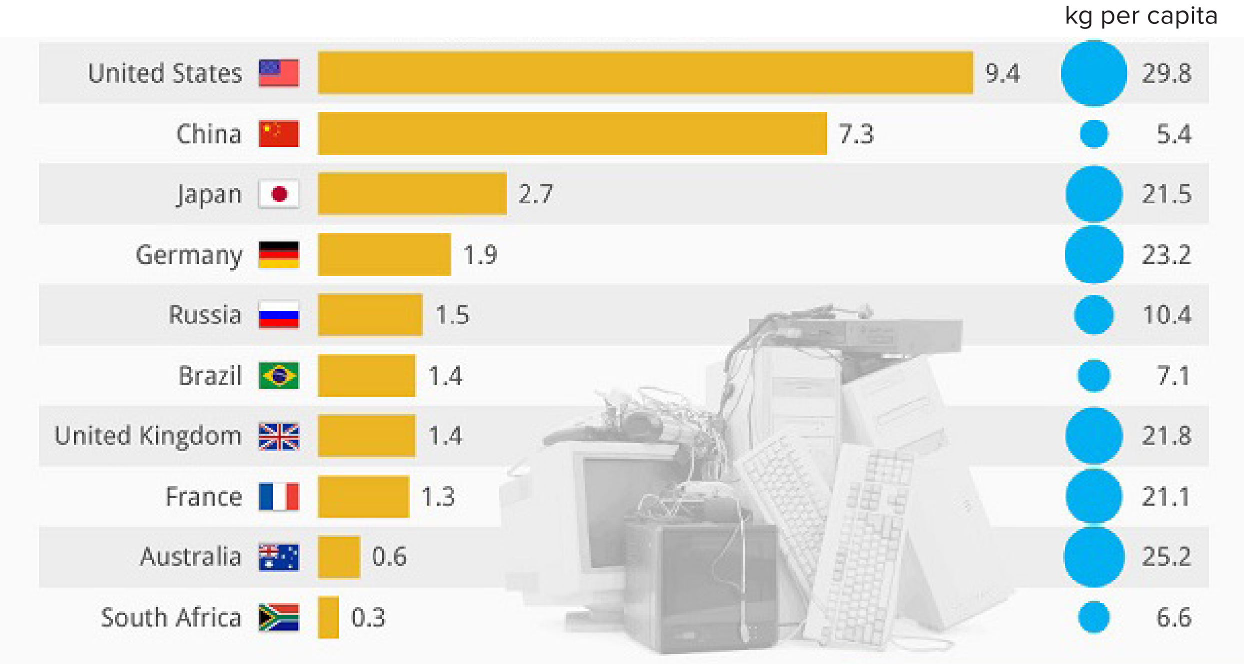
*RWTH Aachen

One example of the e-waste challenge is using the glass in e-waste as a source of silica. The glass fraction of e-waste is a rich alternative source of silicon for production of silicon carbide (SiC) and nitride (Si3N4), but impediments to its use are low purity, technically challenging processing, and economically unattractive manufacturing. However, overcoming these issues may serve key sectors of the electronics industry, such as makers of computer monitors, television sets and other devices with glass screens.

Metals and non-metals in printed circuit boards (PCBs) are a different matter. PCBs contain a diverse and complex mixture of elements consisting of ~ 43% polymers, ~ 34% refractories and ~ 23% metals. It is feasible to extract and recover copper from e-waste in PCBs in the range from 10% to 20% — compare this to the ½ to 1% abundance of copper in ores.

Although e-waste is a relatively new and important component, the waste stream is replete with more conventional end-of-life items that can be recovered and recycled. For example, value-added tyre recycling can replace coal- and coke-based input for steel-making. (Some 2.5 million tyres have been used so far in a pilot program in Australia.) However, the question of the CO_2 emissions that result remains unsolved.

Amount of electronic waste generated in selected countries in 2012 (million metric tonnes)



Basic requirements for a successful circular economy are:

Effective measures required from policy makers:

- Attractive conditions for returning metal-containing waste (deposit systems, collection points, mobile/ pick-up services)
- Subsidisation of processes treating waste streams
- Sensitisation of population/social awareness
- Funded research on innovative processes

Rules and policies required from industry:

- Product design that enables disassembly and recycling
- Development of flexible processes for dynamic waste streams
- Advanced sorting techniques (intelligent sensor systems)

Practices required from citizens:

- Responsible handling of end-of-life products
- Increased awareness of proper waste disposal options

Tyres in a landfill

e-waste

Energy Challenges

(contributing editor G. W. Crabtree, Argonne)

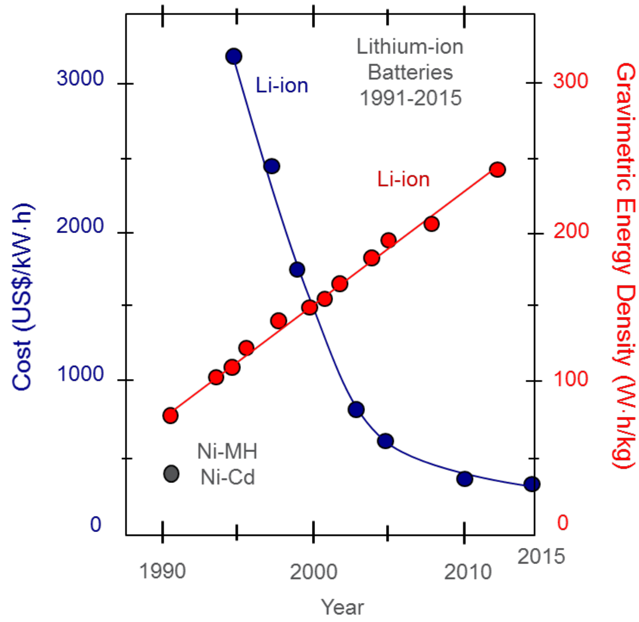
Since the Paris Agreement on Climate Change (2015), addressing climate change has taken on a new sense of urgency, with the realization that carbon emissions must peak in about 2025 and fall to zero by 2060 to 2080 if we are to limit global warming to 2°C above pre-industrial levels. The trajectory we are now following will, at best, limit warming to 3°C or 4°C, and at worst to 5°C or 6°C (Global Carbon Budget 2017 *www.globalcarbonproject.org/carbonbudget*).

The trajectory we are now following will, at best, limit warming to 3°C or 4°C...

To reach a 2°C trajectory, we must accelerate decarbonization of the primary energy carriers: the electricity grid and fossil fuel combustion used for personal vehicles, long-haul air transportation, overland freight and maritime shipping, space and water heating, and industrial processes. There are four active and promising routes to achieve these goals: nuclear energy (here described for India), energy storage for electricity and transportation, carbon dioxide as a feedstock for sustainable chemical fuel, and renewable energy (here described for China).

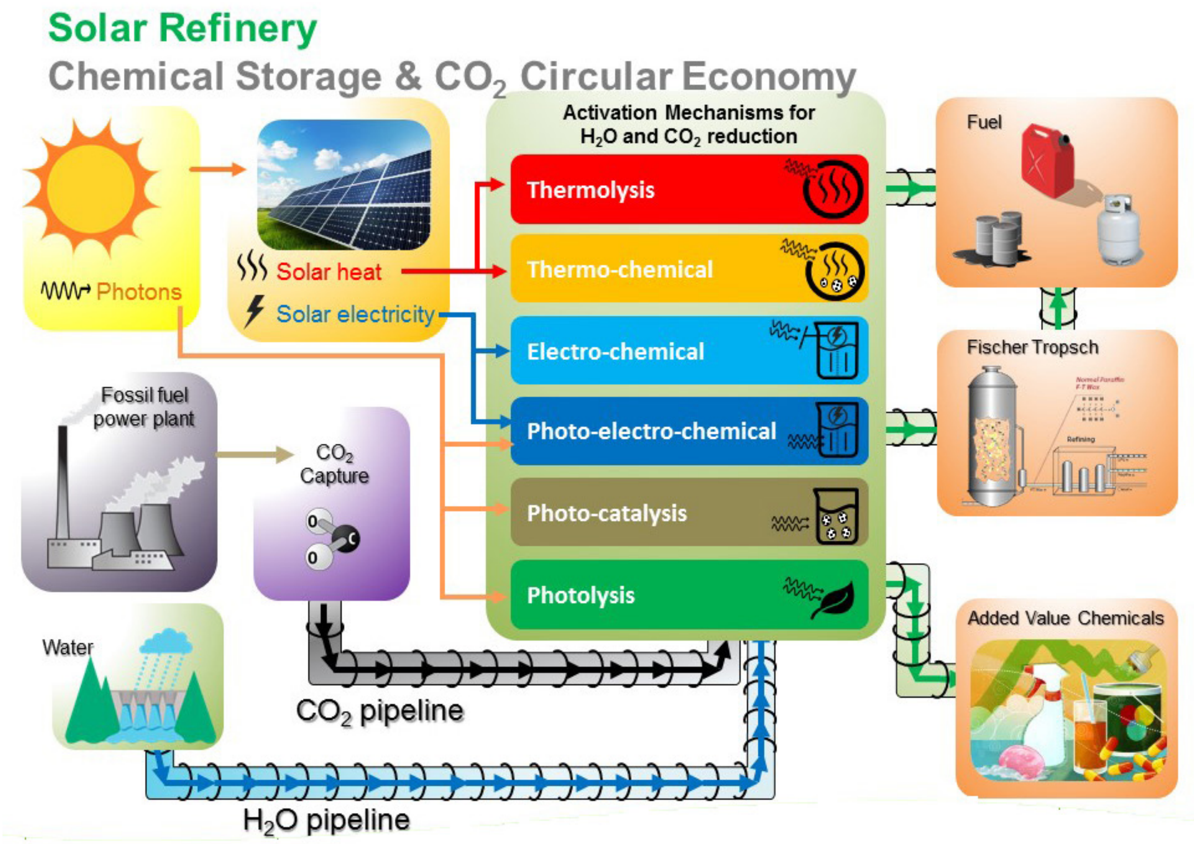
India's nuclear energy program has been well-established since the 1950s, when Homi Bhabba outlined a three-stage plan to use India's relatively abundant thorium reserves to create a hierarchy of reactors capable of supplying India's electricity needs. The plan envisions using conventional power reactors to create ^{239}Pu (stage 1) to fuel fast breeder reactors that would produce electricity while converting native ^{232}Th to fissile ^{233}U (stage 2) which would then fuel ^{233}U reactors that generate electricity as they convert more native ^{232}Th to ^{233}U, thus providing an endless supply of fuel and electricity. The second stage ^{239}Pu fast breeder reactors could produce as much as 200 GW of power in 2045, and the third stage ^{233}U reactors could produce as much as an additional 400 GW of power by 2060, for a total of 600 GW of decarbonized power. India is unique in developing this Th-based approach to nuclear energy and has amassed a wealth of scientific and technical information on its operation. Nuclear energy in conventional and Th-based reactors is an established decarbonized electricity source, responsible for about 16% of global electricity and capable of significant future electricity sector decarbonization.

...energy storage enables disruptive new models for decarbonizing the electricity grid.



Energy storage is an emerging route to decarbonizing the electricity and transportation sectors. Electric vehicles may offer an economic alternative to gasoline powered transportation, with innovation rapidly lowering costs, increasing driving range, reducing charging times, extending battery lifetimes and increasing safety. Lithium-ion batteries lead the electric vehicle effort, but their relatively high cost, short lifetimes and long charging times may prevent them from capturing the mass market and fully decarbonizing personal transportation. A US$20 000, 200-mile (321-km) car with a charging time of minutes and a 15-year lifetime is needed to transform the personal car market; this is well beyond the capability of today's Li-ion batteries. Next generation batteries based on Li metal anodes, Li-sulphur or magnesium (Mg^{++}) as the working ion are ripe for intense development. A step increase of a factor of two or more in energy density, combined with fast charging and a 15-year life, are well within the practical limits of next generation batteries and are needed for full decarbonization of transportation.

Energy storage for the electricity grid is a largely untapped decarbonization opportunity. Replacing fossil fuel with renewable electricity generation introduces weather-dependent variability into the generation mix; replacing fossil generation with nuclear energy introduces the opposite challenge, as nuclear electricity is a steady baseload source that needs modulation to meet diurnal demand profiles. Both challenges can be met by large-scale electricity storage, provided costs are reduced by factors of two to three to compete with cheaper fossil alternatives such as gas turbines. Combined with distributed energy resources such as electric vehicles, rooftop solar, and smart energy management, energy storage enables disruptive new models for decarbonizing the electricity grid.



While renewable generation and energy storage are technologically viable routes to grid and transportation decarbonization, there are as yet no existing technologies to decarbonize combustion of fossil fuels for commercial transport and industrial uses. However, the past two decades have seen production of hydrocarbon fuel from CO_2 and water progress from a scientific notion to lab-scale examples achieving upwards of 10% efficiency and projected costs of less than 0.06€/kWh of chemical energy.

Synthesis of formic acid (HCOOH) has been demonstrated electrochemically, and syngas (H_2:CO) photo-electro-chemically. These fuels are starting points for production of higher hydrocarbon fuels, such as methane and alcohol, through Fischer-Tropsch and other chemistries. Dark electrolysis of CO_2 and water to HCOO- at 71% efficiency and to HCOO-+CO at 82% efficiency with Sn catalysts in gas diffusion electrodes has been demonstrated, with higher efficiencies and the possibility of replacing dark electrolysis with sunlight-driven photo-electro-catalytic synthesis. A variety of syngas compositions have been made, with H_2:CO ratios ranging from 0.5:1 to 5:1. These are the feedstocks for production of ammonia, methane, hydrogen and higher-value chemicals. These advances in creating sustainable hydrocarbon fuel from CO_2 and water with renewable electricity or sunlight are the first steps to creating viable large scale technologies that can replace fossil fuels with the sustainable hydrocarbon fuels that could decarbonize combustion energy.

China integrates renewable energy at all levels of its rapidly developing electricity grid:...

Electricity is fast growing, increasingly dominant and so far the only large-scale energy carrier that can be fully decarbonized with existing technology. The challenge for achieving climate change goals is to deploy renewable electricity widely enough and quickly enough to fully decarbonize electricity and transportation by the 2060-2080 time frame described above. As the largest rapidly modernizing economy, China's progress in deploying renewable electricity is critical to achieving global climate change outcomes. China integrates renewable energy at all levels of its rapidly developing electricity grid: regional, distribution and microgrid. Qinghai Province is a regional example, with a population of 5.8 million people and an area of 721 thousand square kilometres served by 59% hydro, 29% PV, 3% wind and 9% coal. The advent of renewable generation requires innovation in regional transmission to convert the low voltage DC and AC outputs of solar and wind farms to high voltage DC and AC transmission levels with power electronics.

Renewable energy at the distribution level must accommodate a diversity of applications, including industry, villages, cities, neighbourhoods and remote areas such as islands. Each of these applications presents special challenges for power quality, reliability and demand patterns. The distribution grid can accommodate these diverse demands by integrating local generation, such as rooftop solar, and local energy storage designed for local needs, with smart energy management to coordinate local energy generation and demand to best advantage. Haining city provides an example, with 20% of its peak electricity demand supplied by photovoltaics.

...required advances must be created through a vibrant, lively, talented and well supported research community.

Microgrids can be even more innovative and diverse than the distribution grid. They are often located in remote areas or serve special uses, such as industrial plants, commercial buildings, or residential neighbourhoods. They can contain heat pumps, small hydro, rooftop solar, thermal and electricity storage, combining heat and power with smart energy management in highly specialized ways. Off-grid solar plus storage is a viable and fast microgrid solution for individual customers and villages in China. The opportunity for innovative design of microgrids to decarbonize electricity while lowering cost, raising quality, and improving service is enormous.

Policy is needed for three climate change scenarios. Electricity and transportation, renewable energy, nuclear energy and storage are existing technologies that in principle are capable of full decarbonisation, so the policy challenge is to encourage widespread deployment by incentive or mandate. For fossil fuel combustion, we do not have existing technologies capable of full decarbonisation, so the policy challenge is incentivizing basic scientific advances that can create technologies such as large-scale synthesis of hydrocarbon fuel from CO_2, water, and renewable electricity or sunlight. These basic science advances cannot be achieved by policy mandate as can deployment of existing technologies; instead, the required advances must be created through a vibrant, lively, talented and well-supported research community. For both existing and needed future technologies, policy must be designed to create higher levels of efficiency and operation, promoting continuous and disruptive improvement over maintaining the status quo.

Materials-Related Solutions for Industry

(contributing editor P. Wellmann, Erlangen)

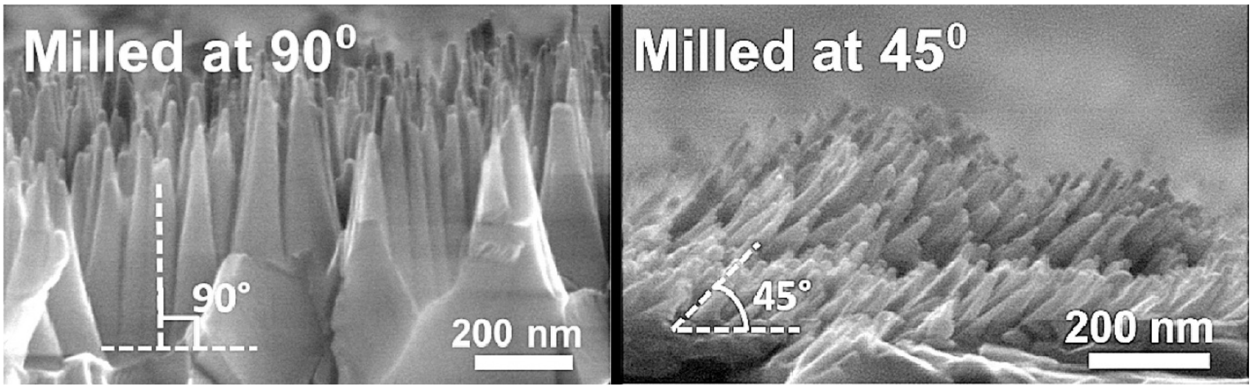
Today's key materials provision, materials processing and materials application sustainability issues can be seen in the example of personal mobility applications.

There are four significant elements in the system chain: (1) renewable energy conversion, (2) flexible power plants to level the time dependence of the electric power supply, (3) sharing energy using electric grids, and (4) handling the major challenge of energy storage on various time scales. In all cases, materials play an important role, and materials modelling using computer simulation has the potential to enhance system efficiency as well as operation lifetime.

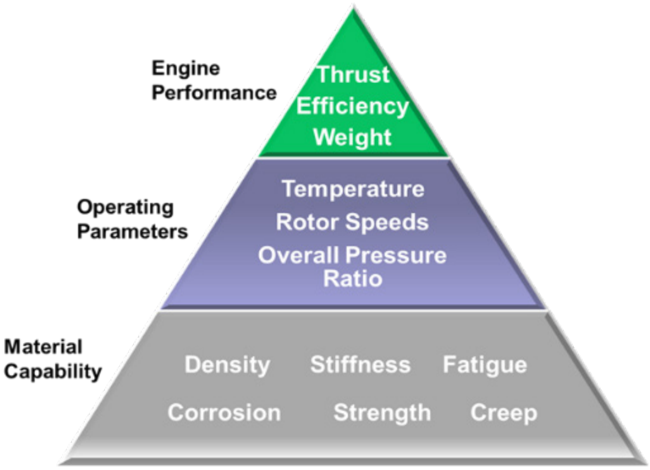
For solar photovoltaic cells and solar thermal power conversion in particular, energy harvesting schemes utilizing low dimensional micro- and nanostructured materials and devices are showing promise. For example, optimizing the performance of chalcopyrite thin film solar cell materials ($Cu[In,Ga]Se_2$ or CIGS) has been achieved by surface structuring with nanotip arrays to increase PV cell efficiency and plasmonic effects that further improve the solar cell performance.

The ubiquitous automobile presents both energy and emission issues. Only partial or full electrification can solve the problems of reducing energy consumption and exhaust emission, and the options for doing so are hydrogen fuel cell electric vehicles and battery electric vehicles. The fuel cell electric vehicle already offers the same driving range available from gasoline fuelled cars. Work underway on on-board hydrogen storage includes metal hydrate materials in which nano- and micro-structured materials play an important role. Of course, other transport considerations include vehicle safety, ensuring that autonomous cars don't crash, and road congestion, for which congestion routing and megacity parking need to be implemented.

The role of advanced materials in the future of aircraft propulsion must also be considered. New materials with high strength and high durability allow for new parts architectures and enable impressive engine performance improvements (lower gasoline consumption, silent motor operation, and improved thermodynamic efficiency). New materials options also imply new manufacturing methods, such as additive manufacturing of engine parts. These advances are aided by extensive physics-based integrated computational materials engineering.



Large scale single-crystal $Cu(In,Ga)Se_2$ (CIGS) nanotip arrays for high-efficiency solar cells



Aircraft need for advanced materials

...advances are aided by extensive physics-based integrated computational materials engineering.

Future raw material demand is and will continue to be a challenge. Sustainability in materials supply will influence emerging technologies that will engender an ever-increasing demand. For example, there is a demand for rare earth elements for use in high performance magnets in wind power plants. Lithium, dysprosium/terbium, and rhenium exhibit a raw material indicator above 200%, meaning that the expected demand for them by the year 2035 will exceed current production levels by more than a factor of three. Tantalum, scandium, cobalt, germanium and platinum exhibit a raw material indicator above 100%, or a factor of two over today's levels. Recycling these chemical elements is inevitable for a growing industry, and product design must take cost-effective recycling into consideration in the future.

Bastnäsit ore contains several rare earths

RECYCLING OUR COMMON FUTURE: REPLACEMENTS

Cars in China, Emissions in South Korea, Water Purification, and Metals for e-Mobility

(contributing editor O. N. Oliveira Jr., São Carlo)

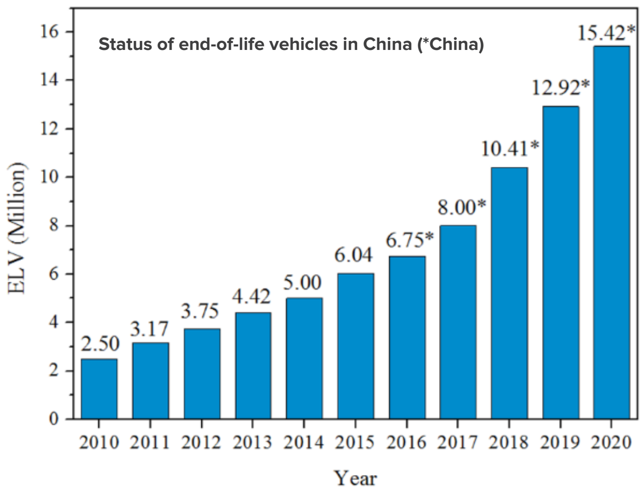
The number of cars manufactured in China, today the biggest producer in the world, is staggering. In 2017, for example, about 1.5 million cars run only by renewable energy (non-fossil-fuel) will have been produced. By the end of 2020, it is estimated that there will be 15 million end-of-life vehicles (ELV). The market share of SUVs (sport utility vehicles) and recreational vehicles has also increased considerably. As a result, China is exploring the application of the 4Rs principle – reduce, reuse, recycle, remanufacture. Remanufacture, in particular, is advantageous because it saves energy and nanomaterials. Several challenges must be addressed for a large-scale remanufacture program, including various aspects of quality control. Testing and checking materials properties will be essential for such a program.

Present technologies for capturing CO_2 are still not sufficiently mature...

The South Korean government has established the target of cutting CO_2 emission by 37% by 2030. Given the present composition of the country's energy sources today, this goal is ambitious and perhaps only achievable if efficient technologies are developed to capture CO_2 and either recycle it by conversion into fuel or sequester it. One potential solution involves titanium silicate nanomaterials with hydrophilic and hydrophobic channels that capture CO_2 and water and could adsorb up to 140 ml/ml; that is, the material can adsorb more than 100 times its own volume. Another approach to capturing CO_2 is to convert it into fuel or chemicals via artificial photosynthesis using solar radiation, with CO_2 and water as input, and $O_2 + H_2$, CH_4, and C_2H_6 as output. Present technologies for capturing CO_2 are not sufficiently mature to solve the problem of reducing CO_2 emission. Realistically, short-term technologies, even if not ideal, are necessary to mitigate the problem of global warming and CO_2 emission. Parallel investment in further research and development on longer-term, more efficient technologies is required.

Many technological problems must be addressed for a possible nanotechnology water remediation revolution to happen. Relevant problems for recycling water include the cost of the purification strategies and the biofouling of the devices used. The topic is not new: Disinfection of water using solar energy has been used since Egyptian times. The question is whether this can be done effectively at low cost.

One possible technology is photocatalysis through semiconductor nanoparticles, such as TiO_2, which release reactive oxygen when illuminated. The highly reactive oxygen generated by such a catalysis process kills microorganisms in water, resulting in clean water and CO_2. The difficulty that prevents this technology's commercialization is related to removing the nanoparticles after use, and one possible solution is to use polymer nanocomposites containing the semiconductor nanoparticles.



Work has shown that polymer nanocomposites made with PMMA (poly(methyl methacrylate)) and TiO_2 also have antibacterial activity when exposed to ultraviolet irradiation. Other composites tried include ZnO/PMMA composites and hybrid 3D graphene and polyporphyrins in which the polymer is the active component. Even though these nanomaterials are amenable to recycling, at the moment their commercialization is still out of reach.

Mobility with electric vehicles (e-mobility) is the ideal test case for sustainable metals management in a circular economy. Because of electric automobiles, there will be an increase in the demand for cobalt, lithium, and nickel, in addition to platinum, for fuel cells that may be employed in electric cars. The market for Li-ion batteries is projected to increase by a factor of 4.5 from 2013 to 2020. [*Umicore*] There could be enough Co, Ni, and Li, because there is sufficient geological availability to enable the take-off of emobility. But 60% of cobalt's world mine production is in the Democratic Republic of Congo (DRC), an area of potential political instability. Another 50% of the world's refined production of cobalt is in China.

Prices may peak, especially because 98% of that metal is a by-product of copper and nickel mining. If there is no corresponding demand for Cu and Ni, prices may be affected.

The inevitable conclusion is that without recycling, there will probably be problems with the Co supply, according to a report from the Joint Research Centre (JRC) of the European Commission. Recycling can be a sustainable source of Co and Li; it can complement the primary supply while bringing environmental advantages over mining and a reduced CO_2 footprint for e-mobility. Recycling, however, poses many challenges. It is a complex process involving collection, dismantling, shredding and sorting followed by metal recycling. There are also less tangible risks for downstream users if the supply is linked to any social and environmental problems, such as mining conditions in the DRC. Attempts to mitigate the problem may include the following:

- Partial substitution of material and increased resource efficiency in the production of battery materials
- Diversification of the primary supply base
- Comprehensive recycling of Co-containing residues
- Responsible sourcing

As already emphasized above in several contexts, end-of-life materials need to find their way into new products. The entire recycling chain must be evaluated. A sound collection infrastructure, recycling incentives, recycling processes that produce high quality products that are economically viable, and enforcement of necessary legislation for monitoring are all needed.

FROM MATERIALS TO SYSTEMS FOR MEGACITIES

Green Energy in Taiwan, Copernicus Projects in Germany, and the Back-End of the Nuclear Fuel Cycle

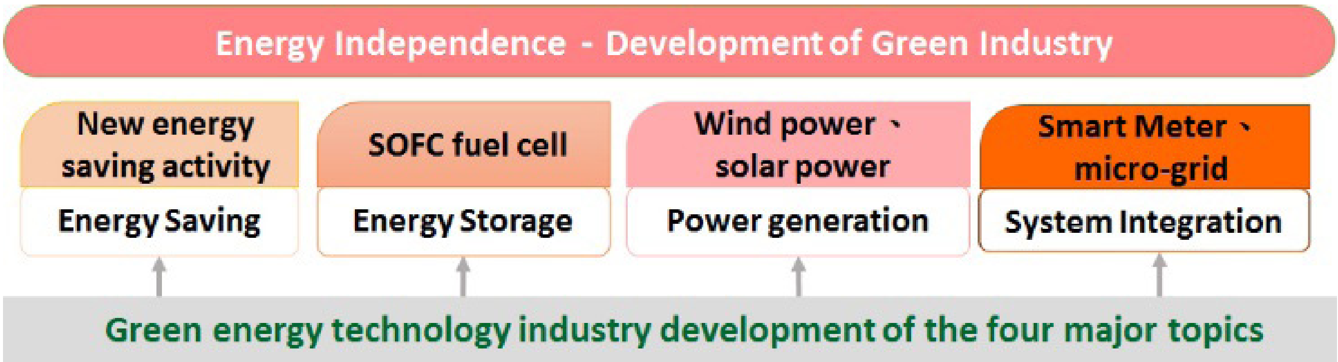
(contributing editor R. C. Ewing, Stanford)

Energy demaind of megacities requires a stable supply

GREEN ENERGY IN TAIWAN

Taiwan has a new energy policy and implementation plan (Electricity Act of January, 2017). Currently, the power system is highly centralized, and over 70% of the base energy comes from fossil fuels: natural gas, coal, and oil. Nuclear plants provide about 15%, but the reactors reach end of life (40 years) by 2024 and will be shut down.

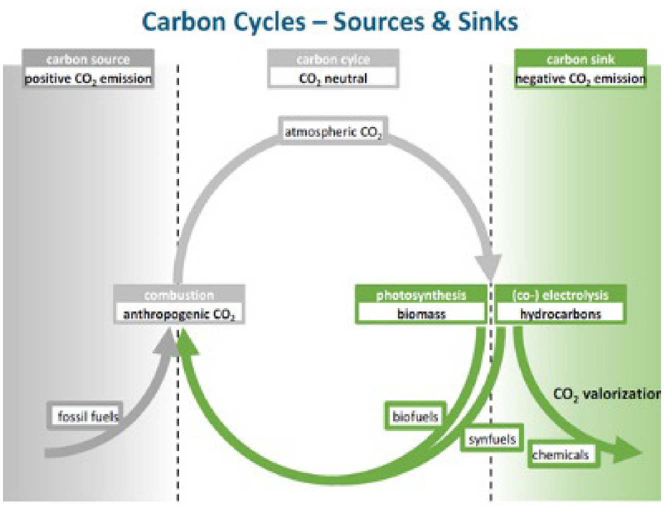
At the same time, the projected increase in power consumption is on the order of some 50% over present day storage. The shortfall will be made up by replacing nuclear with solar and wind and switching to more natural gas over coal and oil.



Taiwan's Green Energy Development Strategy

Taiwan's focus is on creating a microgrid technology to optimize the use of solar and wind, with the added benefit of resilience during disasters. New microgrids are being tested on small, isolated islands near Taiwan, as well as in Myanmar and Shanghai. In 2025, the capacity of Taiwan's solar photovoltaic and offshore wind power plant is expected to reach 20 gigawatts and 3 gigawatts, respectively.

In order to solve the problem of supply instability and grid merging of renewable energy, medium and large renewable energy power plants must have auxiliary services to collaborate and assist with transmission and distribution systems to maintain power quality and supply stability. The smart grid will change the business model by decentralizing the grid and involving customers in the generation and consumption of electricity. Three million smart meters will be installed, and new companies for green energy and power production have been created. Handling the peak load on the industrial side will, however, be a challenge. The approach in Taiwan shows how a relatively resource-poor country can manage its energy production to meet society's needs, and, at the same time, significantly reduce greenhouse gas production.



(From Forschungszentrum Jülich)

GERMANY'S 'COPERNICUS PROJECTS'

In 2015, Germany launched a multipart research initiative on its energy transition called the Copernicus Projects, with the goal of completely renewing its energy system by 2025. Issues addressed include the intermittency of renewables, energy storage, and the efficient transformation of energy forms as they move through the system.

The basic strategy is a systems approach identifying technology options (electro-chemical energy conversion and electrochemical CO_2-reduction by co-electrolysis), reducing the number of chemical steps and increasing efficiency. The lowest efficiency is found in the electrochemical processes. We can hope for the most improvement in this area, for example, by using higher temperature solid oxide fuel cells. Synthetic, liquid fuels will still be needed, mainly for transportation for which we can rely on existing infrastructure. Electrocatalysis using renewable power sources to synthesize liquid and gas fuels from CO_2, treated as a chemical feedstock, should be explored.

For Germany, the analysis suggests that the need for renewables is greater than presently planned or anticipated. Planning efforts have created an integrated energy system that can be analysed and improved. It distinguishes between 'surplus energy' and 'integrated energy' scenarios. The goal is to put the surplus where there is a need–sometimes by using the excess energy to make something like synfuel or a product that uses CO_2.

THE BACK-END PROBLEM

The back-end of the nuclear fuel cycle remains an afterthought: There is a consistent failure to discuss geologic disposal in a substantive way. It is not sufficient to portray nuclear power plants as low CO_2 emitters (which they are) while ignoring the nuclear waste that is generated. The failure to manage nuclear waste may well be the Achilles' heel of nuclear power.

There is a consistent failure to discuss geologic disposal in a substantive way.

Transforming nuclear waste into durable materials may remain an unrealized dream, but it is clear that materials science can enhance confidence in geologic disposal of nuclear waste by the development of durable waste forms. These waste forms can be designed by considering the chemistry, half-life, radiotoxicity and geochemical/hydrologic mobility of each radionuclide in specific geologic environments.

We now have a fundamental understanding of radiation-induced structural transformations that are required to design nuclear waste forms to specific performance requirements, such as high chemical durability and radiation resistance.

PRINCIPAL CONSIDERATIONS INCLUDE		
☐ Chemical complexity of the waste ☐ Large volumes of waste ☐ Ease of processing ☐ Radiation safety ☐ Types of data (short- vs. long-term) ☐ Synthesis technologies ☐ Characteristics of the repository	VERSUS	☐ Long-term durability in the geologic repository ☐ Corrosion and radiation effects ☐ Actual long-term performance ☐ Chemical durability (mechanism and rates) ☐ Radiation effects (accumulation & annealing)

Electricity is the primary mode of power transmission.

FORUM FOR NEXT GENERATION RESEARCHERS

VI WORLD MATERIALS SUMMIT®

Materials Innovation for the Global Circular Economy and Sustainable Society

18th – 19th November, 2017

Council of Europe – European Youth Centre, Strasbourg, France

ORGANIZED BY

E-MRS

EUROPEAN MATERIALS RESEARCH SOCIETY

COUNCIL OF EUROPE
CONSEIL DE L'EUROPE

Next-Generation Researchers who attended their Forum were able to attend expert lectures on a variety of interrelated but wide-ranging topics. While no formal syllabus was followed for this 1½-day event, the lectures were followed by often energetic discussion, engendering new ideas that sometimes departed from perceived orthodoxies. Each of the 26 young participants also had the opportunity to present his or her own research work in a poster session and discuss it with both experts and peers. The authors and titles of those poster presentations are listed in Appendix C of this report.

This section of the Summit report provides an abbreviated summary of the topics covered.

DECARBONATED ENERGY AND STORAGE

(contributing editor L. Fu, Canberra)

Decarbonized energy and storage are the keys to addressing the great challenges, such as fossil fuel depletion and climate change, facing modern society.

Heritage sites

Although other, more obvious, consequences of climate change receive the lion's share of attention and discussion, the integrity of cultural heritage monuments and centres is also at risk due to climatic change as well as an increasing threat of extreme meteorological phenomena and natural hazards. Selected historical sites in Italy and Greece, home to many of the world's heritage sites, have been observed from satellites using the synthetic aperture radar (SAR) interferometry technique. That technology provides a two-dimensional image of a scene obtained by tracking position and ranging sensor-target coordinates, graphically presenting the problems caused by rainfall erosivity, seismic risk and impact from the sea. When SAR technology is combined with *in situ* measurements, on-site surveys, and structural modelling, the environmental impact on historical monuments and centres can be assessed and studied. In this way, we can find solutions for these issues that can be broadly applied. The HERACLES Consortium (*www.heracles-project.eu/consortium-and-boards/consortium*) is coordinating a project aimed at developing an integrated multi-technology methodology for generating the multi-source data needed to protect cultural heritages against negative environmental effects.

Energy storage and CO_2 recycling are essential to supporting the three pillars of the world exchanges of energy and materials—energy, water and food.

Green energy and CO_2

From country to country, there is great diversity in where and how much energy we consume. One universal approach to addressing the global energy issue, referenced frequently at the Forum, focuses on the role of materials in switching to so-called 'green' energy. To obtain abundant, accessible, inexpensive and sustainable energy, we need to consider the current status and looming challenges for renewable energy generation, energy storage, and methods for effective mitigation of CO_2 emissions. Wind energy, PV technology, solar refinery based chemical storage and a CO_2 circular economy all still show wide-open areas for materials improvements.

Energy storage and CO_2 recycling are essential to supporting the three pillars of the world exchanges of energy and materials — energy, water and food. Many routes for moving from carbon sources (coal, oil, and methane) to carbon-free sources (PV, wind and sea turbine and geothermal) have been proposed, as have many ways to achieve carbon recycling and energy storage: storage of supercritical CO_2, plasma dissociation of CO_2, high power electrolysis, synfuels, oxycombustion processes, polymer production, water dams, bacteria processes for a CO_2 cycle, microalgae and biomass, etc.). New materials, to a greater or lesser extent, will play a role in all these activities.

The nuclear electricity generation option

Nuclear energy is one of the options that many countries choose. The energy mix for each country is a difficult, multi-parameter choice, and each country needs to set its own priorities and find approaches leading to its own unique solutions. The lifecycle cost of electricity, including the cost of pollution, greenhouse gases and health burdens, should emerge as weighting factors when considering choices of energy generation and applications.

Among the 450 nuclear reactors worldwide, there are 42 nuclear reactors in India (22 in operation, 20 under construction) with power generation capacity from 200MW to 700MW. To achieve sustainable nuclear technologies, every process in the system needs to be thoroughly analysed, from materials development and modelling to quality control of the operation of the reactor to ensure that its life will exceed ~60 years. The international community has come together to learn from the Fukushima disaster, and we also need to learn from 60 years of nuclear energy history, not just one accident. Short- and long-term policies at national and global levels also need to be developed through the collaboration of economists, social scientists, and policymakers. One current test bed for nuclear power innovation is the MYRRHA facility in Belgium (Multipurpose hYbrid Research Reactor for High-end Applications), which provides a new platform for collaborative efforts on developing nuclear energy and directions for research on reactors with well-managed safety measures.

Failure and the 100 kilo-year experiment

Not all new systems and designs will succeed. Diagnosing partial or complete failures leads to improved systems — failure can be a learning experience. This is a common rationale for testing, redesign and relaunching of our most complex, multifaceted devices. New standards developed from failure analysis persist in many fields today.

However, the field of nuclear waste management and disposal is different. To project the risk and challenges into the far future for geologic disposal of radioactive waste is problematic. A 'failed' geologic repository cannot be directly observed due to the difficulty in projecting future behaviour of a geologic repository over extended spatial and temporal scales.

Poor decisions in the near term may be avoided through careful analysis and awareness of all conceivable influencing factors, such as locating a disposal site near well-drilling activities. But on a 100 kilo-year time scale, failure analysis is not an option.

A 'failed' geologic repository cannot be directly observed...

New materials vs. old methods

Introducing qualitatively new materials and devices into regular use requires in-depth, fundamental understanding and development: Working well on the laboratory bench is only a first step. The promise of materials research for next generation PV technologies is a perfect example. For example, indium phosphide (InP) nanowire solar cells have shown great potential in improving solar cell performance with reduced materials cost. However, conventional material synthesis, device fabrication, and characterization technologies cannot simply be extrapolated to nanomaterials and devices. To achieve high performance devices for real applications, new methodologies must issue from detailed studies of nanomaterial and device design, synthesis, and fabrication with advanced characterization tools.

STRATEGIC MATERIALS, CIRCULAR ECONOMY

(contributing editor A. B. Holmes, Melbourne)

A Fifth Paradigm

In the evolution of investigations, the sequence of paradigms is (1) empirical description, (2) theory and experiment, (3) theory, experiment and computer simulation, and (4) all of the above plus big data. We predict that a fifth paradigm is at hand: machine-generated knowledge. Machine learning will organise and transform big data into knowledge. Current examples of this trend are natural language processing with text analytics and nanomedicine that includes diagnoses based on analysis of massive data acquired from biosensors. In the latter case, users rely on the whole body of data instead of only a few parameters.

Materials science supports such advances through sensors at the nanoscale, signal transduction, and flexible film architectures. Aside from categorizing literary styles or analysing the scientific literature, language processing can be used to detect cognitive impairment. Other applications of machine learning include assimilating data from sensors, such as an 'electronic tongue' that detects gourmet coffee and vintage wines.

Every problem in science (and perhaps society) may someday, in principle, be amenable to formulation and solution by deep machine learning. If that comes to pass, is society prepared?

Value-added waste

The topic of waste stream and recycling threads through all energy and sustainability discussions. The idea of a circular economy, in a nutshell, is making 'green' material products from processing waste. The challenge is to rethink processing and create new opportunities for what is considered 'waste'. We know that, in general, commodity materials cannot be returned to their original fabrication components.

Tyre recycling, its contribution to steel-making, and concerns about the CO_2 produced, were mentioned earlier in the Summit report. [*OneSteel*] Another advance involves glass waste, particularly end-of-life automotive windscreens. Plastic laminate combines with silica and iron oxide slags to reduce silica to the ferrosilicon alloy used in cast iron, as an alloying element in steel, and as a deoxidizer.

Ferrosilicon Alloy

Electronic waste offers a wide variety of metals, ceramics and plastics: 20-50 million tonnes made up of 30% ceramics, 40% plastics, and 30% metals. Cu and Cu-Sn alloys from waste circuit boards can become high value-added alloys.

Among the many goals of the new initiative to turn waste into value at the University of New South Wales, SMaRT@UNSW, is putting potential end-users in touch with waste sources.

Arid lands

In the climate change discussion, desertification is less frequently mentioned but serious nonetheless. Causes include drought, vegetation destruction, wind erosion, over-reclamation and overgrazing, the last two of which are caused by humans. Over 40% of the land and a third of the world's population is at risk from desertification. China suffers the most serious desertification in the world — 50% of its national territorial area. Water can restore this land to useful applications, but there is massive evaporation, which can be dozens or hundreds of times greater than precipitation.

Desertification and deforestation are major problems

Over 40% of the land and a third of the world's population is at risk…

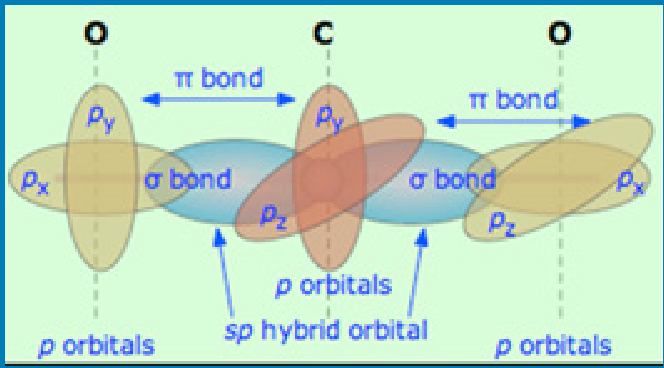
One potential technique for rehydrating desert land to an arable state uses a water-conducting polymer network based on polyacrylamide. This technique is much more effective than traditional low-volume water irrigation techniques. However, there are problems with this approach: The polymer is distributed manually in the soil surface, it will take enormous resources to cover the land needing treatment, and the polymer lifetime is expected to be only two years. This means massive resources will be needed to maintain the land in an arable state. Only natural re-vegetation would reduce the need for further irrigation. The technique may have applicability in specialized situations. The materials solution to the watering mechanism is the combination of a water-absorbent polymer and water-conducting particle layers. A polyacrylamide (PAM)/montmorillonite (MMT) composite is used today to mitigate the arid conditions.

Carbon dioxide conversion

In the current inventory of energy usage across the globe, fossil resources account for over 80% of our requirements, and it is envisaged by many that by 2050 the world's energy needs will still be served in large part by fossil fuels. For example, the International Energy Agency's Energy Technologies Perspectives suggests that by 2050, 50% of the total energy supply will still be from fossil fuels. One way to reduce future carbon use is through the capture and utilisation of CO_2 by catalytic reactions, re-using it by reducing it to combustible hydrocarbons or even to alkenes for commodity organic chemicals. Plans for reuse of CO_2 assume that carbon capture is a solved problem, but removing it as a dilute component from flue gases is still a real challenge. Unless there is a legislative motivation, the cost for businesses to invest in this technology is too high. Nevertheless, partial removal of CO_2 from various emission sources is worth pursuing. Stable, solid CO_2 absorbents might mitigate capture problems.

Assuming that removal is indeed possible, the focus becomes the chemical, catalytic and electrochemical methods of reducing CO_2 to a less oxidized form of carbon and producing hydrocarbons. There is significant promise in various catalytic methods, particularly in the recently reported direct conversion of CO_2 into gasoline fuel (Wei, Jian, *Nat. Comm.* 8:15174, May 2017).

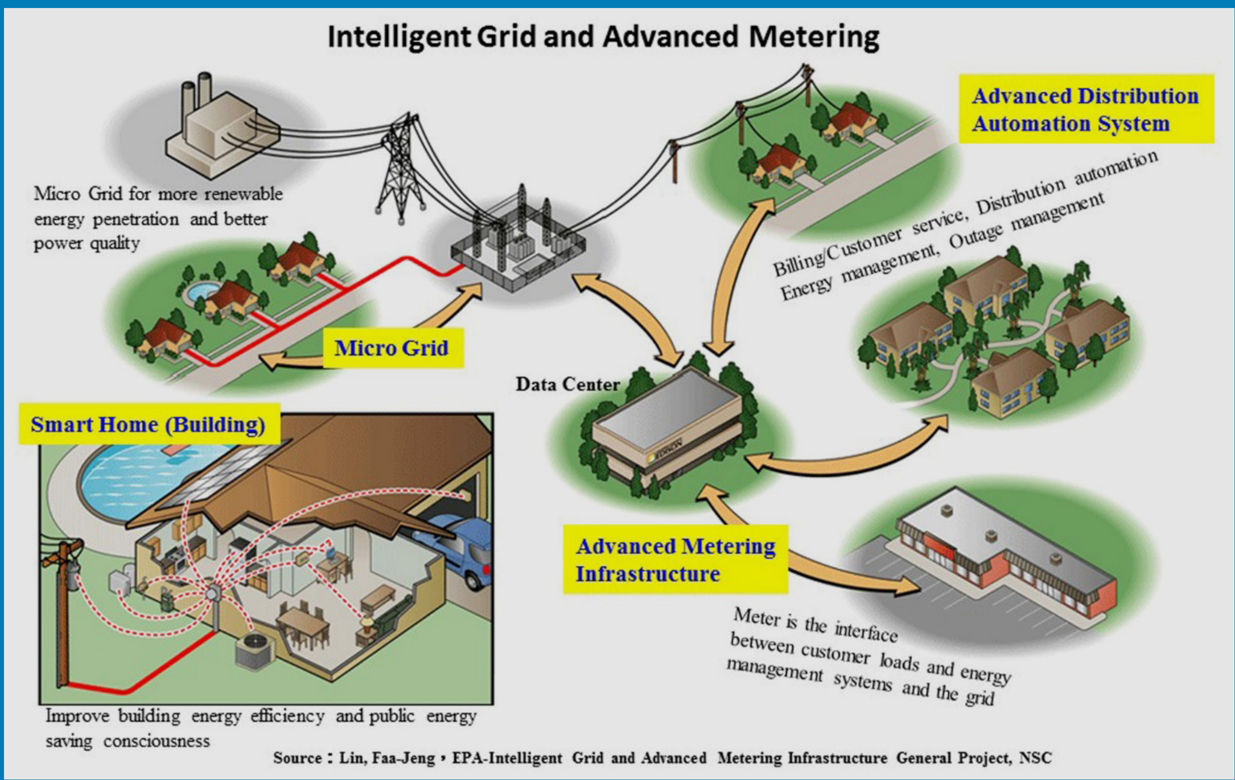
There is a wide variety of end products from the various catalysis-enabled reactions that convert CO_2. A recent catalyst option is $Ni/U/Al_2O_3$ with highly stable uranium nanoparticles. Nitrogen-doped graphene, N-doped carbon nanotubes (CNT), CNT-supported iron-and cobalt-based catalysts and others also promote methanation, hydrogenation and electrocatalysis reactions.



The Carbon Dioxide Culprit

NUMERICAL SOCIETY, FLEXIBLE ELECTRONICS AND NANOMATERIALS

(contributing editors O. N. Oliveira Jr., São Carlos, and L. Fu, Canberra)



Electricity in Taiwan

Today, approximately 75% of the energy consumed in Taiwan comes from fossil fuels, and even worse, these fossil fuels are all imported. There are challenges in the new renewable energies targets set by the Taiwanese government. As described earlier, in the new energy policy act, Taiwan has set a goal of reaching an energy consumption fuelled 30% by coal, 50% by natural gas, and 20% by renewables by 2025. The country is to scrap all nuclear power by 2025, when the most recent of their power plants completes its 40-year life. The two main motivations for this decision were the Fukushima disaster in Japan in 2011 and the recognition that the nuclear power plants are too close to highly populated areas.

In order to achieve the ambitious goal of 20% renewable energy, Taiwan has made changes in their energy policies and has established a program to develop smart grids, including smart microgrids. Significant changes in policy are creating new possible players to generate and sell energy. Taiwan will change from an energy monopoly, with a public company generating, distributing and selling energy, to a mixed public-private model. With the new energy act, energy will be generated by the public company and others (companies or individuals). Distribution (the grid) will remain with the public company, while retail will be in the hands of the public company and others (companies or individuals). Most important, owing to the varied needs of different geographical regions (though the country is small, it has several remote islands), there will be small power plants, with micro-production. In technology, the emphasis is on the need to generate and consume energy effectively, which can be assisted by smart grids. Using smart grids helps solve issues like customer participation, integration of all generation and storage options, new markets and operations, power quality for the 21st century, asset optimization and operational efficiency, self-healing, and resilience against attacks and disasters. For a smart grid to function, a sensor network must send data to the switching centre, which makes decisions about the interconnected microgrids. For example, based on weather forecasts, the intelligent system may predict which power plants to switch on. Beyond the situation in Taiwan, some sort of 'smart system' is part of plans in many regions. These normally involve ubiquitous sensing, use of 'big data' methodologies for data analysis, and even machine learning in some instances.

Nanomaterials and applications

The term "nanomaterials" is normally associated with man-made materials with dimensions ranging from 1 to 100 nm, the properties of which are bound to depart considerably from those of the same materials in the micro- or macroscales. Typical examples of such nanomaterials are metallic, oxide and polymer nanoparticles, carbon nanotubes and other types of 1D structures, and graphene and other 2D materials. The development of bottom-up and top-down approaches to fabricating and controlling the properties of nanomaterials has permitted applications in virtually any area of materials science and technology. For example, nanomaterials are now essential for what has been called 'nanomedicine', serving as integral parts of biosensors for diagnosis, artificial organs, controlled drug release systems and therapeutic strategies such as hyperthermia and photodynamic therapy. With nanomaterials, it has been possible to conceive new paradigms for electronics, including flexible, wearable electronics.

...nanomaterials are now essential for what has been called 'nanomedicine'...

In energy, nanomaterials are key to reaching high efficiency in solar cells, fuel cells and batteries, as well as in innovative applications requiring water splitting. For the food industry, smart packaging relies entirely on nanomaterials, while quality control can be performed with nanotech-based sensors in electronic tongues and electronic noses. Some applications may seem surprising, for they are related to structural materials used in the automobile and space industries, in which the dimensions never appear to be nanoscopic. Even materials used for decades and centuries, such as ceramics and composites, have their mechanical (and other) properties enhanced if adequate control of their nanoscopic arrangement is achieved. Advances in nanotechnology have also had an impact in the use of materials from natural sources, including biomolecules and polysaccharides. This makes the field of nanomaterials truly multidisciplinary, requiring an integrated research approach.

Nanomedicine – the future of diagnostics and treatment

A 'future cast' for our field

Perhaps an even more far-reaching application of nanomaterials is in building devices to generate data and feed a machine learning system to take advantage of 'big data' methodologies. These smart machines are being built with the convergence of two important movements.

...we may envisage a new paradigm in which knowledge will be generated by machines...

On one hand, data from ubiquitous sensing schemes are stored and curated in order to become machine readable; on the other, computational linguistics methods are being used to 'teach' machines to read. Examples include sensing data from electronic tongues, to correlate with the human perception of taste, and biosensing data to develop a computer-assisted diagnosis system. The ability of machines to acquire language, use complex networks and visualize information is illustrated by the classification of text.

Most important, if these movements are successful, we may envisage a new paradigm in which knowledge will be generated by machines, with no human intervention, for the first time in history. The implications of such a shift in science and technology paradigms for the job market is a discussion that implies potential new demands on the training of materials scientists and engineers.

Nanomaterials for health

Nanotechnology is already present in much of today´s medicine and health sciences. Perhaps the best examples are the novel drug delivery systems that are revolutionizing the treatment of many diseases and increasing life expectancy. Though the most visible face of nanotechnology in medicine is associated with the use of nanomaterials, fundamental studies in nanosciences are at the core of nanotech-based approaches to solving problems in health care. In the words of Richard E. Smalley (1943-2005), 1996 Nobel Laureate: "*Human health has always been determined on the nanometer scale; this is where the structure and properties of the machines of life work in every one of the cells in every living thing. The practical impact of nanoscience on human health will be huge.*"

By way of illustration, one of the most relevant public health concerns today, the problem of bacteria developing resistance to antibiotics, can only be solved with basic research related to the nanosciences, for at least two reasons: (1) Techniques like Langmuir monolayers are required to unravel the mechanisms through which novel antibiotics can fight superbugs, and (2) drug development is now mostly based on nanotechnology.

Applications for the direct use of nanomaterials have been implemented in all relevant areas of medicine, including diagnosis, therapy and monitoring. In diagnosis, nanomaterials like metallic nanoparticles, carbon nanotubes, and graphene are employed in conjunction with biomolecules to produce biosensors, immunosensors and genosensors with high sensitivity and selectivity — an extension of the electronic tongue idea. Advanced imaging techniques also make use of nanomaterials. In drug delivery, controlled release at the desired target is entirely dependent on nanomaterials, ranging from liposomes to dendrimers to nanoshells and other more sophisticated multifunctional nanoparticles for drug delivery and imaging, the so-called nano-vectors for imaging and therapy. Indeed, the term 'theranostics' is being used for multifunctional platforms conceived to integrate targeting, delivery and reporting (or biosensing). Controlled drug release with nanomaterials is also crucial for state-of-the-art therapies, including immunotherapy, thermotherapy, photodynamic therapy, and gene therapy. In the future, nanocameras in surgery may allow for close-up visualisation of the human body regions involved, perhaps with nano-sized surgical instruments.

Monitoring health is an integral part of preventive medicine, and there has been an increasing number of sensors and devices developed to monitor body functions. Some of these devices are made with wearable technologies that demand nanomaterials and their integration with biological systems. Nanomaterials are important for regenerative medicine, in which the body is stimulated to rebuild organs and systems. Artificial skin and other artificial organs rely heavily on nanotech methods. This is closely related to tissue engineering, in which cell growth and guidance must be controlled with biomimetic materials surfaces that contain appropriate cell signalling elements. Fundamental research is again key for this type of development because cells sense the surrounding environment via membrane receptors.

Major nanotoxicology research efforts are necessary [...] because the toxicity [...] of nanomaterials varies...

The most advanced products incorporating nanoparticles in the broad personal healthcare market can be found in the cosmetics industry: Close to 1000 products had been created by the end of 2013, some 40 of which are sunscreens. As with any product related to health, possible toxicity effects need to be investigated. Major nanotoxicology research efforts are necessary in this area because the toxicity (beneficial in therapy but deleterious in side effects) of nanomaterials varies greatly depending on their size, shape and coatings.

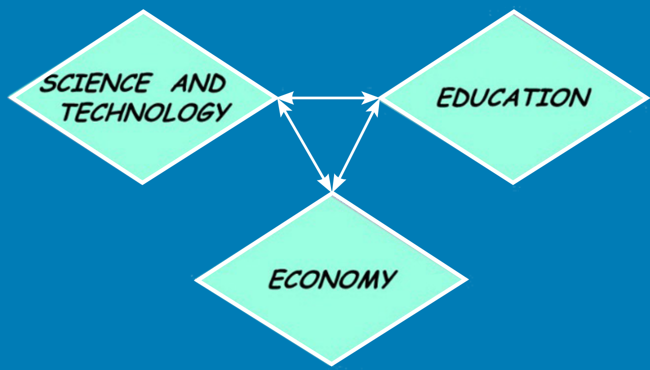
In addition to the overall development of nanomedicine, which is obviously beneficial to the whole world, nanotechnology may assist both developing and underdeveloped countries in specific needs, such as in the diagnosis and epidemiological control of neglected and/or tropical diseases. Nanotechnology is already enabling decentralization of health services with point-of-care diagnosis and strategies based on the 'lab-on-a-chip'.

A 'future cast' for medicine

Last but not least there is a movement for medicine to evolve into what's called P4 medicine: predictive, preventive, personalised and participatory. Such an endeavour can only be realised with a convergence of various types of technology, from an equally wide variety of areas, including nanotechnology, biology, medicine, pharmaceutical sciences, computer science, linguistics and social sciences. The systems to be developed within this P4 paradigm, such as computer-assisted diagnosis systems, require concepts and methods from big data, data analytics and machine learning. Immense challenges will have to be tackled, not only in terms of technology but also related to ethical issues, safety and social acceptance.

The magic triangle for human wellbeing

The value of education and science for the economy and for the wellbeing of society may be taken for granted, but it could benefit from an evidence-based review. Describing technological progress generated by discoveries in physics and materials science is straightforward. But we ought also to use quantitative methods to establish correlation and possible causation effects between scientific discoveries, knowledge and wellbeing.



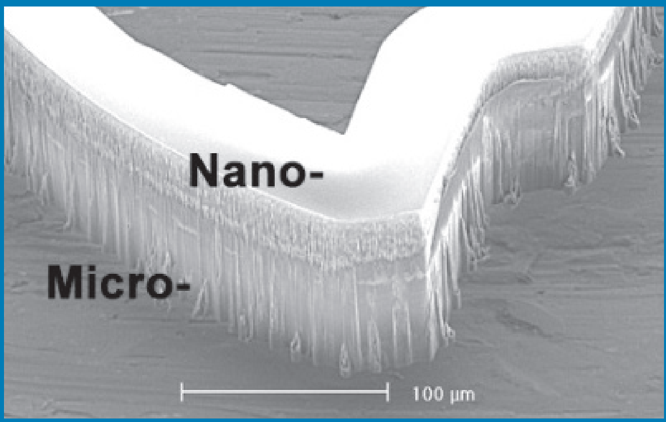
Some basic questions to be answered:

- Can the case study method be replaced by a concept of composite indices to retrieve relevant correlations in a multidimensional parameter space?
- Are there clear correlations between science/technology, education and economy-related indices?
- What is the role of education in science and technology for economic growth and thus gross domestic product?
- Can we move from correlations to causations?

Using data from the Human Development Reports (United Nations Development Programme), PISA (Programme for International Student Assessment), and TIMSS (Trends in International Mathematics and Science Study), we can conclude that human capital is an important factor for a nation to reach high indices of human development. However, for developing nations, there was no strong correlation between such indices and the number of years people spent in school. There is an increasing need to identify quantifiable sociologic terms and develop mathematical methods to pursue identification of factors that enhance human development, especially in developing societies.

Bridging the micro and nano worlds

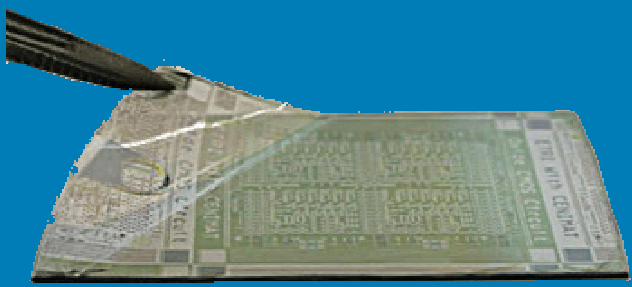
There are excellent examples of employing the superior properties of nanomaterials for real world applications.



For example, developing diamond thin film deposition and top-down nanofabrication processes improves the material properties of nanocrystalline diamond thin films, especially the mechanical properties. Nanostructured diamond technology has been used by a Swiss watch manufacturer [*Ulysse Nardin*] for fabrication of lubrication-free wear-resistant micro components for high-precision mechanical parts of watches. Another use of the diamond thin film and nanofabrication technique is the creation of ultra-thin scalpels (1/1000 the width of a conventional scalpel), which have medical applications such as cataract surgery.

Paper electronics

Self-sustained, low-cost paper electronic systems are being developed. Flexible and optically transparent paper can be made by employing the unique properties of nanostructures, such as nanocellulose. This paper is an attractive substrate for electronic devices due to its light weight, low cost, recyclability, compatibility with biological material, and easily degradable properties. New concepts, such as developing paper solar cells, energy storage devices, and circuits based on transistor architectures, have been pursued. Paper for transistor architectures, as well as relevant development of printed biosensors and electrochromic devices, have been achieved at the Centre of Excellence in Microelectronics Optoelectronics and Processes (CEMOP) of the Universidade Nova de Lisboa.



Solar farms

Large photovoltaic installations, involving both mature and developing PV technologies, have been deployed in developed and developing countries. The main challenges related to the high penetration of PV systems include implementation of energy storage, demand-side response, distributed generation, and smart grids.

A variety of solar cell forms and manufacturing/processing options exists.

Silicon crystallisation and growth, amorphous silicon, thin film deposition, organic PV, substrates and encapsulation, and nanomaterials to enhance performance are only a few factors to consider.

VOICE OF NEXT GENERATION RESEARCHERS TOWARDS BUILDING A SUSTAINABLE SOCIETY

(Compiled by Muxina Konarova & Parinaz Akhlaghi from contributions by all Forum attendees)

The authors would like to thank the E-MRS and all associated organizations for hosting the Forum for Next Generation Researchers at the VI World Materials Summit 2017 in Strasbourg. Such events clearly emphasize the importance of the dialogue between young researchers and leading senior scholars. This venue also created an excellent atmosphere for young researchers to understand the progress in materials science and the future challenges ahead. Young researchers and senior scholars had the opportunity to interact, debate and participate in small-group discussions addressing current and future challenges of our society. Here, in this document, we summarise and highlight our views on how a sustainable society could be created and what we should do to overcome the challenges we face today.

Energy is the key element of our daily activities, and a substantial amount of energy is needed to provide high-quality food, air, water and education. Energy consumption will increase as human population increases; however, energy is sourced from non-sustainable, non-renewable resources, and this remains one of the challenges. We need to find an alternative energy source that is renewable and environmentally friendly. Although there are alternative energy sources (solar, wind, geothermal, biomass), their implementation in our existing infrastructure is very slow, yet severe impacts of fossil-based energy to our planet are visible (high CO_2, sea acidity, sea level rise, abrupt weather events, and desertification). What should we do to address this slow progress?

The following three main approaches may accelerate the transition to alternative energy: multi-organizational approach, multi-cultural approach, and multi-functional materials approach.

1. MULTI-ORGANIZATIONAL APPROACH: WHO IS INVOLVED?

1.1 Government, political leaders

All scholars need easy access to political leaders to provide up-to-date technical knowledge about why the consumption of fossil-based energy sources is a serious problem. Political leaders need to understand that the solution for alternative energy cannot be solved by scientists alone. Scientists need access to infrastructure and funding to cultivate existing knowledge and create new process technologies. Political leaders need to promote bilateral exchanges between scientists and politicians. Only government and political leaders can facilitate the fast transition to alternative energy sources.

1.2 Higher education (universities, research institutes)

Education plays a key role in diminishing the differences between poor and rich, white and black, and male and female. Education must be spread equally without boundaries, with fewer barriers between institutions, and cross-country collaborations must be promoted. The higher education sector needs to provide job security for young researchers by communicating with funding agencies and providing them with the advantages of having experts in fast-growing fields. Universities must sustain their talent to help solve society's problems, including alternative energy technologies.

1.3 Industry/business leaders

The interaction between industry and higher education is insufficient and thus impedes successful collaboration in solving society's problems. Industry leaders should also be part of the alternative energy solutions. They should take some of the responsibility, as members of society, and should promote research donation, exchange and access to their infrastructure. Institutions of higher education must provide an easy pathway for industries to be involved in fundamental research and be receptive to industry input for establishing joint projects that address practical issues.

2. MULTI-CULTURAL APPROACH: WHO IS INVOLVED?

We need to promote international actions and ask each country to be part of the journey. Local knowledge is critical in addressing environmental problems and must be accessible by all to evaluate the economic viability of emerging technologies. Indigenous local resources must be taken into account to preserve cultural values and history. For example, countries like India may have complications with land acquisition, public acceptance and environmental clearances that may delay the transition to alternative energy technologies. Younger-generation researchers must be exposed to different societal challenges in different countries. Interaction between countries may be enhanced by exchanging knowledge and expertise through international mobility grants and joint research projects. Such collaborative international linkages will create dynamic scientific communities on this planet.

3. MULTI-FUNCTIONAL MATERIALS APPROACH: WHAT IS INVOLVED?

Advances in science and technology have resulted in multi-functional, efficient and reliable materials with unique properties. Nanoscale engineering[1] enabled us to develop innovative materials based on metal oxides,[2-4] metal alloys,[5-7] carbon materials (graphene,[8-9] carbon foams[10]) and plant-based bio-materials such as cellulose[11] that could replace finite, precious metal sources. Further development of these materials and better understanding of material properties at an atomic scale will provide solutions for building a prosperous, sustainable future equipped with renewable energy,[12-15] rechargeable batteries,[16-17] low-emission engines,[18] microchannel reactors,[19-20] paper-based electronics[21-22] and smart medical devices[23-25] and grids.[26]

[1-26] [**NOTE**: *Citations 1 through 26 in the paragraph above refer to the list of references in Appendix* **C**.]

Three full articles have been contributed by participants in the Forum for Next Generation Researchers. They are reproduced as appendices **D**, **E**, and **F only in the online version of this report**.

Appendix **D**
Details of current renewable energy technologies and the role of materials science in the context of energy are given in *Transition to Carbon-free Energy – A Comparison of Germany, Australia and India* (Michael Simon, Anirudh Sharma, G.V. Prasad Reddy, and Martin Hynes).

Appendix **E**
The role of nanocomposites in biomedical applications is described in *Nanocomposite Hydrogels and Their Therapeutical Potential* (Yanhua Cheng, Thaís N. Barradas, and Manjunatha Pattabi).

Appendix **F**
Smart grid perspectives are provided in *The Current Status of Smart Grid Development: Social, Political and Economic Perspectives* (Kassio Papi Silva Zanoni, Zhao Yong, and Pierre Denis).


Centre Strasbourg
Jeunesse Strasbourg

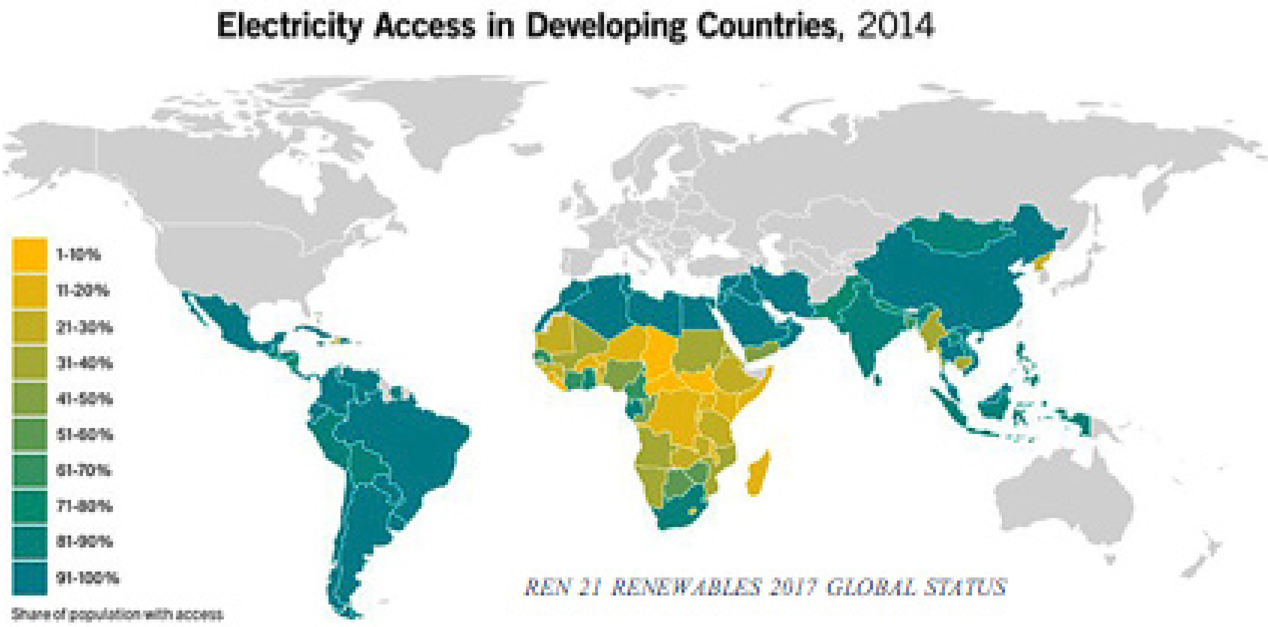

Les jeunes pour les droits de l'Homme en ligne


Les jeunes pour les droits de l'Homme en ligne
Young people for human rights online

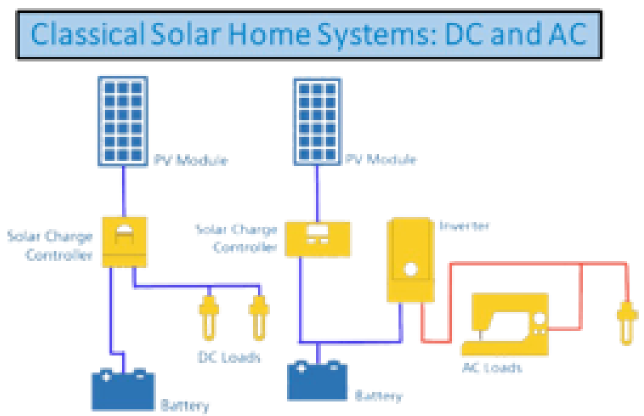
FROM MATERIALS TO SYSTEMS FOR SMALLER COMMUNITIES AND INDIVIDUAL MOBILITY

Rural Power, Green Catalysis, CO_2 Conversion, and All-solid Lithium-ion Batteries

(contributing editor J. Martínez-Duart, Madrid)



The substantial worldwide increase in renewable energies during the past decade is well known. However, the development of renewable energy options in rural areas, especially in those located in developing countries, has not been sufficiently emphasized. Rural areas typically have low populations but abundant local renewable sources. They are now attracting a large share of investment in renewables because there are still close to 1.5 billion people (about 20% of the world population) living without electricity.



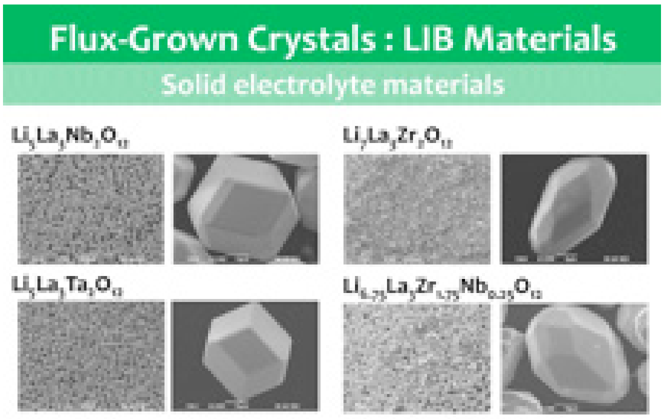
Renewable energy can contribute to the development of electrification in rural areas through the implementation of distributed small renewable power systems or electricity home systems (EHS), often based on solar panels and wind mini-turbines. Recently, these off-grid systems have begun to be connected through mini-grids to enhance overall security and avoid blackouts. With the declining cost of batteries, these installations are also often provided with energy storage to partially maintain a uniform access to power.

Some consequences of electrification of rural areas include new job opportunities, affordable remote area energy, product innovations as new technologies are tested, economic development from new sources of energy, and development of enabling technologies like energy storage and demand-side energy management.

PROMISING CHEMISTRIES

A novel "flux coating" crystal growth technique for fabricating high quality crystals for next-generation all-solid lithium-ion rechargeable batteries has been developed at the Center for Energy and Environmental Science at Shinshu University (Japan). These batteries will provide high energy and power densities as well as non-flammability to mobile electronics, electric vehicles, and so on. These batteries have solid electrolytes to increase the packaging density and the intrinsic safety of the batteries. The flux-coating technique is simple, low-cost and environmentally benign compared with conventional methods.

Compared with conventional powders, the flux-grown $LiCoO_2$ crystals show excellent charge-discharge performance, close to the theoretical values for this kind of cathodic material. The high crystallinity of the obtained $LiCoO_2$ increases the low Li-ion mobility observed in materials with poor crystallinity and numerous interfaces. By changing the concentrations of the Li and Co, several crystals with controlled composition can be obtained on different kinds of substrates. Various other compositions have been grown for Li-battery use.



The synthesis of carbon nanomaterials is a rapidly growing field of nanotechnology, mainly due to new applications in areas such such as green catalysis and CO_2 conversion, which reduces CO_2 concentration in the atmosphere and simultaneously synthesizes useful organic products.

When they act in support of metals like Pt, Ni, and so on, nitrogen-doped carbon nanomaterials show a large improvement in catalytic properties — a green catalysis phenomenon. The enhanced catalytic activity can be explained as due to a narrowing of the metallic particle size distribution, a strong increase in the carbon-metal binding energy, and an increase in the speed of the electron transfer in the catalytic reaction. The use of less expensive, environmentally benign and corrosion-resistant carbon nanomaterials holds promise as a way to replace metal catalysts.

...nitrogen-doped carbon nanomaterials show a large improvement in catalytic properties...

Conversion of captured CO_2 may be effected by carbon nanomaterials when they act as supporters of metal catalysts. The reduction of CO_2 through electrocatalytic, photocatalytic, or electrochemical catalytic methods based on carbon nanomaterial catalysts has potential for future development. A few examples of CO_2 conversion processes are summarized in the following table.

The first reaction listed shows how methane mixed with CO_2 can be converted into versatile syngas using Ni supported carbon nanotubes as catalysts. Syngas is a mixture of H_2 and CO and has multiple applications in industrial processes. This reaction, called 'dry reforming', shows significant environmental benefits since it could consume atmospheric methane, one of the major greenhouse gases with a warming potential 72 times that of CO_2.

The second reaction shows that N doped carbon nanotubes can be efficiently used for the catalytic reduction of CO_2 to CO. The resulting CO can then be used to produce syngas if mixed with hydrogen.

And the third reaction shows that CO_2 can be electrochemically reduced to CO or to CH_4 by using catalysts based on nitrogen-doped carbon nanotubes. Finally, it has also been reported that electrochemical conversion of CO_2 to ethanol (C_2H_5OH) can be done using a copper nanoparticle/nitrogen-doped graphene electrode, which suggests a synergistic effect from interactions between Cu and the carbon nanomaterial. There is, of course, interest in ethanol as a transport fuel, especially when mixed with gasoline.

Examples of Carbon Dioxide Conversion Processes

1.	CO_2 conversion of methane to syngas ('dry' reforming)	$CH_4 + CO_2 = 2H_2 + 2CO$ ($\Delta H^\circ_{298} = +247$ kJ/mol)
2.	CO_2 reforming with carbon	$CO_2 + C = 2CO$ ($\Delta H^\circ_{298} = +172$ kJ/mol)
3.	Electrochemical reduction of CO_2 to CO and CH_4	
4.	Electrochemical conversion of CO_2 to ethanol	

DISRUPTIVE MATERIALS FOR THE FUTURE

Nanomaterials, Nanomedicine, Autos, Batteries, Fuel Cells, and Outer Space

(contributing editor A. Taub, Ann Arbor)

Novel materials and manufacturing processes are necessary for the next generation of electronics and other devices used in medical, energy and transportation applications. These advanced materials themselves are needed for both incremental improvement of the technologies in use today and the development of new breakthrough applications.

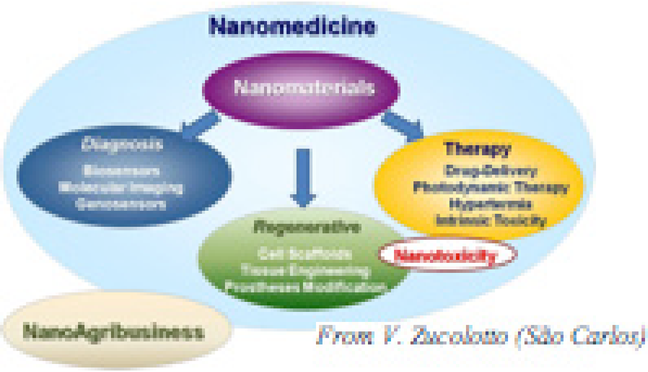
GENERAL APPLICATIONS

There are major opportunities for the growth of nanotechnologies due to the convergence of engineered nanomaterials with electronics, photonics, energy, and bioscience. A new generation of 'e-textiles' for wearable electronics, based on the integration of fibre-based and electronic/photonic materials, is emerging. Major advances in carbon nanotubes, graphene and smart materials are leading to a wide range of new applications including flexible, printable electronics, energy harvesting devices, and new sensors.

Integration of big data analysis tools with these new sensors is a very promising area.

MEDICAL SECTOR

Novel materials are continuing to enable major progress in medicine and the health sciences. These developments are contributing to remarkable improvements in quality of life and longevity. The applications span diagnosis, therapy and regeneration and together are a key enabler for personalized medicine.



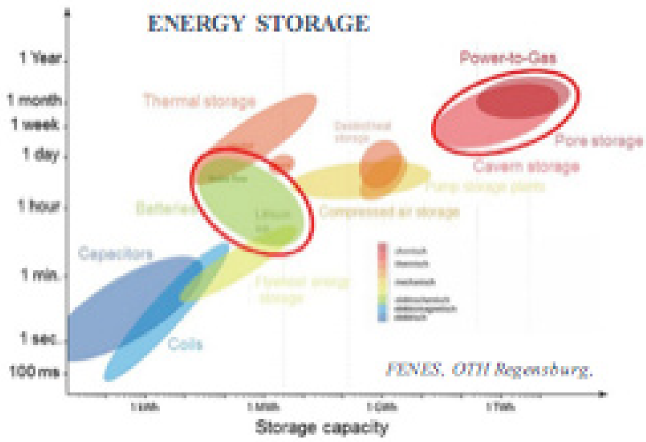
The market for nanomedicine is large and growing, expected to reach nearly US$400 billion by 2023, despite the long timeframe for development and clinical certification. It appears that the Asian countries will lead in the development of this technology. Although there remains no 'official' definition of nanomedicine, there are probably more than the ~150 drugs classified as nanomedicines, as well as a journal with a name that attempts a multi-field field definition: *Nanomedicine: Nanotechnology, Biology, and Medicine* (Elsevier, B.V.).

New nanomaterials are becoming available for nanoscopic approaches to biomarkers and biosensors. These biosensors and biomarkers are composed of a combination of organic and inorganic materials. Integration of big data analysis tools with these new sensors is a very promising area.

Nanomaterials are also being developed for new drugs, enabling controlled release of the medications, and for tissue engineering to produce artificial organs, a process in which cell growth and guidance must be controlled with biomimetic surfaces integrated with cell signalling elements.

TRANSPORTATION AND ENERGY SECTORS

Sustainable solutions are required for the land, sea and air transportation sectors, especially the development of technologies that utilize renewable energy sources to power vehicles while minimizing the emissions of CO_2 and other pollutants.



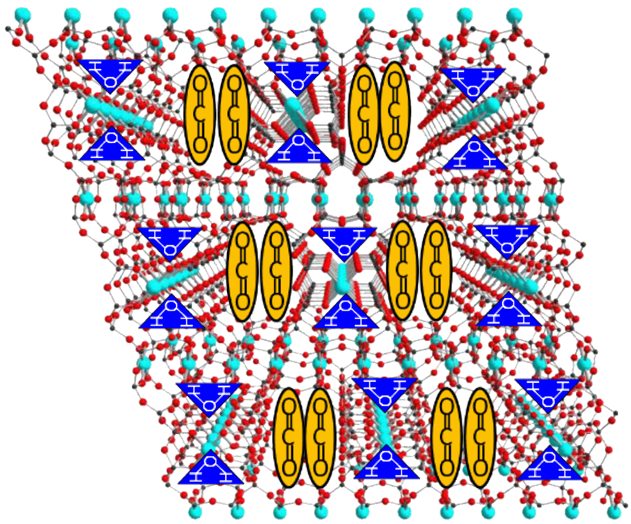
Renewable liquid and gaseous fuels for the internal combustion engine are CO_2 reduction options that use the existing infrastructure. Compressed natural gas (CNG) is also a viable option, with demonstrated CO_2 reduction of ~15%, and significant CO_2 reduction can be obtained using biofuels. In addition, there is progress being made in artificial photosynthesis, which can take advantage of 10% CO_2 concentration in stationary-source flue gas, where significant progress is being made in CO_2 capture, particularly for humidified sources. The captured CO_2 can then be processed into various fuels that take advantage of nanoscale catalysts.

The end game for automobile propulsion is electrification. This can address the issues of today's internal combustion engine — energy inefficiency and tailpipe emissions. There are two options for electrification: battery and fuel cell. The two systems have different advantages and challenges and both are beginning to be offered in the marketplace.

Both battery and fuel cell vehicles have to handle thermal management at much lower temperatures than those found in internal combustion engine vehicles. Improved thermal transfer fluids and systems are needed, and new materials are being developed.

Hydrogen offers real promise as a broad-based energy carrier for both mobile and stationary applications.

The challenge for battery electric vehicles is higher cost and lower energy and power density compared with today's fossil-fuelled internal combustion engines. Both the cost and energy density of batteries are improving significantly (see the *Energy Challenges* subsection earlier in this report). Exploration of alternatives to Li-based batteries and alternate electrodes such as Si-based anodes is increasing. Solid state cells also offer promise.



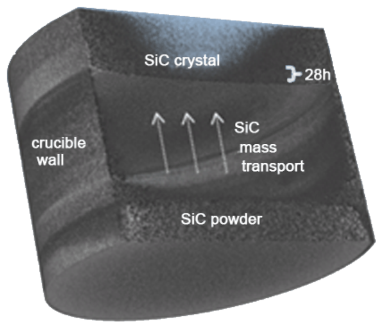
Copper silicate crystal (SGU-29) traps CO_2 and water in humid flue gas.

Hydrogen-fuelled, polymer electrolyte membrane (PEM) fuel cell powered vehicles can meet today's driving range requirement, but still require a significant cost reduction to be competitive with the internal combustion engine. There is also a need to decrease the size and cost of the on-board hydrogen storage tank. Today's systems are based on compressed hydrogen gas tanks. Progress is being made in solid state hydrogen storage based on nano-structured materials.

Hydrogen offers real promise as a broad-based energy carrier for both mobile and stationary applications. Moving toward a hydrogen economy is a complex task, involving the creation of the production and delivery infrastructure coupled with transitioning the devices that use energy from today's fuels to hydrogen. This requires a public-private partnership involving local, national and global governments, companies from sectors including energy production, fuel storage and delivery, and stationary and mobile energy devices for electricity generation and transportation.

Microorganism and biomimetic approaches to producing fuels, including hydrogen, offer great promise for a low cost, sustainable supply of this critical material. Solar production of hydrogen by electrolytic water splitting is also making good progress. Enzymes and other bioinspired materials for use as catalysts in this process are being explored.

Recent demonstration programs in the UK have shown that using the existing natural gas infrastructure to safely transport hydrogen holds promise.



Electronic devices and their associated software are now a dominant element of automotive vehicle content. High efficiency power electronics are needed for the electrification of the vehicle, whether powered by batteries or hydrogen fuel cells. Silicon-based devices are now approaching their theoretical limit, and wide bandgap semiconductors are needed to reach higher performance levels. SiC, GaN, Ga_2O_3 and diamond-based electronics offer new pathways to higher performance power electronics usable at higher operating temperatures and/or power levels. SiC is the most mature of these materials, and progress is being made in increasing the yield for producing low defect single crystals. GaN is difficult to produce in large area bulk form, but epitaxial growth on a Si wafer is promising.

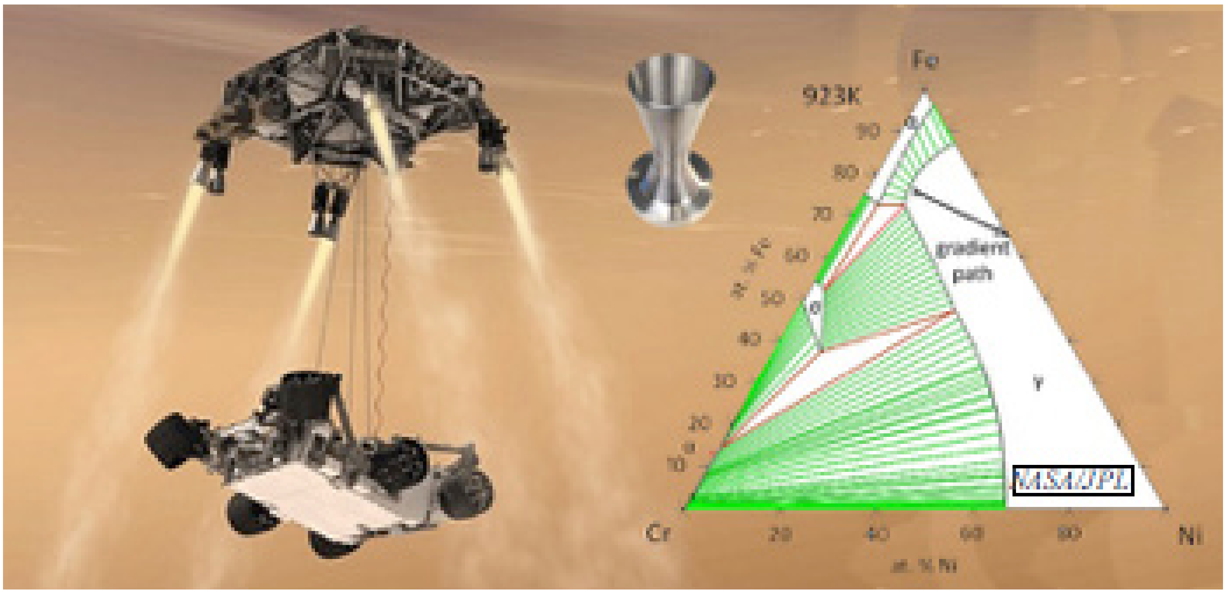
MATERIALS FOR SPACE

New materials and manufacturing technologies are critical for enabling safe operation of not only terrestrial-based transportation but also for robotic landers on hostile space bodies, and additive processing of metals promises to produce breakthrough technologies for adaptive use in space.

...carbon fibre composites [..] can reduce weight by up to 60%.

Significant efforts are underway in both alloy development and associated processing, including 3D printing, cold spray, e-beam and other approaches. These techniques are very amenable to the production of functionally graded materials capable of producing structures with tailored properties at different locations in the components. This helps in accommodating various performance demands, including mismatch of coefficients of thermal expansion (CTE) when joining components for differential temperature environments.

For both space and terrestrial transportation, reduced weight is key for increased payload and reduced fuel consumption. Progress is being made both in advanced high-strength steels (AHSS) capable of being stamped at room temperature and in aluminium alloys. These materials can enable weight reductions ranging from 20% for AHSS to 45% for aluminium, compared with low-carbon steel, for automotive body structures. Work is also underway to lower the cost of carbon fibre composites that can reduce weight by up to 60%. A weight-optimized structure consists of mixed materials, and new techniques are being developed for robust, corrosion-resistant joining of these materials.



To close the formal Summit programme, 'Materials and Technologies Available for a Globally Sustainable Future: Focus on Key Sectors' was discussed by a panel of assembled Summit speakers who made short presentations on key problems. The following two sections summarise their findings.

ROUND TABLE REVIEW-1

(contributing editor J. R. Blizzard, E-MRS)

SUSTAINABLE ENERGY

Many perspectives related to energy in the broadest sense arose during the Summit. A major issue after Fukushima is the question of nuclear power, and already some countries have decided to close nuclear stations in favour of renewable sources. However, the consensus is that nuclear generation must remain an option. The real issue for nuclear is the strategy for managing nuclear waste, and it is evident that there is a need for a new nuclear waste management organisation and funding scheme in which the generators take responsibility. Public engagement to get consent is essential, despite much aversion to nuclear in any form. The solution must ensure that efforts address the regulatory, technical and societal issues to finally achieve safe geological disposal, with safety assured for 100,000 years.

The development of many applications, from nuclear and wind power, to storage, transportation, and other vital sectors such as health and defence, relies on the availability of rare earth elements. Many applications need permanent magnets, for which rare earth elements are essential. Today, the main source of these currently irreplaceable elements is China, which accounts for over 40% of the world's known resources. A major challenge for materials research is to develop new substitute materials that can replicate the properties of these scarce materials.

The development of many applications […] relies on the availability of rare earth elements.

Concern over climate change caused by greenhouse gas (GHG) emissions drives the desire for clean energy. Road transport, both cars and commercial vehicles, is one major source of these emissions. Sustainable mobility is proceeding rapidly with the advent of new types of vehicle that are superior in energy use, environmental effect, safety, congestion and affordability. Faster-charging batteries, improved hydrogen cells, lighter materials, improved sensors for autonomous driving, self-cleaning sensor windows and low-rolling-resistance tyres are all in development.

The debate about the appropriate mix of energy sources that ensures sustainable availability is ongoing and likely to continue for years to come. There is no global optimal solution that satisfies local geography, varying atmospheric conditions and weather, and local political realities.

For example, in South Australia, a 50% reliance on renewable sources without adequate provision for base load supply led to severe power outages when storms damaged many wind farms. Those difficulties were compounded by problems with the grid and an inability to supplement the load with gas-fired plants. The local government response has been to install a massive Li-ion battery as backup, and the federal government has commissioned a review of the national energy market. Nevertheless, while batteries are one option for storage, they are not yet cost-effective, and pumped hydro may be a better solution for Australia, as over 22 000 suitable sites have been identified.

To achieve Australia's goal of a 28% reduction in greenhouse gases by 2030, coal is initially being replaced by renewables and storage, with natural gas as a backup. Carbon capture and sequestration (CCS) is considered unlikely near term. Photovoltaics (PV) may be cheaper than wind power after 2020, but the best option could be pumped-hydro storage, batteries, and concentrated solar thermal (CST). [*See the image on the cover of this report of Chile's Atacama1 solar thermal plant.*] Nuclear is a viable base load option, but wind, PV, and CST could provide the long term solution. For such advances to be effective, it is essential that enhanced interconnectivity and a smart electrical distribution grid be established.

Energy provision in Europe, especially within the EU, varies because each member state has its own energy policy, but the energy and climate goals are common: to reduce GHG emissions by 40% and increase supply by renewables and energy efficiency by 27%, each by 2030.

Nuclear is a viable base load option, but wind, PV, and CST could provide the long term solution.

Energy sources vary widely from state to state, with coal varying from 0 to 80%, nuclear from 0 to 80% and renewables from 10 to 80%. It is therefore difficult to predict any joint actions. Cooperation enables the fluctuating output of renewable energy sources (RES) to be smoothed, with a consequent reduced need for backup sources and storage. Europe has two distinct wind paths, a northern and a southern. The southern countries produce a surplus, useful especially when Germany in particular requires backup. It has been suggested that the goal should be to reduce the demand of European society from 5 to 2kW per person. However, it is recognised that Germany, for example, cannot be fully reliant on RES. Thus another CO_2-free system is necessary, and research into new fusion concepts and fission must be intensified — and reintroduced if it has been abandoned.

India has a major energy supply challenge: a population of 1.3 billion people, 30% of whom have no access to a power supply. Currently, coal is the source for 66% of electrical energy in India. Another 32% is provided by RES and about 2% by nuclear generation. Demand is growing very rapidly, and although the government is pushing for increased RES, many coal-based power plants are under construction in an attempt to provide power for all.

'…the 2015 Paris Accord on Climate Change is a major technological challenge.

In Taiwan, a target of 20% RES by 2025 has been set by the president, and a smart grid is being developed with widespread application of smart meters. The whole population is considered to be participating in the project, and many small RESs are provided to the grid.

The United States has three main concerns: transportation, decarbonisation and an energy grid that requires high regulation because it is very diverse, with some 2 000 utilities whose business model might be considered to be under threat. At the state level, many actions are underway, and changes are needed to some regulations. Achieving the targeted reduction in emissions set by the 2015 Paris Accord on Climate Change is a major technological challenge. However, there is good support at state and municipal levels, and it is possible that the targets set in Paris may be achieved.

ROUND TABLE REVIEW-2

(contributing editor M. Hynes, Strasbourg)

WATER

- More recycling is needed with effective management of 'grey' water.
- More energy efficient treatment of saltwater is needed to produce potable water.
- Further development of efficient irrigation techniques is needed to offset desertification.

It is difficult to see how these targets can be met with current policies.

ENERGY MIX MODELS – EUROPE

Whilst European countries demonstrate a wide range of energy source dependencies, a common strategy has been agreed upon:

- Decrease GHG emissions by 40% by 2030
- Raise renewable energy systems to 27% of the mix by 2030
- Improve energy efficiency by 27% by 2030

It is difficult to see how these targets can be met with current policies.

It appears that we would have to shift from demand of approximately 5kW per person down to 2kW per person in order for renewable energy systems to be sufficient for our needs in the foreseeable future. Estimated figures for Germany support this conclusion.

There will be additional benefits from increased Europe-wide collaboration and interconnection; this could include a 30-40% increase in the back-up and storage systems capacity demanded for reliability and a 10-20% reduction in back-up power. Despite these improvements and increases in renewable energy systems, a much greater proportion of CO_2-free sources must be deployed. The only systems that have demonstrated sustainable production to date have been nuclear systems.

The impracticality of most forms of energy storage systems have been well illustrated by an Irish project styled 'Spirit of Ireland'. In this project, no match could be achieved between potential electrical storage requirements and probable renewable variability over time periods of two to three days.

INDIA

Currently, nuclear power provides 4.78 GW or 2.3% of total demand in India, which is proposed to more than triple by 2032. The role of fast breeder reactors will become increasingly dominant, with thorium-based systems contributing strongly.

CHINA

The situation in China shows a shift in the role of coal versus wind and solar, such that these would contribute more, and coal would drop to one fifth of 2015 levels by 2050. Nuclear would stay relatively static at 2020 levels. With this potential variability, storage appears to be the key challenge when in 2030 'erratic' sources could account for 38% of the total demand.

...a nuclear waste management strategy must be an effort that addresses both technical and societal issues.

NUCLEAR WASTE – SOME NEXT-STEP CRITERIA

- Create a nuclear waste management organisation and funding scheme that would assign responsibility to the utilities–a 'polluter pays' principle.
- Develop a new process of public engagement, in which a consent-based process is based on a redistribution of power among affected parties.
- Integrate all activities at the back end of the nuclear fuel cycle by aligning incentives to the final goal of geological disposal.
- Realise that, by its very nature, a nuclear waste management strategy must be an effort that addresses both technical and societal issues.

- Revise the regulatory approach such that quantitative probabilistic analysis is only one element of a safety-based approach to the safety analysis.

It is possible that hydrogen-fuelled vehicles will play an increasing role...

RARE EARTH MATERIALS

Rare earth materials have a role in reducing energy consumption in construction as well as energy demand in the built environment.

- Demand for lithium in 2035 is projected to be 3.7 times the production in 2013.
- For heavy rare earths (dysprosium, terbium) demand will be 3 times the production in 2013.
- Demand for rhenium will be 2.4 times its 2013 production.

It will be challenging to meet this level of demand, which in turn will promote improvements in recycling strategies as well as increased efforts to substitute alternative designs and materials.

MOBILITY

Greater variety in the sources of transport fuels deployed for personal transportation, public transit and freight is expected, and greater use of electric vehicles will yield benefits in primary fuel usage as well as diversity in demand management. We may see new ideas for managing peak demand and matching demand with variable renewable sources, such as incentivised timing for charging batteries, or even return to the grid from electrical vehicle batteries during peak demand.

It is possible that hydrogen-fuelled vehicles will play an increasing role, as mobile storage systems become more economically feasible, and systems for distribution are improved.

REPORT TO THE SUMMIT FROM THE FORUM FOR NEXT-GENERATION RESEARCHERS

(contributing editor J. R. Blizzard, E-MRS)

The presence of the select group of twenty-six next-generation researchers at the Forum and the Summit was much appreciated by the senior researchers. There was enthusiastic and excellent participation, with both individual and shared perspectives on topics under discussion. The Forum provided, as its primary goal, the opportunity for broadening the knowledge of the young researchers through an educational programme consisting of a series of lectures by senior scientists. However, the event was most certainly a two-way interaction, in which participants displayed their own research in poster sessions and contributed their own ideas on how sustainability challenges might be overcome. It is likely that these young researchers will maintain contact, which may result in their collaboration in future projects.

...the event was most certainly a two-way interaction...

CONCLUSIONS

It is clear that care for and maintenance of our small planet is essential, and it is important that the materials community participate in looking after the planet. Concerns need to be brought to decision makers, but for policymakers, documents need to be very succinct.

What of the priorities on which the Summit was meant to focus?

The public acceptance of nuclear in some countries is a particular problem.

Half the world's population is likely to be living in megacities by 2050, and it is clear that the necessary energy requirements will not be fully met by RES. The possibility is that nuclear power will be important, but location of the necessary infrastructure may pose problems, as will the management of waste. The safe management of 250 tons of plutonium needs serious consideration, and suggestions for developing small modular reactors will not solve the issue of waste management. The public acceptance of nuclear in some countries is a particular problem. However, it is important to keep the option for nuclear generation open, as experts believe that nuclear should be part of the mix. It is clear that there is an increasing use of coal, and this will intensify the need for advances in clean coal technologies. A significant improvement in the efficient use of energy is needed, which will have the benefit of reducing demand.

For developing communities, providing energy by RES and improving storage facilities are promising options. Conventional generation is practical, but carbon capture and sequestration (CCS) is very expensive and unproven. CO_2 should be collected locally and could be transformed locally. CO_2 conversion is a viable option, but the required scale of transformation will be difficult to achieve. Treatment by 'bolt-on technology' at the back end of a generating plant is not impossible.

Hydrogen is an option, and electrolytic methods for hydrogen generation are available, but storage is a problem.

Overall, it is clear that different societies will have different solutions for providing energy. Germany and Taiwan are rejecting nuclear power, and the world will learn if that is a viable option. Others, such as China and Korea, are developing both nuclear power and RES in order to meet their high demand for energy. The United States recognises the need to meet demand for power and, despite the huge cost, to solve the nuclear waste issue. Clearly, depending on the views of the various societies, there are many options, but some will not meet that society's needs and will need to undergo significant modification. The world will learn from failure, and each society will reach its own solution.

Circular energy enhancement will rely on adequate and efficient cost-effective methods of recycling. Currently, it is not economical to recycle many high technology components, even though they contain small quantities of valuable elements. This is an issue with Li-ion batteries. There is not a current problem with lithium, but some other elements, such as cobalt, are in short supply. There is a definite need for public education to develop social and cultural awareness of the need to recycle valuable materials. Collection and separation, or segregation, of materials is a significant problem that needs to be addressed by public authorities worldwide. The developing concept of deposit systems to encourage recycling is a potentially important initiative.

Disruptive technologies need very careful integration in the field of individual health management. Wearable electronics with sensor applications, nanotechnology, and nanoparticles — and their toxicity implications — all need serious consideration. It is evident that materials science will play the crucial role in future developments.

The young researchers stressed that all areas — energy generation, storage, transport, water provision and conservation, health and combatting climate change — depend on international collaboration and agreement between policy- and decision-makers. The importance of materials research in solving problems is very evident. It is essential that the various policies adopted internationally ensure that future generations of researchers are educated and trained to continue the work of the present generation of young researchers.

SEEKING CONSENSUS

(contributing editors R. C. Ewing, Stanford; O. N. Oliveira, São Carlos; E. N. Kaufmann, Argonne)

NUCLEAR VS. RES

While the debate over proposed renewable energy solutions versus nuclear power is ongoing, these alternatives are not mutually exclusive. Perhaps the debate can be framed in the following way.

Energy systems interact with society at many different points. In the most obvious way, energy systems provide energy (and create waste) that society uses (or must dispose of). However, there are many other points of contact with society that vary depending on the structure of government and financing of energy projects, views on safety, methods of regulation, and the general attitude of the public in different nations and regions. This close coupling of energy systems with society means that different types of societies will have different solutions. As noted above, some countries, such as Germany and Taiwan, try to do without nuclear power. This is a grand experiment, and we should all be pleased that they attempt the non-nuclear path. We will learn from their outcomes. We will also learn from China and Korea as they pursue the nuclear plus renewable option. Other countries will provide their own experiences from which to glean some planning guidance. The United States, in particular, struggles with expansion of the nuclear option and with the nuclear waste issue. Consider the recent failure to complete two nuclear power plants in the state of South Carolina (after spending US$9 billion) and the failure of the effort to create a geologic repository at Yucca Mountain, Nevada, for nuclear waste disposal (after spending US$10 billion).

...the important point is [...] the compatibility of different energy producing systems with different societies.

From a scientific viewpoint, we understand the physics and chemistry of different power sources and distribution systems. We can all do the standard bookkeeping to describe the energy needs of a country or the world. But the important point is not the physics or energy bookkeeping but rather the compatibility of different energy producing systems with different societies. The good news is that there are many solutions. The bad news is that some will fail, but then, sometimes 'failure is good'. It is how we learn. Within this context, there is room for all scientific activities and proposed solutions.

GENERAL COMMENTS

One of the main aims of the Summit series has been to discuss how materials research and development can serve society by helping solve pressing and long-term problems, such as those related to water, CO_2 emission and climate change, desertification, energy, health care, and so on. This sixth Summit concentrated primarily on sustainable materials and energy, though presentations and discussions also covered other topics, as is clear from the preceding report.

Almost all topics discussed in the Forum and the Summit made it clear that a multidisciplinary, integrated approach is required to address the major challenges. For sustainability, for instance, integration with other fields such as economics and social sciences is essential, because sustainability depends not only on materials technology (and other technologies) but also on factors such as economic viability and social acceptance. Materials science is also key to artificial intelligence (AI) systems, the Internet of Things (IoT), computer-assisted diagnosis, nanomedicine, and more.

Because societal conditions and problems are often determinative, their significance is a factor mentioned in connection with most energy and sustainability propositions.

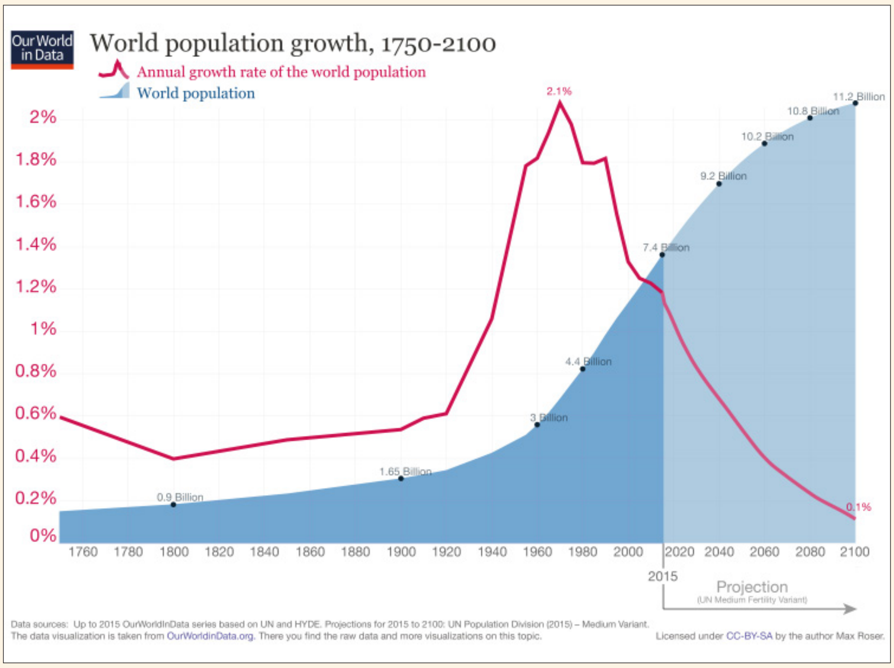
Another characteristic of our discussions of possible solutions for tackling climate change, reducing pollution, and getting the required energy for society is that there are no global solutions that can be applied in all regions of all countries at any time. This conclusion was reached repeatedly. For energy, examples from Taiwan, Germany, South Korea, and India indicated that the technological choices for energy generation, storage and delivery have to be different, for they depend on the resources of the country (or region) and on the profile of energy usage. Experts contend that nuclear energy is there to stay in India, for the country cannot afford to find other sources to cater to its very large population, especially considering that the consumption per capita is still much lower than in developed countries. As for sustainable materials, various examples pointed to the need for localized solutions that deal with recycling. Recycling programs in Australia highlight the importance of electronic waste and show that recycling in some cases is only viable economically if materials processing is done close to where waste is generated.

Because societal conditions and problems are often determinative, their significance is a factor mentioned in connection with most energy and sustainability propositions. Understandably, therefore, consideration of ethics and values in research and development programs rises in importance.

SPECIAL SUPPLEMENT
USEFUL BACKGROUND STATISTICS

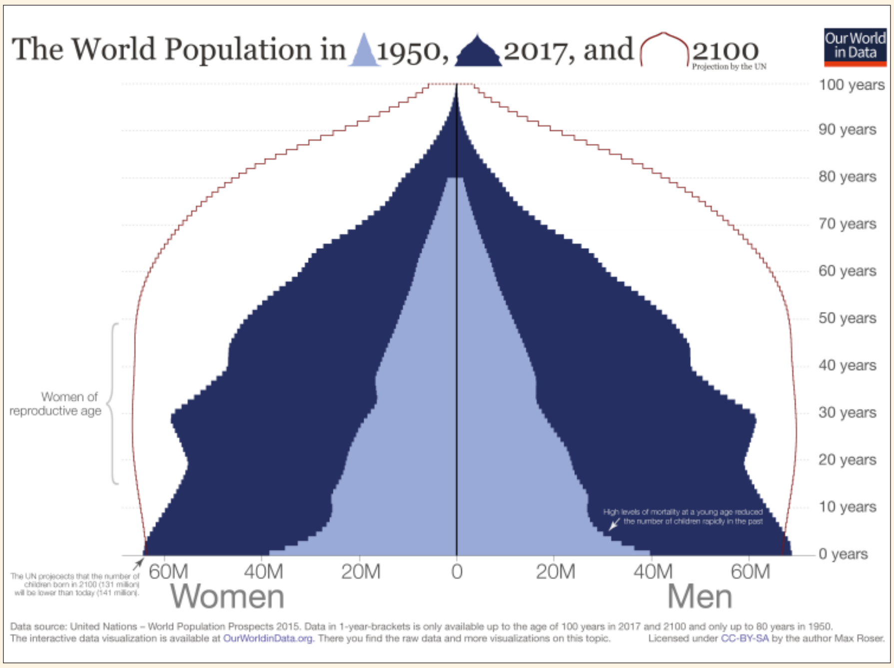
ELECTRIC VEHICLES DECARBONISE MOBILE POWER

WORLD POPULATION



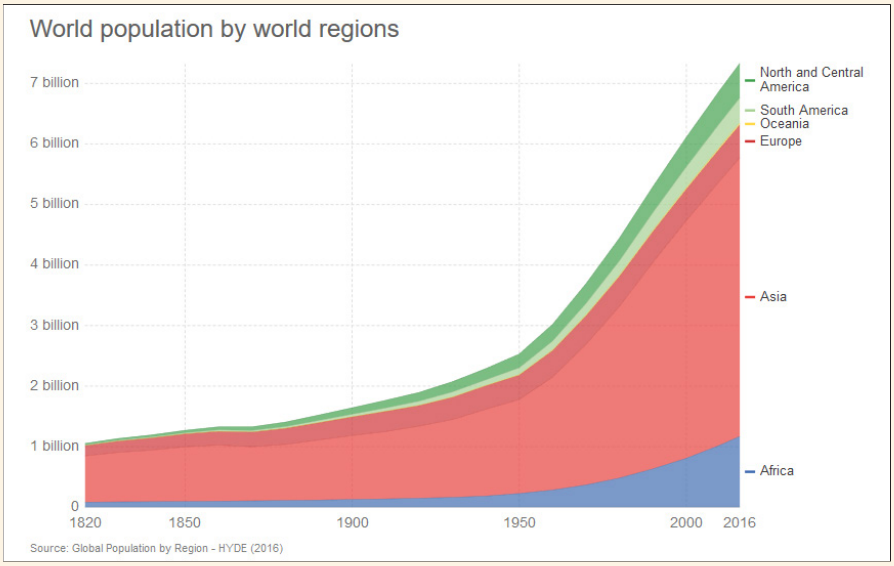
The world population was estimated to have reached 7.6 billion as of 2017. The United Nations estimates that the world population will further increase to 11.8 billion by the year 2100.

The UN projections show a continued increase in population in the near future, with a steady decline in population growth rate. The highest population growth rates — global population increases above 1.8% per year — occurred between 1955 and 1975, peaking at 2.06% between 1965 and 1970. The growth rate declined to 1.18% between 2010 and 2015 and is projected to decline to 0.13% by 2100.



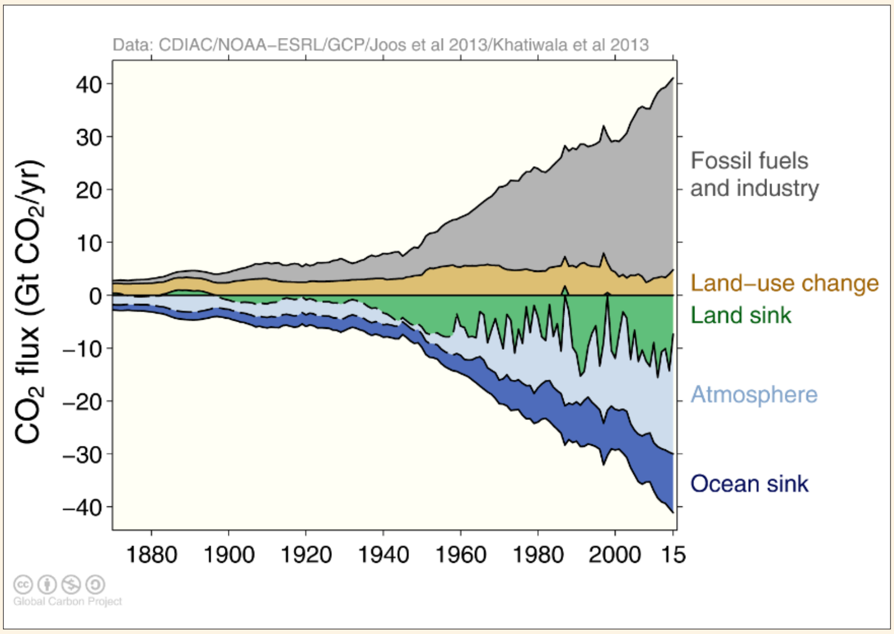
Age distribution has also changed. In 1950, the narrowing of the pyramid just above its base is testimony to the fact that every fourth child died before it reached the age of five. In 2100, this situation will no longer exist.

The world population pyramid also shows the base of the structure in 2100 to be narrower than today's, meaning there will be fewer children born than today. Between 1950 and today, a widening at the base of the pyramid was responsible for the increase of the population. From now on, the increase will be due to the maturation and longevity of the population above the base.

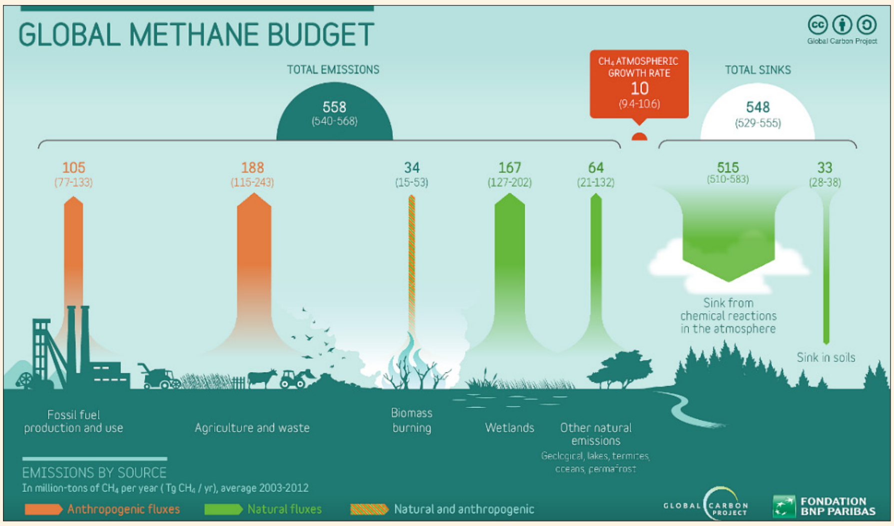


As of 2016, Asia is the most populous continent, with its 4.6 billion inhabitants accounting for 63% of the world population. Africa comes second, with around 1.2 billion people, or 16% of the world's population. Europe makes up 7.5% of the population, while South America is home to around 415 million (5.7%). North and Central America have a population of around 572 million (7.8%), and Oceania about 32 million (0.4%).

POLLUTANTS



Over the last fifty years, global carbon emission caused by industry and transport has risen so sharply that the concentration of carbon dioxide in the atmosphere has reached a record level of more than 400 ppm (parts per million) — even though the planet's oceans, soil and vegetation absorbed more CO_2 in that period than at the start of the 20th century.



Unlike CO_2, atmospheric CH_4 concentrations are rising faster than at any time in the past two decades and, since 2014, are now higher than all but the most greenhouse-gas-intensive scenarios. A likely major driver of the recent rapid rise in global CH_4 concentrations is increased biogenic emissions, mostly from agriculture. Other sources, including emissions from the use of fossil fuels, have also increased.

COMPARISION OF FUEL TYPES

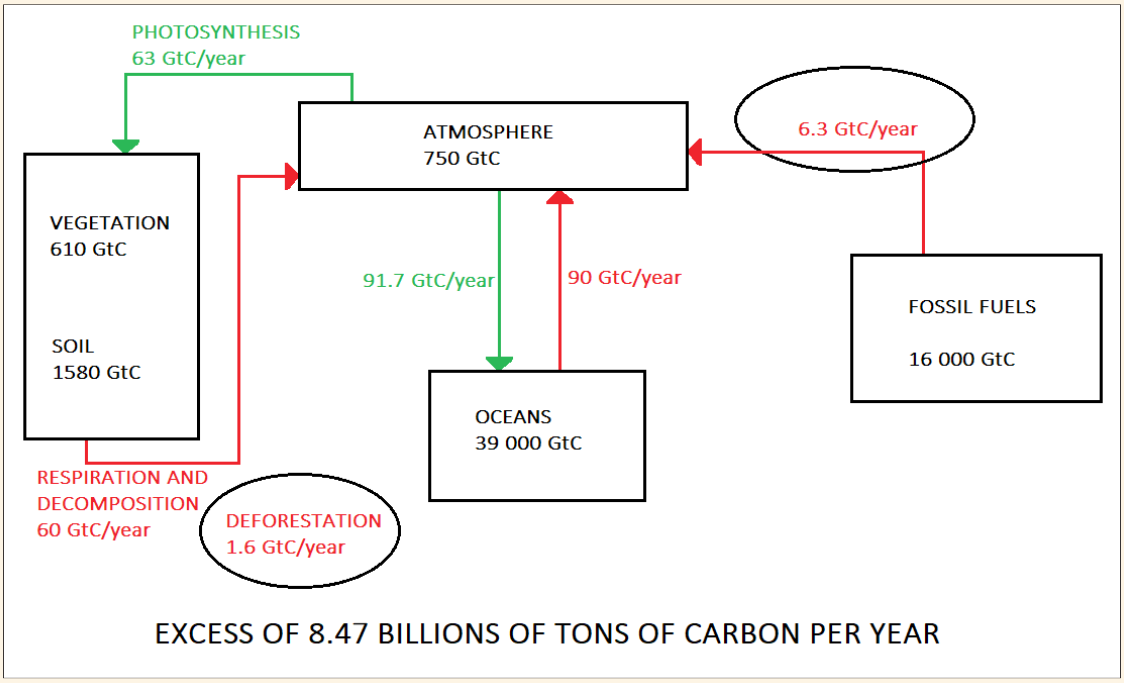
Emission of pollutants in incoming energy units in small domestic sector installations

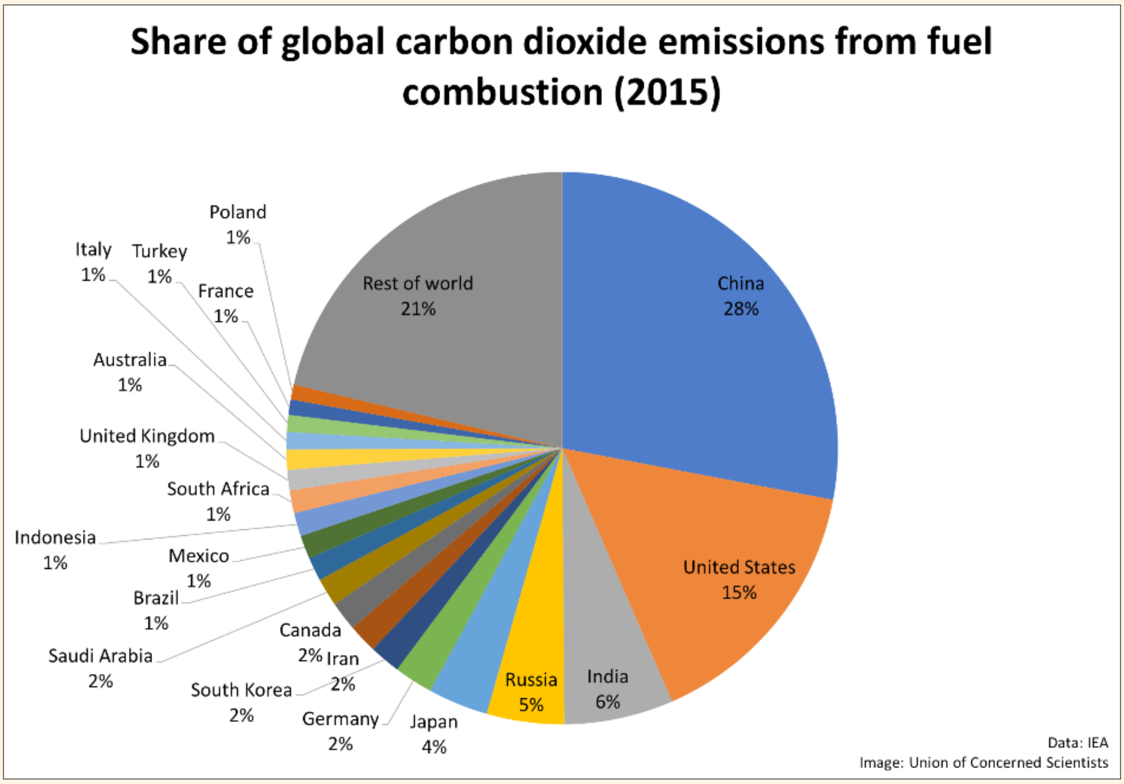
	Coal	Heavy fuel	Domestic fuel	Natural gas	Wood
Sulphur dioxide / SO_2 (g/GJ)	623	**885**	95	0.5	20
Nitrogen oxides / NO_x (g/GJ)	50	**170**	50	50	50
Non-methane volatile organic compounds / COVNM (g/GJ)	15	3	3	2.5	**1522**
Carbon monoxide / CO (g/GJ)	500	15	40	25	**6417**
Dust / (g/GJ)	150	24	15	0	**358**
Dioxin / ng/GJ)	**385**	5	0	0	100
Polycyclic Aromatic Hydrocarbons PAHs / (µg/GJ)	1150	5	0	0	**328 000**

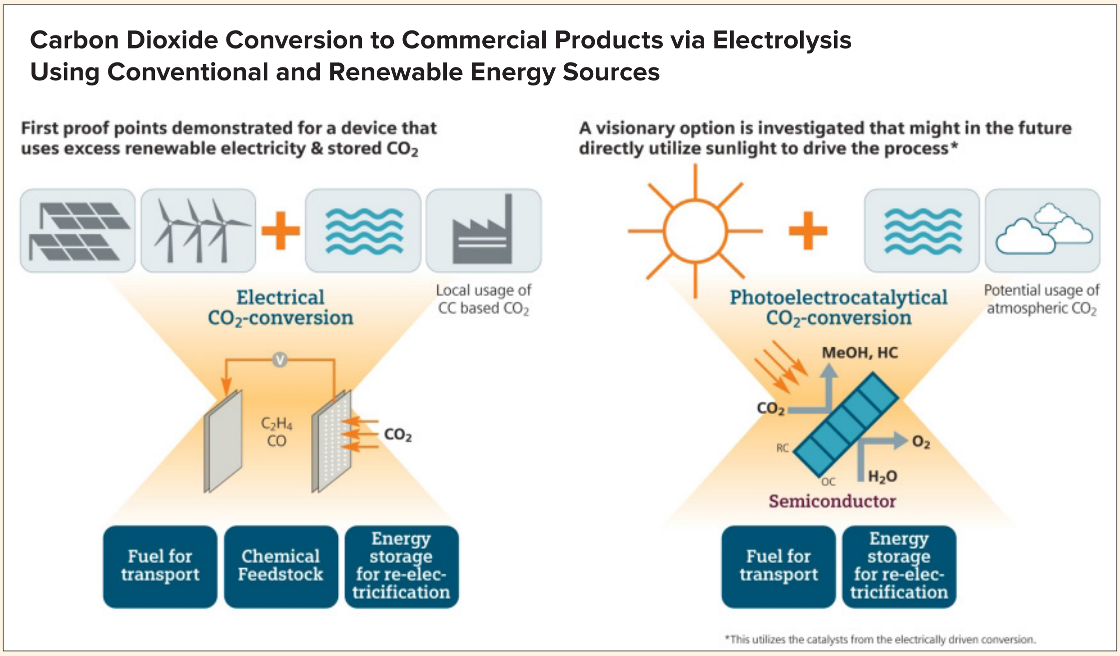
Source: CITEPA, 2003. GJ= Gigajoule

Globally, natural gas is the cleanest fuel type, whichever pollutants are taken into account. At the other extreme, the carbon footprint of wood is far from being neutral, despite being 'natural'.

WORLD BALANCE OF CO_2



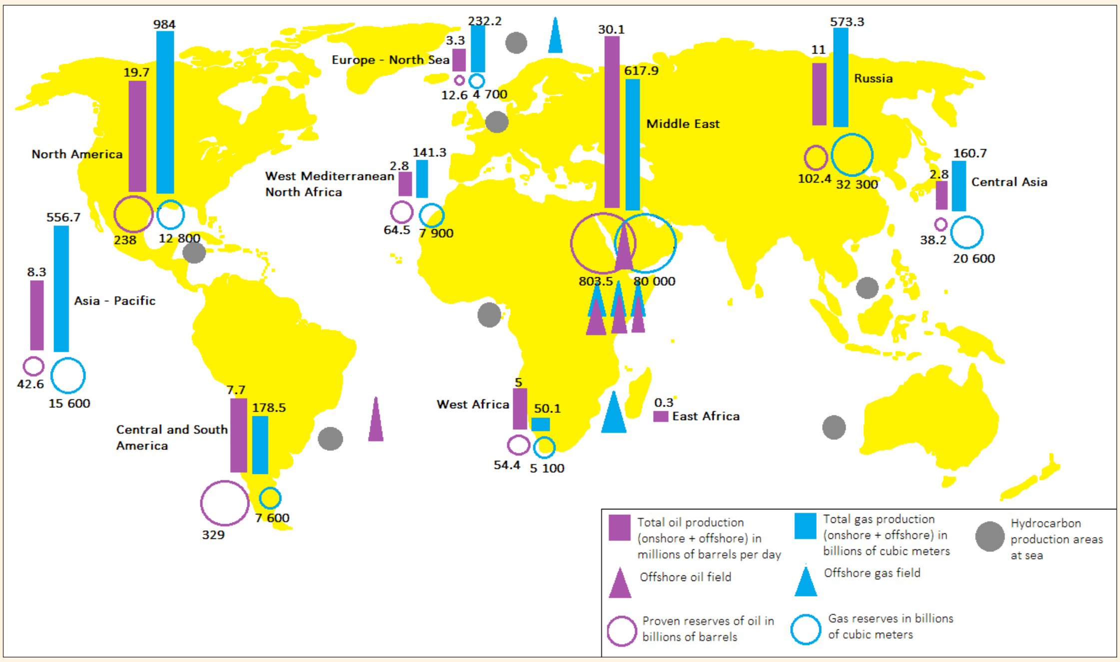




Source: Siemens

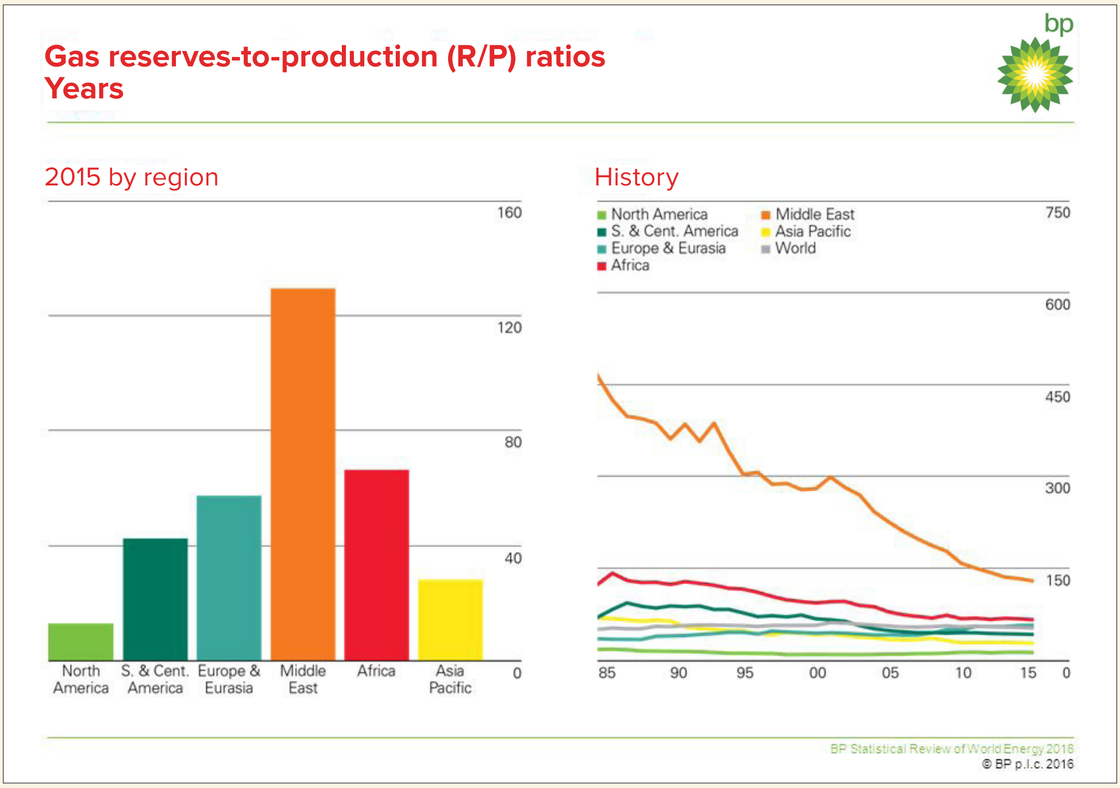
FOSSIL FUELS

Current production



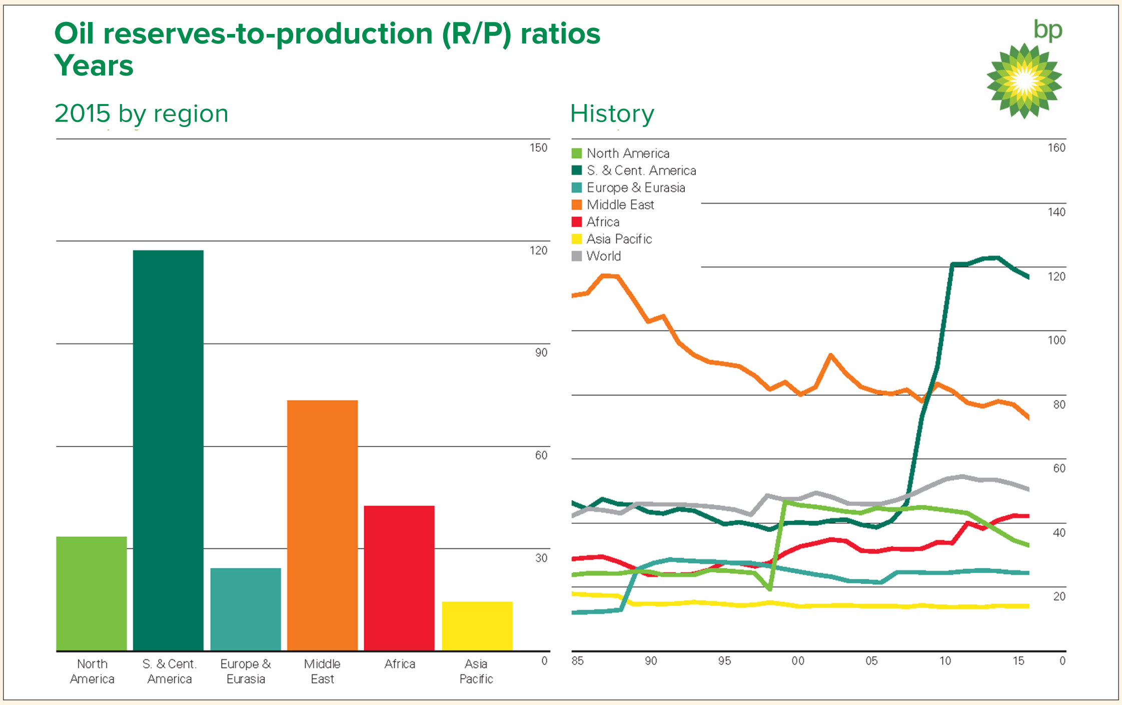
Source: BP Statistical Reviews of Energy, 2016

Global proven gas reserves



Source: BP Statistical Reviews of Energy, 2016

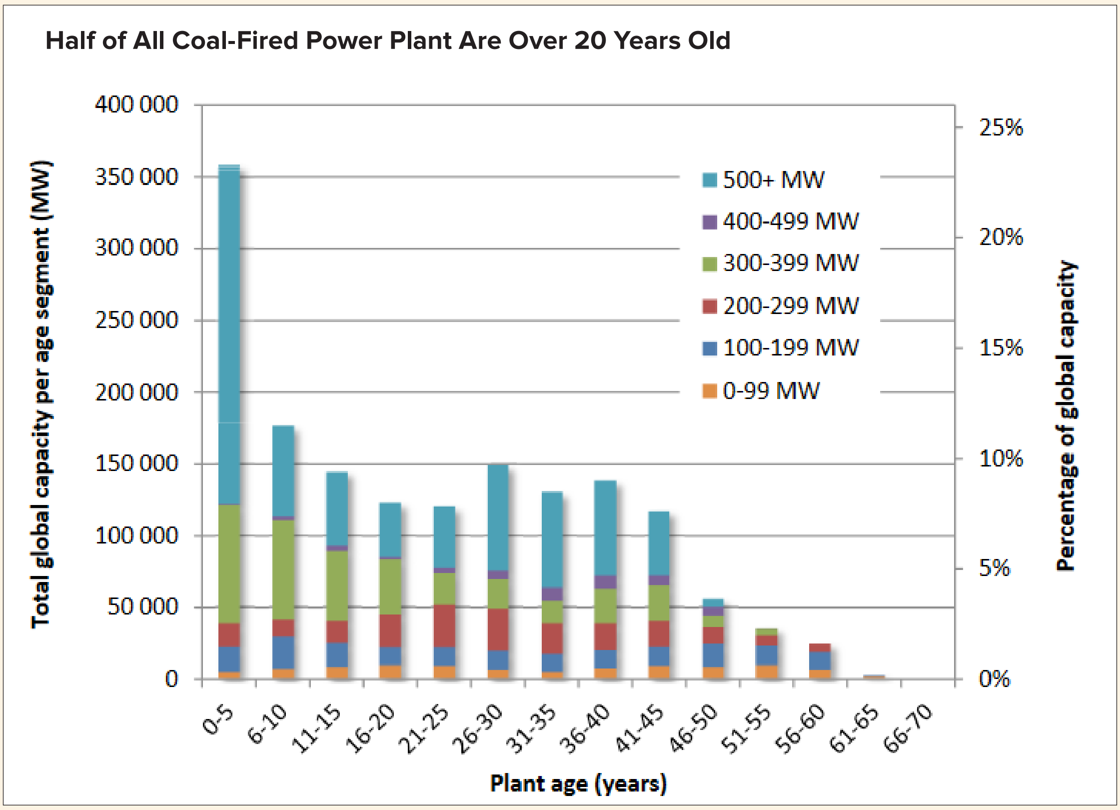
Global proven oil reserves



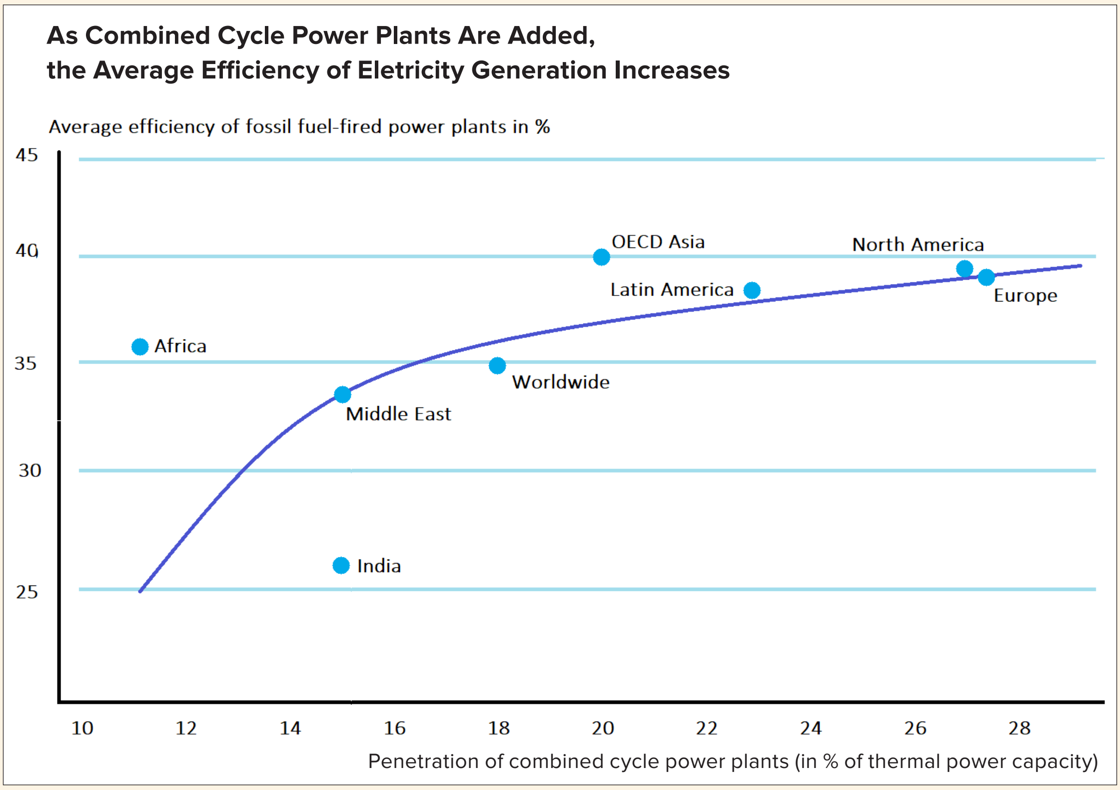
Source: BP Statistical Reviews of Energy, 2016

TURBINE EFFICIENCY

There is enormous potential to reduce coal consumption by doubling turbine efficiency (from 25% to 55%) using new materials

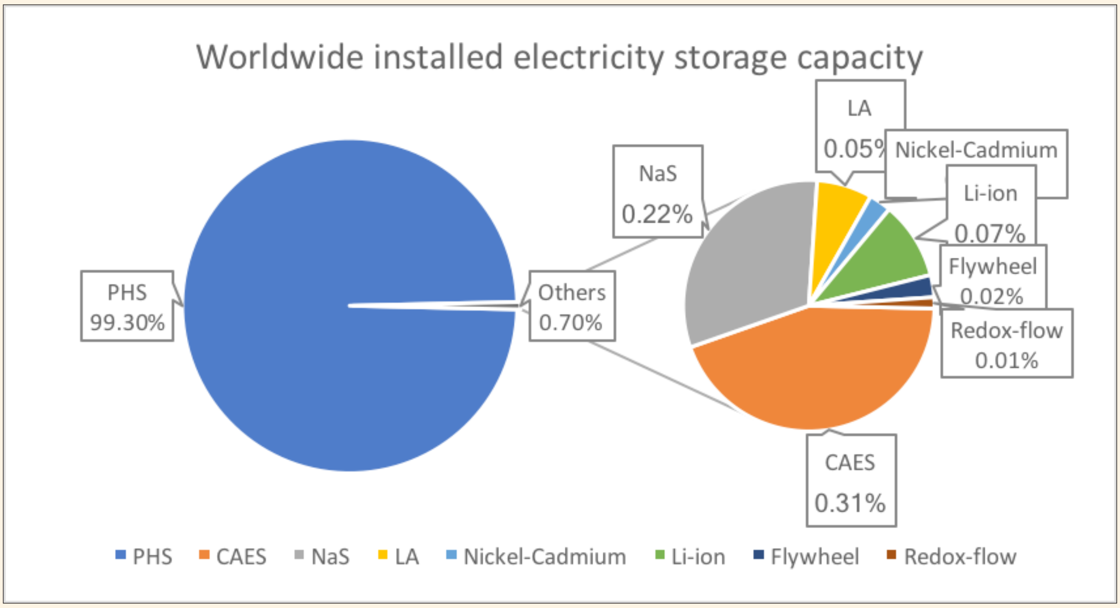


Source: International Energy Agency, 2012



Source: Enerdata, 2009

HIGH POWER ELECTRICITY STORAGE: NOT SOLVED!



Source: IEA Analysis, 2010

ELECTRICITY STORAGE TECHNOLOGIES – TECHNICAL PERFORMANCE

Type	Maturity stage	Typical Power output (MW)	Response time	Efficiency (%)	Lifetime (years)	Lifetime (cycles)
Pumped hydro	Mature	100 – 5,000	Sec-min	70-85	30 – 50	20,000 – 50,000
Hydrogen	Demonstration	100 – 500	Min	< 40	10 – 30	n.a.
CAES	Deployed	100 – 300	Min	50 – 75	30 – 40	10,000 – 25,000
Flywheel	Deployed	0.001 – 20	< Sec-Min	85 – 95	20 – 30	> 50,000
Li-ion battery	Deployed	0.001 – 5	Sec	80 – 90	10 – 15	5,000 – 10,000
NaS battery	Deployed	1 – 200	Sec	75 – 85	10 – 15	2,000 – 5,000
LA battery	Deployed	0.001 – 200	Sec	65 – 85	5 – 20	> 10,000
VRB	Deployed	0.001 – 5	Sec	65 – 85	5 – 20	> 10,000
SMES	Demonstration	< 10	< Sec	90 – 95	20	> 30,000
Supercapacitator	Demonstration	< 1	< Sec	85 – 98	20 – 30	> 10,000

Source: IEA Analysis, 2010

Type	Investment cost Power (USD/kW)	Investment cost Energy (USD/kWh)	O&M costs per year (% of investment cost)	Discharge
Pumped hydro	500 – 4,600	30 – 200	1	Hours
CAES	500 – 1,500	10 – 150	4-5	Hours
Hydrogen	600 – 1,500 (electrolyser) and 800 – 1,200 (CCGT)	10 – 150	5	Min
Li-ion battery	900 – 3,500	500 – 2,300	3	Min-hours
NaS battery	300 – 2,500	275 – 550	5	Hours
LA battery	250 – 840	60 – 300	5	Hours
VRB	1 000 – 4,000	350 – 800	3	Hours
Flywheens	130 – 500	1,000 – 4,500	n/a	Min
SMES	130 – 515	900 – 9,000	n/a	Min
Supercapacitator	130 – 515	380 – 5,200	n/a	Sec-min

Source: IEA Analysis, 2010

ENERGY STORED BY VARIOUS FUELS

The main challenge in the field of energy is:

How can we manage energy storage?

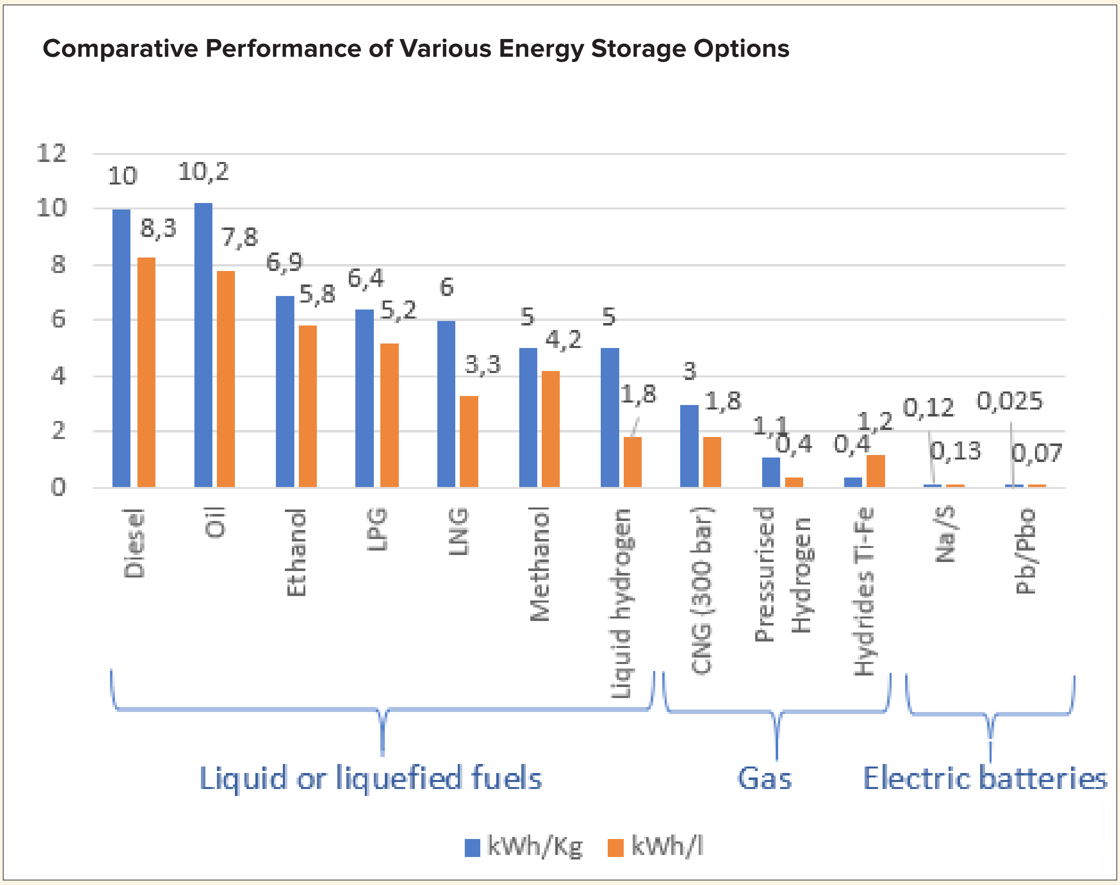
Just an example:

60 Kg of battery = 15 KWh max

60 Kg of syndiesel = 660 KWh

Source: Daimier-Benz

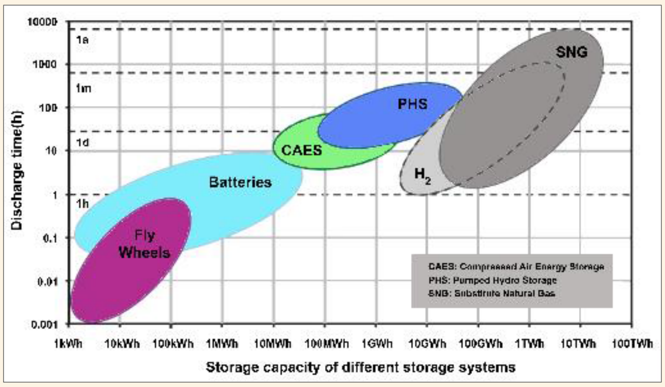
ENERGY STORED PER Kg FOR LIQUID, GAS OR BATTERY



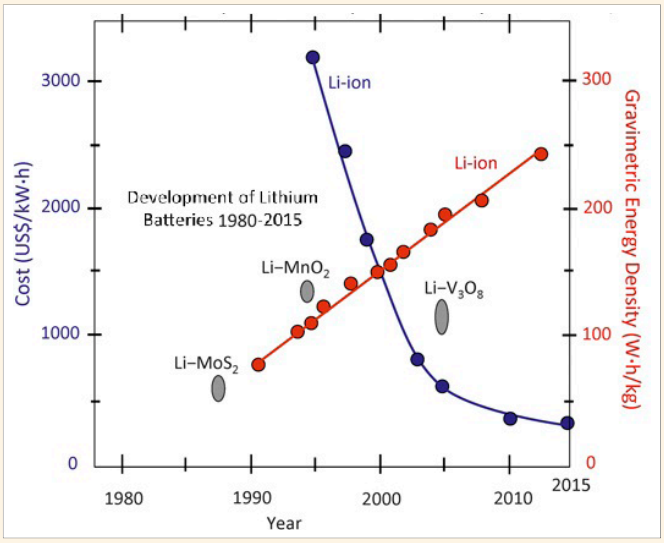
Source: Daimier-Benz

ENERGY STORAGE FOR CARS

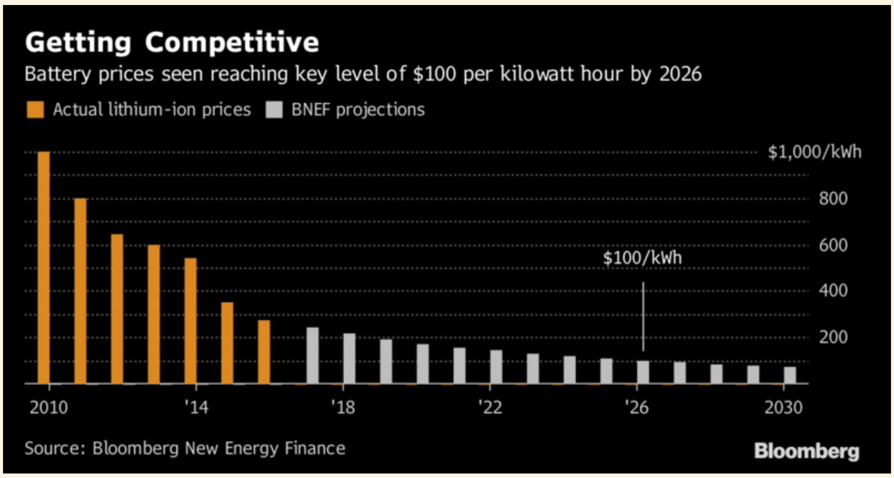
German Federal Minister of Education and Research J. Wanka filling up the gas tank of her service car with synthetic fuel prepared by recycling CO_2 (splitting water and CO_2 with green electricity and an adequate catalyst)



Direct storage of electricity is still very limited in batteries. Gas or liquid offers a much better solution today.



Evolution in recent years of the cost per kW h for Li batteries and gravimetric storage capacity. The cost remains high.



Expected evolution of the cost of batteries as expected by Bloomberg.

ENERGY OR FOOD

WATER REQUIREMENT FOR ENERGY PRODUCTION (L/MWh)

	Petroleum extraction	10 – 40
	Oil refining	80 – 150
	Coal integrated gasification combined cycle	950
	Natural gas combined cycle power plant	200 – 3,000
→	Nuclear power plant closed loop cooling	950
	Geothermal power plant close loop tower	1,900 – 4,200
	Enhanced oil recovery	7,600
	Nuclear power plant open loop cooling	94,000 – 277,000
	Corn ethanol irrigation	2,270,000 – 3,670,000
→	Soy bean biodiesel irrigation	13,900,000 – 27,900,000

Source: 23/10/09 P516 Science, vol. 326

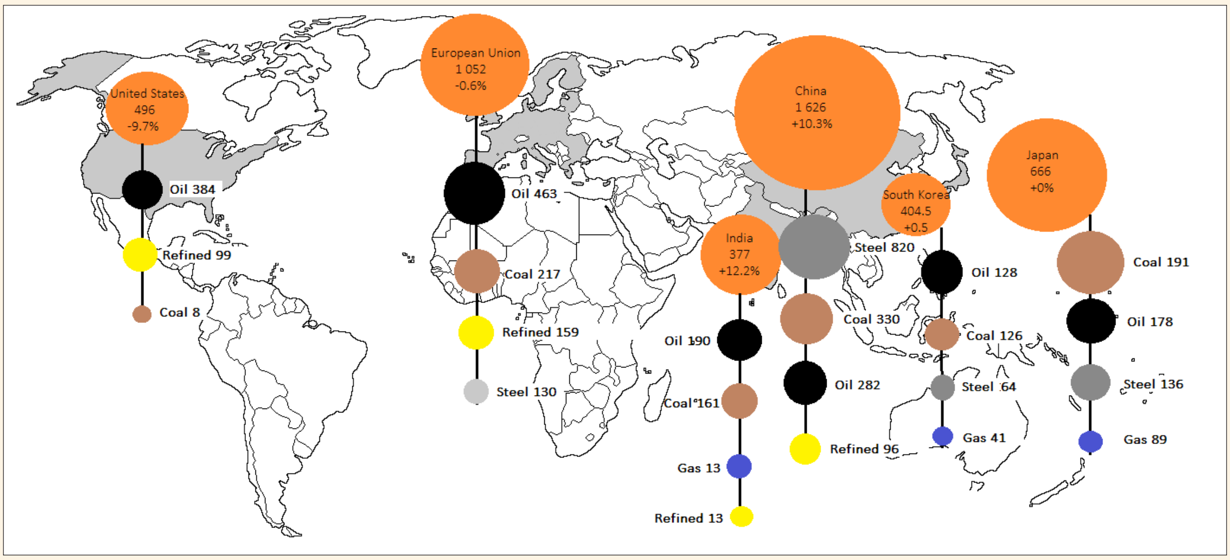
ANNUAL BIOFUEL PRODUCTION AND ENERGY CONVERSION EFFICIENCY BY PHOTOSYNTHETIC ORGANISMS AND ELECTRICAL ENERGY PRODUCTION BY A PHOTOVOLTAIC CELL

Oil Producer	Fuel Production [kg/(ha year)]	Energetic Equivalent [kWh/(ha year)]	ECE (%)
Oil palm	3,600 – 4,000	33,900 – 37,700	0.16 – 0.18
Jatropha	2,100 – 2,800	19,800 – 26,400	0.09 – 0.13
Tung oil tree (China)	1,800 – 2,700	17,000 – 25,500	0.08 – 0.12
Sugarcane	2,450	16,000	0.08
Castor oil plant	1,200 – 2,000	11,300 – 18,900	0.05 – 0.09
Cassava	1,020	6,600	0.03
Microalgae	91,000	956,000	4.6
Si-based PV cell		3×10^6	14.3 (Efficiency)

Source : greenfuelonline.com

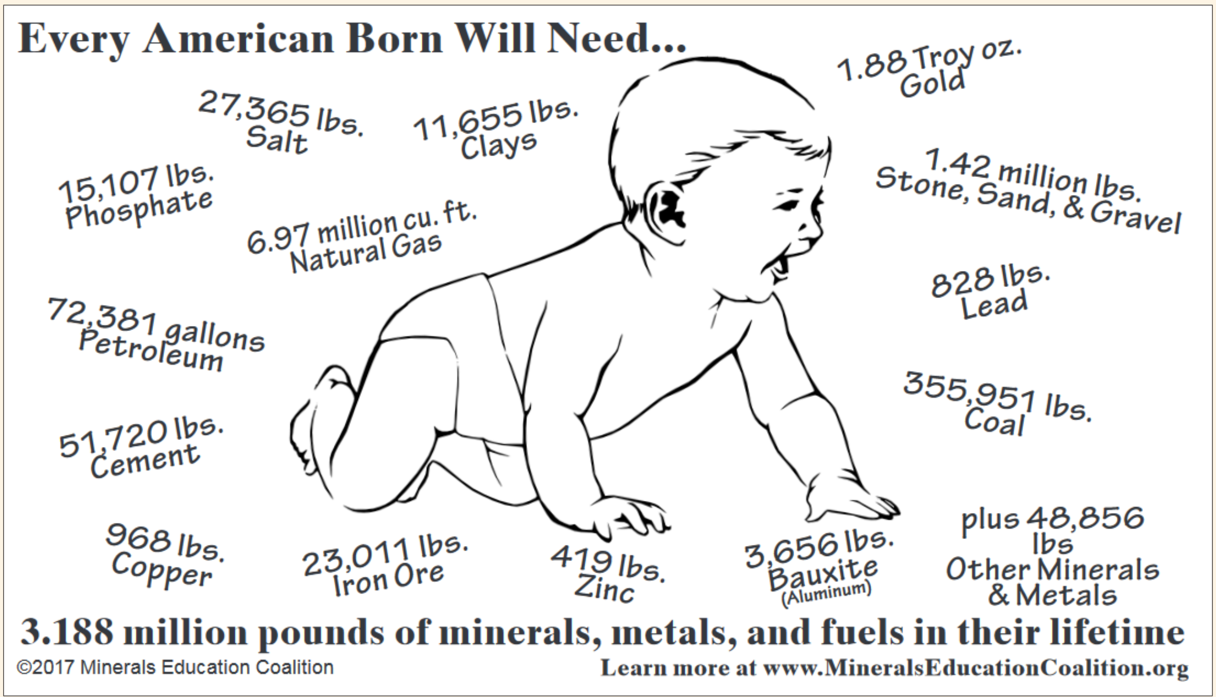
RAW MATERIALS

Worldwide import of raw materials



Source: ISEMAR (Institut Supérieur d'Economie Maritime)

Consumed raw materials in a lifetime for an advanced country (USA)

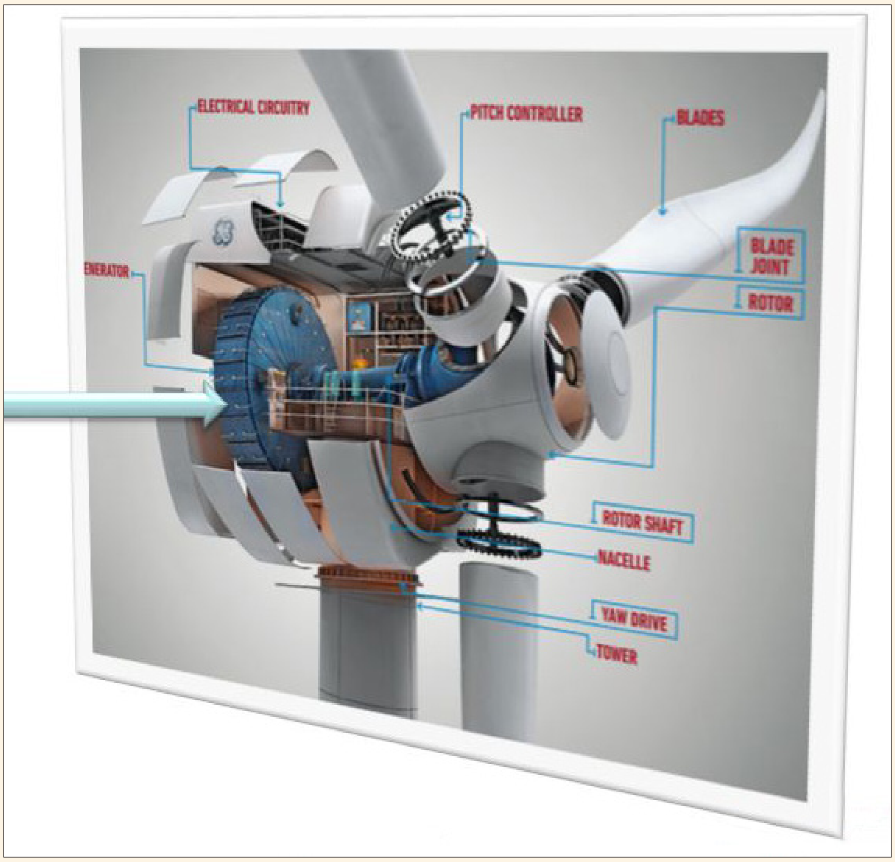


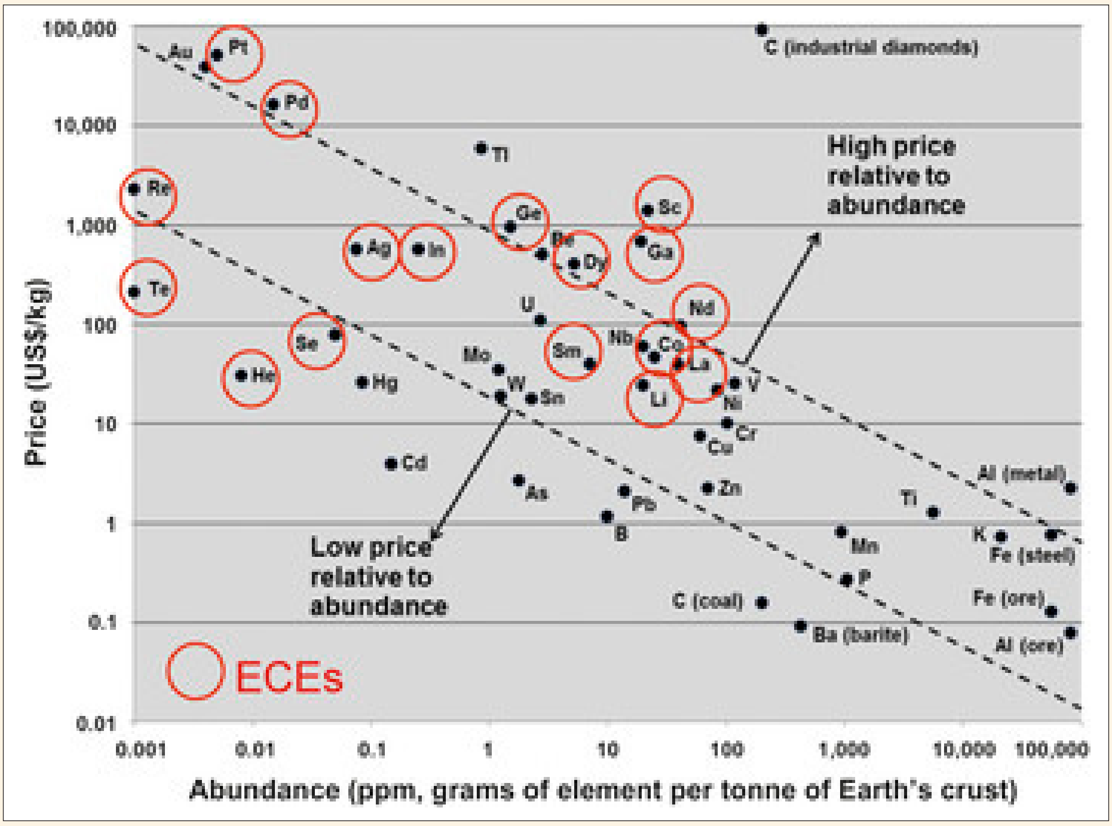
CRITICAL ELEMENTS: ABUNDANCE, NEED, COST

Magnets in wind turbines per MW installed:

Nd, Dy, Fe, B magnets about 600 Kg:

- 25 Kg Dy
- 185 Kg Nd





Source: US Geological Survey, US Energy Information

RECYCLING MATERIALS: AN ABSOLUTE NECESSITY

The most sophisticated high-performance materials may be the most difficult to recycle

Electrical waste

METAL	MAIN PRODUCERS	RECYCLING
Antimony	China (87%), Vietnam (11%)	28%
Bismuth	China (82%), Mexico (11%),	1%
Cobalt	DR Congo (64%), China (5%), Canada (%)	0%
Germanium	China (67%), Finland (11%), Canada (9%), USA (9%)	2%
Indium	China (57%), South Korea (15%), Japan (10%)	0%
Magnesium	China (87%), USA (5%)	9%
Niobium	Thailand (32%), Indonesia (26%), Vietnam (8%), India (8%)	1%
Scandium	China (66%), Russia (26%), Ukraine (7%)	0%
Tantalum	Rwanda (31%), DR Congo (19%), Brazil (14%)	1%
Tungsten	China (84%), Russia (4%)	42%
Vanadium	China (53%), South Africa (25%), Russia (20%)	44%
PGM (-Pd)	South Africa (83%)	14%
REE	China (95%)	< 5%

Source: European Commission, Critical Raw Materials, 2017

APPENDICES
A–F

APPENDIX A

Summary of Desired Automotive Materials Advances

(contributing editor J. R. Blizzard, E-MRS)

The auto industry today is reinventing the automobile using a new 'DNA' that will make our future vehicles more sustainable in terms of energy, the environment, safety, congestion, and affordability. This new automotive DNA depends on the development of key materials to encompass a range of technological solutions including:

- **Partial and full electrification of the propulsion system**
    - Batteries – durable, high-power energy cells capable of fast recharging and end of life battery remanufacture and reuse
    - Fuel cells – low-cost catalysts, high capacity hydrogen storage materials, reduced cost bipolar plates, and durable hydrophobic-hydrophilic coatings
    - Motors – low-cost, high-performance permanent magnets
    - Power electronics – reduced cost, efficient, solid-state power devices
    - Higher-conductivity wiring
    - Thermal management – improved low-temperature heat transfer materials and waste heat recovery materials
    - Durable, low-cost solar panels
    - 'Motion energy harvesting' materials
- **Energy from renewable sources**
    - Biofuels, preferably 'drop in'
- **Low-rolling-resistance tyres**
    - Aerodynamics
    - Low-cost 'smart materials' for exterior panels
    - Smart adaptive fibres to tailor stiffness to conditions
    - Durable, compatible matrix materials
- **Climate control**
    - Refrigerant alternatives
    - Localized heating-cooling solutions
    - Thermal management of the 'parked-car greenhouse'
- **Weight reduction**
    - Ambient temperature stamping of generation-3 advanced high-strength steel
    - Higher strength gear and shaft materials
    - Low-cost aluminium sheet
    - Thin-wall ferrous, aluminium and magnesium castings
    - Higher temperature aluminium and magnesium casting alloys
    - Low-cost carbon fibre composites
- **Low-cost carbon fibre, faster moulding, and recyclable end products**
    - Low-cost, adjustable, compliant seat materials
    - Mixed material joining technology
- **No-crash autonomous driving**
    - Reduced-cost sensors (radar, lidar, night vision)
    - 'Look ahead' road friction coefficient sensor
    - Durable reflective coatings for infrastructure
    - Self-cleaning 'sensor windows' for dirt and snow
    - Low-cost, high-bandwidth communication and processors

APPENDIX B

Editors, Organizers, Participants

SUMMIT INTERNATIONAL ADVISORY COMMITTEE

R.P.H. Chang	IUMRS (USA)
G.-C. Chi	Chairman TSGIA (Taiwan)
B.V.R. Chowdari	President MRSS (Singapore)
S. Das	MRSI (India)
H-U. Habermeier	Past President IUMRS (Germany)
Y. Ikuma	President MRSJ (Japan)
C. Jagadish	President AMRS (Australia)
E. N Kaufmann	Argonne N L (USA)
G. Kiriakidis	President E-MRS (Greece)
S.W. Lee	President IUMRS (Korea)
I. Manna	Director IIT Kanpur & President Institute of Metals (India)
J.G.C. Moreno	President MMRS (Mexico)
O.N. Oliveira, Jr.	President BMRS (Brazil)
A. (Y-M.) Peng	President MRST (Taiwan)
B. Raj	Director, National Institute of Advanced Studies (India)
W. Soboyejo	President MRSA (Africa)
H. Tu	Vice-President C-MRS (China)
F. Unger	President European Academy of Sciences & Arts (Austria)
G-Y. Yeom	President MRSK (Korea)
B. Wei	President C-MRS (China)
L. Zhou	Former President IUMRS

SUMMIT ORGANIZING COMMITTEE

J. Amouroux	E-MRS & University Paris VI (France)
J. Blizzard	E-MRS (France)
H. Fecht	Institute University Ulm & EUREKA (Germany)
Y. Han	Secretary General CMRS (China)
M. Hynes	President ESF (France)
R. Martins	Former President E-MRS & University Lisbon (Portugal)
J.R. Morante	E-MRS & IREC (Spain)
J.P. Massue	Former President E-MRS (France)
S. Pfister	E-MRS (France)
S. Schoeffter	E-MRS Administrative Director (France)
P. Siffert	Secretary General E-MRS / Chair (France)
M. Van de Voorde	Member Science Council French Senate and National Assembly
J. Williams	Vice President, Academy of Sciences (Australia)

ILLUSTRATION ATTRIBUTIONS (BY PAGE NUMBER)

Page	Topic	Source
Front cover	Atacama1	(*https://www.theguardian.com/environment/2015/dec/22/desert-tower-raises-chiles-solar-power-ambition-to-new-heights*)
Title page	Li-ion cell	M. S. Islam and C. A. J. Fisher, Chem. Soc. Rev., 2014, 43, 185-204
iv	"Climate Change" text block	🅭
iv	Globe-in-Hand ($\overline{c}$ Carlo Levi quotation)	G. Padeletti
iv	Evolution of Materials Chemistry	J.-M. Lehn
vii	Nuclear Power Plants	🅭 Creative commons
viii	Circular Economy "Loops"	S. Langkau
1	UN SDG Relationship Diagram	M. Zebaze-Kana
2	Elements of UK Strategy	J. Loughhead
3	Wind Power Growth	J. Loughhead
4	Transparent Bus	R. Martins
4	Roll to roll gravure printing	A. B. Holmes
4	Oxide Nanowires	R. Martins
4	Micro-factories for Waste	V. Sahajwalla
5	The Circular Economy	B. Friedrich
6	Electronic Waste by Country	V. Sahajwalla
6	Tyres in a Land Fill	V. Sahajwalla
6	e-Waste	V. Sahajwalla
7	Lithium Ion Batteries	G. Crabtree
8	Solar Refinery	J. R. Morante
10	Nanotip Arrays	Y.-L. Chueh
10	Aircraft Need for Advanced Materials	D. Furrer
10	Bastnäsit Ore	S. Langkau
11	End-of-Life Vehicles in China	D. Weng
12	Megacities	🅭 Creative commons
13	Taiwan's Green Energy Development Strategy	Y. Chen
13	Carbon Cycles	R.-A. Eichel
14	Transmission Towers	🅭 Creative commons
15	Electricity Access in Developing Countries	J. Martinez-Duart
15	Classical Solar Home Systems	J. Martinez-Duart
16	Flux-Grown Crystals	K. Teshima
16	CO_2 Catalytic Utilization (table)	Z. Ismagilov
17	Nanomedicine	O. N. Oliveira, Jr.
17	Energy Storage	H. Bolt
18	Copper Silicate Crystal	K. B. Yoon
18	Silicon Carbide	P. Wellmann

ILLUSTRATION ATTRIBUTIONS (BY PAGE NUMBER)

Page	Topic	Source
19	Ternary Diagram, Nozzle, Lander (composite image)	D. Hoffman
NG-4	Printed Circuit Board	V. Sahajwalla
NG-4	Ferrosilicon Alloy	V. Sahajwalla
NG-4	Desertification and deforestation	Y. Han
NG-5	The Carbon Dioxide Culprit	Z. Ismagilov
NG-5	Intelligent Grid and Advanced Metering	G.-C. Chi
NG-6	Nanomedicine	🅭 Creative commons
NG-8	“Magic Triangle”	H.-U. Habermeier
NG-9	Nano- Micro-	H. Fecht
NG-9	Foil Electronics	R. Martins
S-1 – S-16	All	in loc. cit. or 🅭
Various	Assorted illustrations and photographs of persons and venues	Staff or 🅭

SUMMIT PARTICIPANTS

AMOUROUX, Jacques	Université P.et M. Curie, Paris, France
BATTAINI-DRAGONI, Gabriela	Deputy Secretary General, Council of Europe, Strasbourg, France
BEGIN COLIN, Sylvie	IPCMS, University of Strasbourg, France
BIRICH, Alexander	IME-RWTH Aachen, and EIT KIC Raw Materials (assistant B Friedrich), Germany
BLIZZARD, John R.	31 Heath Road South, Locks Heath, Southampton, United Kingdom
BOLT, Harald	Member of the Board of Directors Forschungszentrum Jülich GmbH, Germany
BUZEK, Jerzy	President of the European Parliament (2009-2012), President of the Committee on Industry, Research and Energy (ITRE) of the European Parliament, Brussels, Belgium
CARROCCIO, Sabrina	Institute of Microelectronics and Microsystems (IMM), CNR, Catania, Italy
CHANG, R.P.H.	Director, Materials Research Institute, Northwestern University, Evanston, United States
CHEN, Yenhaw	Associate Director, Institute of Taiwan Economics Research, Taipei, Taiwan
CHI, Gou-Chung	Chairman Taiwan Smart Grid Industrial Association, Taipei, Tawan
CHUEH, YU-LUN	Department of Materials Science and Engineering, National Tsing Hua University, Hsinchu, Taiwan
CRABTREE, George W.	Joint Centre for Energy Storage Research (JCESR) Argonne National Laboratory (ANL) , United States
DEGUELDRE, Claude	Department of Engineering, Lancaster University, United Kingdom
DENEKEN, Michel	President, University of Strasbourg, France
EICHEL, Rüdiger. A.	Director Institute of Energy & Climate Research, (IEK-9): Fundamental Electrochemistry), Forschungszentrum Jülich, Germany
EWING, Rodney C.	Department of Geological Science, School of Earth, Energy & Environmental Science, Stanford University, United States
FALQUI, Luciano	Project Manager, SME PLASTICA ALFA Spa, Catania, Italy

FECHT, Hans-J.	Director Institute of Micro and Nanomaterials, University Ulm & EUREKA/ Metallurgy Europe Cluster Office, Ulm, Germany
FELDER -FLESCH, Delphine	IPCMS, Dept des Matériaux Organiques, Univ Strasbourg, France
FONTECAVE, Marc	Laboratoire de Chimie des Processus Biologiques & Collège de France, Paris, France
FORTUNATO, Elvira	Vice-Chair of the European High Level Group-SAM, CENIMAT-I3N, FCT-UNL, Caparica, Portugal
FRIEDRICH, Bernd	Director IME-RWTH Aachen, and EIT KIC Raw Materials, Germany
FURRER, David	Director, Manufacturing Technologies, Pratt & Whitney I Materials and Processes Engineering, East Hartford, United States
FU, Lan	Research School of Physics and Engineering, Australian National University, Canberra, Australia
GRIMMEISS, Hermann	Past President E-MRS, University of Lund, Solid State physics, Sweden
GUTIERREZ WING, Claudia E.	President of NRS Mexico, Instituto Nacional de Investigaciones Nucleares, Depertamento de Tecnoklogia de Materiales, Ocoyoacac, Mexico
HABERMEIER, Hanns-Ulrich	Science Consulting International, Guest at Max-Planck Institute, Former President of IUMRS, Stuttgart, Germany
HAGELÜKEN , Christian	Director EU Government Affairs, UMICORE AG & Co KG, Hanau, Germany
HAN, Yafang	Secretary General, C-MRS, Beijing, China
HOFMANN, Douglas C.	NASA Jet Propulsion Laboratory, California Institute of Technoogy, Pasadena, United States
HOLMES, Andrew Bruce	Fellow BIO21 Institute, University Melbourne, President of the Academy of Sciences, Parkville, Australia
HYNES, Martin	President, European Science Foundation, Strasbourg, France
ISMAGILOV, Zinfer	Director Institute of Coal Chemistry and Materials Science, Kemerovo, Russia
JAEGER, Wolfgang	Institute for Materials Science, Christian-Albrechts-University, Kiel, Germany
JAGADISH, Chennupati	President A-MRS, Research School of Physics and Engineering, Australian National University, Canberra, Australia
KAUFMANN, Elton N.	Former President MRS, Argonne Emeritus Scientist, Argonne National Laboratory, United States
KIM, Jong-Min	Department of Engineering, Electrical Division, University of Cambridge, United Kingdom
KIRIAKIDIS, George	President E-MRS, IESL/FORTH & University of Crete, Heraklion, Greece
KLEIBER, Michal	Former Minister of Research and President of the Polish Academy of Science, Institute of Fundamental Technological Researchof Polish Academy of Science, Warsaw, Poland
KOSER, Ole	Center of Excellence Manager, Casting & Metallurgy, ESI Group, Calcom ESI SA, Saint-Sulpice, Switzerland
KURZYDLOWSKI, Kryzstof	Materials Design Division, Faculty of Materials Science & Engineering, Warsaw University, Poland
LANGKAU, Sabine	Competence Center Nachhaltigkeit und Infrastruktursysteme Fraunhofer-Institut für System- und Innovationsforschung ISI, Karlsruhe, Germany
LEE, Soo Wohn	President of IUMRS, Sun Moon University, Chungcheongnam-do, South Korea
LEHN, Jean-Marie	Nobel Laureate in Chemistry, ISIS, University of Strasbourg, France
LEWANDOWSKA, Małgorzata	University of Technology, Warsaw E-MRS, Poland

LIU, Kai	Changchun Institute of Applied Chemistry, Chinese Academy of Science, China
LIZ, Jorge	Coordinator Network Projects, Clustes & Umbrellas, EUREKA Secretariat, Brussels, Belgium
LOEFFLER, Beat	CEO CLINAM Foundation, Basel, Switzerland
LOJKOWSKI, Witold	Head Laboratory of Nanostructures, Institute of High Pressure Physics, Polish Academy of Science, Warsaw, Poland
LOUGHHEAD, John	Chief Scientist Advisor and Director General, Department of Business Energy and Industrial Strategy, London, United Kingdom
MARTINS, Rodrigo	Past President E-MRS & University Lisbon, Portugal
MASSUE, Jean-Pierre	E-MRS past President, Member of the Senate of the European Academy of Science and Art, Paris, France
MICHAELIS, Diana	IME-RWTH Aachen, and EIT KIC Raw Materials (assistant B Friedrich), Aachern, Germany
MOEDAS, Carlos	European Commissioner for Research, Science and Innovation, European Commission, Brussels, Belgium
MORANTE, Joan Ramon	E-MRS Ex. Com & IREC, Catalonia Institute for Energy Reserch, Sant Adrià del Besos, Spain
OLIVEIRA Jr., Oswaldo N.	Istituto de Fisica de Sao Carlos, Universidade de Sao Paolo, Sao Carlos, Brazil
PADELLETTI, Giuseppina	ISMN – CNR, Roma, Italy
PAN, Fusheng	President Chongqing Academy of Science & Technology, Director National Engineering Research Centre for Magnesium Alloys, Chongqing University, China
RAJ, Baldev	Director National Institute of Advanced Studies, Bengalore and former President of the Academy of Engineering, New Delhi, India
SAHAJWALLA, Veena	Director Centre for Sustainable Materials Research & Technology (SMART), university of New South Wales (UNSW), Sidney, Australia
SAMORI, Paolo	Laboratory of Nanochemistry, ISIS, University of Strasbourg, France
SIFFERT, Paul	E-MRS Secretary General, Strasbourg, France
SMITH, George	Tiokamak Energy Ltd, United Kingdom
SRIRAM, Sharath	School of Engineering, RMIT University of Melbourne, Australia
TAUB , Alan	Director College of Engineering, University Michigan, Ann Arbor, United States
TESHIMA, Katsuya	Director, Center for Energy & Environmental Science, Department of Materials Chemistry, Shinshu University, Nagano, Japan
TORRES GUERRA, Leticia M.	Facultad de Ingenieria Civil, Departamento de Ecomateriales y Energia, UANL, Mexico
VAN DE VOORDE, Marcel	Amsterdam, The Netherlands
WAGNER, Friedrich	Past Pressident, European Physical Society, Greifswald, Germany
WELLMANN, Peter	Materials Department 6, Electronic Materials & Energy Technology University of Erlangen-Nürenberg, Germany
WANG, Yibo	National science & technology Smart Grid Key Technology Research & Development (A), Chinese Renewable Energy Society Photonics, Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing, China
WENG, Duan	School of Materials Science 1 Engineering, Tsinghua University, Beijing, China

WANG, Min	School of Materials Science 1 Engineering, Tsinghua University, Beijing, China
YOON, Kyung-Byung	Korea Center for Artificial Photosynthesis, Department of Chemistry, Sogang University, Seoul, South Korea
ZEBAZE KANA, Martiale G.	Chief of Section Capacity Building in Science and Engineering, UNESCO, Paris, France
ZHANG, Tao	Vice-President, Academy of Science, Beijing, China
ZHENG, Yongtao	Stat Key Laboratory of Rare Earth Resource Utilization, Changchun Institute of Applied Chemistry, Chinese Academy of Sciences, Changchun, China
ZSCHECH, Ehrenfried	Past President FEMS, Director Fraunhofer-Institut for Ceramic Technologies and Systems (IKTS), Dresden, Germany
ZOZ, Henning	President & CEO, ZOZ GmbH, Wenden, Germany

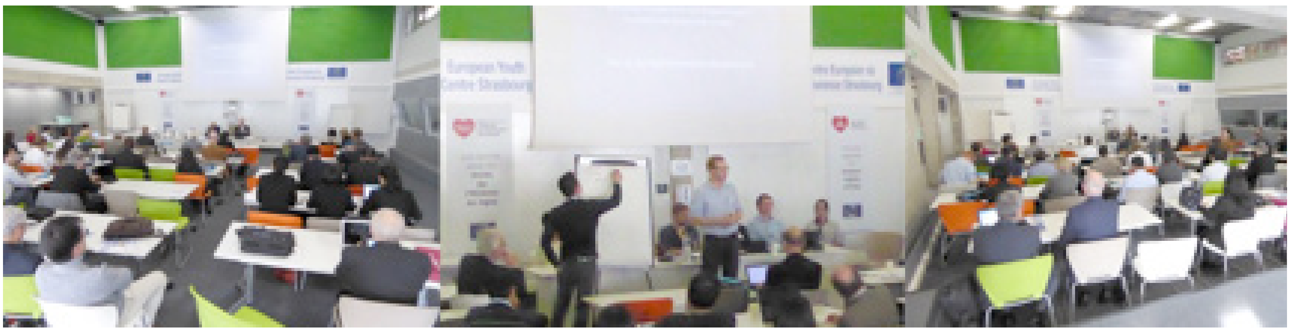
FORUM ORGANIZERS

Baldev RAJ	National Institute of Advanced Sciences, Bangalore (India) – Chairman
Jacques AMOUROUX	Université P. et M. Curie, Paris (France) & E-MRS – Scientific Co-ordinator
Hans FECHT	University of Ulm (Germany) & EUREKA/Metallurgy
Lan FU	Australian National University, Canberra (Australia)
Yafang HAN	BUAA, Beijing (China)
Martin HYNES	ESF President, Strasbourg (France)
Elton KAUFMANN	Argonne National Laboratory, Argonne (USA)
Malgorzata LEWANDOWSKA	WUT, Warsaw (Poland) & E-MRS
Rodrigo MARTINS	Uninova, Lisbon (Portugal) & E-MRS
Juan R. MORANTE	Director IREC, Barcelona (Spain) & E-MRS
Sharath SRIRAM	RMIT University, Melbourne (Australia)
Peter WELLMANN	University of Erlangen (Germany) & E-MRS
Jim WILLIAMS	Vice-President, Academy of Sciences, Australia

FORUM LECTURERS

Giuseppina Padeletti
Juan R. Morante
Jacques Amouroux
Baldev Raj
Rodney Ewing
Lan Fu
Osvaldo N. Oliveira, Jr.

Veena Sahajwalla
Yafang Han
Zinfer R Ismagilov
Gou-chung Chi
Hanns-Ulrich Habermeier
Hans-Jürgen Fecht
Rodrigo Martins



APPENDIX C

Citations to Forum Participants' Work

NEXT-GENERATION RESEARCHERS & THEIR RESEARCH TOPICS/POSTERS

(Reference list to *Voice of Next Generation Researchers towards Building a Sustainable Society*, page NG-10)

1. Ranjith Ramadurai, "Functional nano-composites, thin films and devices", Department of Materials Science and Metallurgical Engineering, Indian Institute of Technology Hyderabad, India.
2. Rui Ran, "High-surface-area MnO2-based nano oxides with enhanced low-temperature catalytic activity for automotive emission control", School of Materials Science and engineering, Tsinghua University, Beijing, China.
3. Jampaiah Deshetti, "Oxygen vacancies enhance the photoactivity of stable Cu2O", School of Science, Royal Melbourne Institute of Technology, Australia.
4. Chengjun YU, "TEM Tomography Studies on Cubic Copper Oxide Nanoparticles Cycled at Different C Rates", Department of Microsystems, University College of Southeast Norway, Norway.
5. Jiangfeng Song, "Hot tearing of Mg-Ca binary alloys", Chongqing University, China.
6. G.V. Prasad Reddy, "Mechanical Properties of Advanced Materials for Future Energy Systems", Materials Development and Technology Division, Indira Gandhi Centre for Atomic Research, India.
7. Pierre Denis, "Nanostructured metallic glass thin films", Ulm University, Institute of micro and nanomaterials, Germany.
8. Eduardo G. Cividini Neiva, "Graphene-based nanocomposites applied in energy storage", Department of Chemistry, University of Blumenau, Brazil.
9. Matilde Eredia, "Morphology and electronic properties of electrochemically exfoliated graphene", Université de Strasbourg, Institut de science et d'ingénierie supramoléculaires (ISIS), France.
10. Gisele Amaral-Labat, "Sustainable catalyst support from kraft black liquor for application in direct ethanol fuel cells (DEFC)", Department of Metallurgical and Materials Engineering, University of São Paulo, Brazil.
11. Parinaz Akhlaghi, "Preparation and Characterization of Novel Nanomaterials for Biomedical Applications", University of Campinas, Brazil.
12. Martí Biset-Peiró, "CO_2 valorisation through plasma-catalysis renewable energy", Catalonia Institute for Energy Research (IREC), Spain.
13. Anirudh Sharma, "Slot-die coated polymer solar cells with interfacial materials processed using environmentally friendly solvents", Flinders Centre for Nanoscale Science and Technology, Flinders University, Adelaide, Australia.
14. Hailong YU, "Surface Chemistry and Nanostructure of Energy Material", Beijing National Laboratory for Condensed Matter Physics, Chinese Academy of Sciences, China.
15. Kassio Papi Silva Zanoni, "Chemical Concepts for Energy Conversion and Sustainability", Institute of Physics of Sao Carlos, University of Sao Paulo, Brazil.
16. Amartya Mukhopadhyay, "Li-ion batteries: from materials perspectives to cell development", Indian Institute of Technology (IIT) Bombay, India.
17. Michalis Charalampakis , "Transparent conductive materials group-overview of research activities", university of Crete, Greece.
18. Michael Simon, "Microtopography-based Friction Simulation", Daimler R&D Research Center Ulm & University Ulm, Germany.
19. Aurelien Lepoetre, "Development of Plasma Microreactors for Chemical Synthesis", Institut de Recherche de Chimie Paris Chimie ParisTech, France.

20. Muxina Konarova, “Super-compact chemical reactors for valorising flared gas”, The University of Queensland, Brisbane, Australia.
21. Inês Cunha, “Cellulose Ion Ecosticker applied as gate dielectric in paper electrolyte-gated transistors”, CENIMAT/i3N, Portugal.
22. Paul Grey, “Electrolyte and Paper Gated Transistors”, New University of Lisbon, Faculty of Science and Technology, Portugal.
23. Sebastian Schütt, “Direct Deposition of CdTe Sensor Layers on the Medipix2 Read-out Chip by MBE”, Freiburg Materials Research Centre (FMF), Albert-Ludwigs University, Germany.
24. Thais Nogueira Barradas, “Hydrogel based stimuli-responsive nanocarriers: Transdermal application of drugs for therapeutic use, Institute of Macromolecules (IMA)”, Federal University of Rio de Janeiro, Brazil .
25. Yanhua Cheng, “Synthesis and characterizations of clay/P(MEO2MA-co-OEGMA)/chitosam semi-IPN nanocomposite hydrogels”, Donghua University, Shanghai, China.
26. Yong Zhao, “Smart grids in China”, Institute of Electrical Engineering, Academy of Sciences China.

Three full articles were contributed by participants in the Forum for Next Generation Researchers. They are reproduced as appendices D, E, and F only in the online version of this report.

APPENDIX D

Details of current renewable energy technologies and the role of materials science in the context of energy are given in *Transition to Carbon-free Energy – A Comparison of Germany, Australia and India* (Michael Simon, Anirudh Sharma, G.V. Prasad Reddy, and Martin Hynes).

APPENDIX E

The role of nanocomposites in biomedical applications is described in *Nanocomposite Hydrogels and Their Therapeutical Potential* (Yanhua Cheng, Thaís N. Barradas, and Manjunatha Pattabi).

APPENDIX F

Smart grid perspectives are provided in *The Current Status of Smart Grid Development: Social, Political and Economic Perspectives* (Kassio Papi Silva Zanoni, Zhao Yong, and Pierre Denis).

WORLD MATERIALS SUMMITS

I. Lisbon, Portugal 2007, 4-5 October (Held under the auspices of: Portuguese European Presidency)
INTERNATIONAL COOPERATION IN MATERIALS RESEARCH:
Key to Meeting Energy Needs and Addressing Climate Change

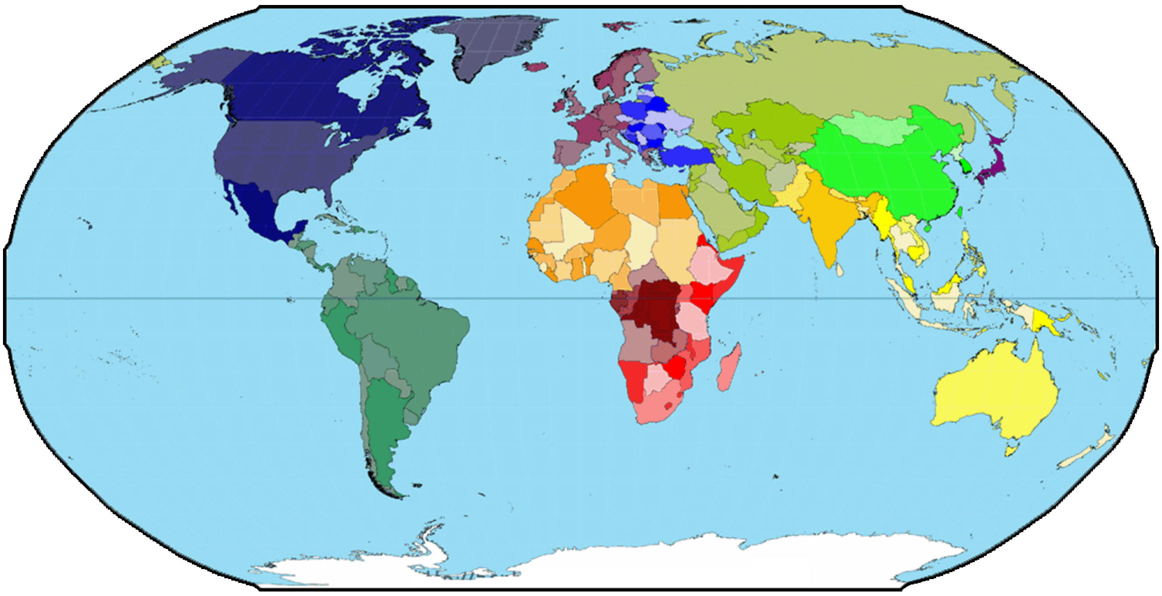
II. Suzhou, China 2009, 12-15 October
CREATE INTERNATIONAL COOPERATION TO ADDRESS ENERGY-RELATED MATERIALS SOLUTIONS

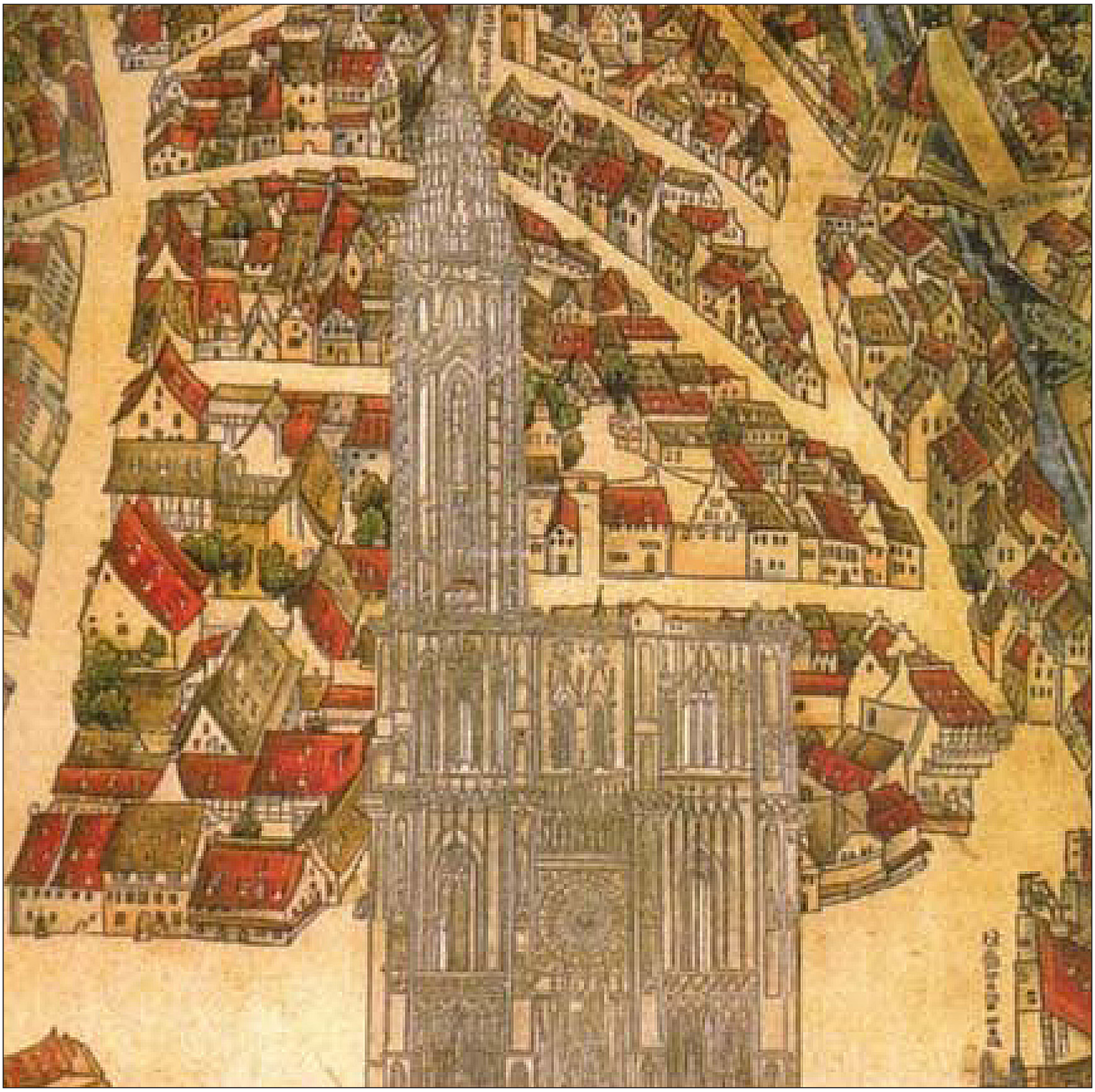
III. Washington DC, United States 2011, 9-12 October
MATERIALS RESEARCH ENABLING CLEAN ENERGY AND SUSTAINABLE DEVELOPMENT

IV. Strasbourg, France 2013, 12-15 October
MATERIALS: A KEY ENABLING TECHNOLOGY FOR SECURE ENERGY & SUSTAINABLE DEVELOPMENT

V. Rizhao, China 2016, 18-20 October
ADVANCED MATERIALS FOR SUSTAINABLE SOCIETY DEVELOPMENT

VI. Strasbourg, France 2017, 20-21 November
MATERIALS INNOVATION FOR THE GLOBAL CIRCULAR ECONOMY AND SUSTAINABLE SOCIETY





APPENDIX D

Transition to Carbon-free Energy – A Comparison of Germany, Australia and India

Michael Simon[a], Anirudh Sharma[b], Prasad Reddy G.V.[c], Martin Hynes[d]

[a] Daimler R&D Center, Wilhelm-Runge-Str. 11, Ulm, Germany & University Ulm, Institute of Micro and Nanomaterials, Ulm, Germany

[b] Flinders Centre for Nanoscale Science and Technology, Flinders University, Adelaide, SA 5042, Australia.

[c] Indira Gandhi Centre for Atomic Research, Kalpakkam-603102, TamilNadu, India.

[d] European Science Foundation, 67080 Strasbourg cedex, France.

1.0 INTRODUCTION

Over the past decades, the total primary world energy consumption (including transportation and electric energy generation) has increased rapidly. The energy supply being the key factor in balancing the economic development and growing population of many of the countries, the total primary energy supply (TPES) has been noticed to increase significantly from 102,569 TWh in 1990 to about 168,519 TWh in 2015.[1]

The early sources of power generation are mainly based on fossil-fuels coal, oil and gas that are being gradually and continuously phased-out with the introduction of renewable energy (RE) and carbon-free energy (CFE) sources in different countries. This has led the global energy industry on the verge of a third industrial revolution, largely being driven by the RE sources,[2] where RE technologies constitute more than 50% of all the new power plants built worldwide every year.[3] Although CFE techniques (solar, wind, hydro, geothermal and nuclear) have increased much in the last few years, their contribution for the worldwide TPES is nominal. The deployment of CFE techniques is critical due to the intrinsic attributes of carbon-based energy sources: the limitedness of carbon-based resources and evolving conflicts of controlling them, the negative impacts on the environment and global climate due to carbon-based emissions (e.g. CO_2). Although it is possible to achieve entire power generation based solely on CFE sources, it is limited by techno-socio-economic-policy issues specific to each country.

The report briefly outlines the current energy scenario, the CFE potential and its large-scale integration with the grid, followed by material issues to support the transition to carbon-free energy, for different exemplary countries (Australia, India and Germany).

2.0 CURRENT ENERGY SITUATION IN THE DIFFERENT COUNTRIES

To understand the differences and commonalities of the reviewed countries, a short introduction to the past and current energy market situation is given below.

2.1 Germany

Germany is the largest and economically strongest country of Europe. Due to this, its political influence on the European Continent is large and therefore it has a vanguard role concerning the European Energy market. Although the gross domestic product of Germany 2016 has increased by 50% compared to 1990, the primary energy consumption has decreased by 10%. Furthermore the amount of carbon-free energies in the primary energy consumption has been increased a lot regarding the last 10 years ([exxonmobile.de] 2015: 14.8% of primary energy consumption), but the main primary power sources are still oil (33.5%), natural gas (22.4%) and coal (22.7%). Nuclear energy has been reduced and is currently up to 5.5% of total primary energy consumption.

Germany has declared the so-called "Energiewende" – a national decision to completely overcome fossil and carbon-based energy sources and only rely on renewable energy sources in all three energy sectors (heat, electricity and transportation). In this context, Germany also decided to shut down all nuclear power plants in the next decades due to the negative qualities of nuclear power and nuclear waste (long-term storage, power plant accidents, radiation, etc.).

2.2 Australia

Australia has a wealth of energy resources (both renewable & non-renewable). So far, Australia's energy sector has been the backbone of its modern economy and is the basis of its growing stature as an energy superpower. Australia is one of the largest exporter of coal, uranium and LNG, contributing to earnings of $71.5 billion in 2013-14 and accounting for 7% of the Australian GDP.[3] By 2020, Australia's annual energy exports are expected to reach $114 billion, expected to further enhance job creation, higher income and improved living standard of the Australian community.[4] However, due to the abundant resources of coal and gas the current Australian energy sector is largely reliant on fossil fuels for Australia's primary energy consumption as well as for international trade, with coal being the biggest energy material exported globally . Till 2014-15, over 83% of electricity in Australia was still produced using coal and gas[5].

In order to respond to climate change, the Australian government plans to reduce Australia's total greenhouse gas emissions by 80% on 2000 levels by 2050.[7] Efforts are underway to increase the share of renewable energy technologies in particular wind and solar, to produce energy.

2.3 India

India is home to 1.324 billion people as on 26th Oct. 2017 i.e. about 17.74% of world's population. As on 30th September 2017, the total installed capacity of electricity generation amounts to about 322 GW, (Appendix 1, Fig.3) with more than 55% of generation based on coal. Renewables energies (bio-mass, solar, wind and small-hydro) account for 17.7% of the total installed capacity.[6] Unfortunately, India is not blessed with adequate natural resources of oil, gas, quality coal and uranium-235 and hence a large portion of these sources are imported. To decrease this dependency and also to limit the CO_2 emissions, India has been striving hard to deploy RE/CFE on a large scale for past few years. This is particularly evidenced in solar energy that has seen an increase in capacity from just 11 MW in 2011 to 13 GW in 2017 (September) and also in wind capacity from 23 GW in 2014 to 32.5 GW in 2017. The current installed capacity of hydropower (~ 49 GW, 95% of which is from large-hydro) is just a small % of its assessed resource. Currently, the share of nuclear energy in power generation is small amounting to an installed capacity of 6.78 GW from 22 operating nuclear power plants.

3.0 CARBON FREE ENERGY: POTENTIAL TO MEET GROWING ENERGY DEMANDS

Many countries, in particular India, cannot completely opt CFE (wind, solar, hydro, nuclear, geo-thermal and ocean tides/waves) for power generation due to the techno-socio-economic-policy issues coupled with high energy demand. This section shows the different potentials the considered countries have to meet growing global energy demand using carbon-free energies.

3.1 Germany

In the context of the Energiewende, the introduction of carbon-free energies in Germany is not only optionally but necessary to meet the national and international decision and promises Germany made in the past.
From the current point of view, one key to a complete emission free energy sector, an emission free electric energy sector is crucial. Here, only wind energy (onshore / offshore, in 2016 ca. 11.9% of electric energy mix [Bundeswirtschaftsministerium]) and photovoltaic (5.6%) have further development potentials. Water Power potentials (3.2%) are nearly outworn. From a current point of view, hydrogen technologies also have no important role in the German energy sector but may become important if further efficiency gains are achieved. For the transportation sector, a final emission-free (not oil-based) technology has not put through. From a current point of view, the most promising technologies are electric and hydrogen-based powertrains. Nevertheless, currently the so-called alternative drivetrains only play an unimportant role in Germany (e.g. in January 2017 completely electric driven cars <1% of total registered cars in Germany [Kraftfahrtbundesamt Germany]).

3.2 Australia

Australia is well placed to tap into the global renewable energy market and continue to be a one of the global energy power. Australia have an extensive range of renewable energy sources with large areas in Australia with average wind speed of 7 $msec^{-1}$, tidal energy of 1 GJ m^{-2} and above, geothermal energy with more than 3 km of sediment and temperature of over 200 °C at 5 km. Most importantly, Australia receives 58 million PJ of solar radiation annually, which is the highest average solar radiation of any continent,[7,8] which can be harvested using advanced photovoltaic and solar thermal technologies.

Currently, renewable sources contribute little over 2% of Australia's total energy production (Fig 4).[4] It is important to note that in order to achieve energy security via renewable technologies (which promises affordable, accessible and resilient power supply system with minimum carbon footprint), simultaneous development and application of energy storage technologies would be crucial, particularly in connecting remote off-grid areas, considering Australia's vast geographical size.

As the fleet of coal based power plants across Australia approach their lifetime and are due for large scale replacement in the next ten to twenty years,[9] smart investments in the renewable energy sector could be a massive opportunity to create new jobs and cleaner energy.

3.3 India

India has committed to reduce emissions by 33-35% below the 2005 levels by 2030. For this, CFE sources have been thoroughly explored, and the estimated potential is given in Table 1.0 (Appendix-1). The power requirement in 2022 is estimated at 434 GW of which India has set the target of generating 175 GW from RE sources (Small hydro:5 GW, Biomass:10 GW, Wind:60 GW, Solar: 40 GW rooftop photo-voltaic plus 60 GW of medium and large scale power plants (of both solar PV, concentrated solar power-CSP)).[10-12] CSP with storage technology (a viable option to meet both peak as well as base load power)‘ appears to be economical option compared to solar PV (that has installation cost and low commercial efficiency). India yet to build robust manufacturing base for solar cells and supporting instruments to materialize the full potential of Solar energy. Further, India need to scale down deploying large-size MW grid connected SPV and focus on decentralized solar applications in line with the global trend, in order to reduce the transmission and storage infrastructure. In view of the above, large scale projection of solar power appears to be reassessed [10]. The wind power expansion is technically feasible, as turbines up to capacities of 2.5 MW are being manufactured in the country, along with modern turbines based on permanent magnet generators. However, it is limited by land acquisition and competition from solar power. India has developed sufficient maturity in manufacturing of small hydro power equipment’s and thus the hydro target of 5 GW by 2022 appears to be achievable provided environmental clearance and public acceptance is granted. India is also benefitting from the joint capacity additions of hydropower with neighboring Bhutan and Nepal countries. The current nuclear capacity is very small and India has ambitious plans to expand its fleet by utilizing fertile fuel Thorium (as 25% of global reserves are in India) and by development of self sustainable advanced fast breeder reactors and several other nuclear technologies (e.g. fusion power). India has conceptualized the Th-based Nuclear reactor as a first of its kind in the world and plans to deploy commercially around 2030.

4.0 CHALLENGES IN LARGE SCALE INTEGRATION OF CARBON FREE ENERGY

Considering the three main energy sectors of a countries energy consumption, electric energy is probably one of the key factors and first major step if a transition to carbon-free energies shall be successful. Here, especially political considerations and the demands on the grid system of a country might be critical. Also here, the situation might be different in the single countries and cannot be generalized. Therefore, the situation in the three considered countries is outlined below.

4.1 Germany

The main challenges considering a carbon-free transition (see above: increasing solar and wind energy, shutting down nuclear power) in the German electrical sector are probably mostly based on political than technological issues. In the future, politics have not only to enforce the grid upgrade within Germany to get wind energy produced in the North to the consumers and heavy industries in the South but also have to further improve the integration of the German grid into a European-wide, digitalized energy grid including an intelligent load balance. In this respect, an European-wide energy market with new conditions has to be formed to promote renewable energies Europe-wide – in a manner all participating countries can conclude. From a technological point of view, especially new storage and grid stabilizing technologies have to be developed. Better storage technologies are also an important item considering the German transportation sector. As mentioned before, common combustion engines are currently dominating the market. Electric and emission-free driven transportation is negligible. Besides political considerations the main problem of especially current electric drive is the short range of battery-based cars and transportations. Here, better batteries will help to overcome consumer’s qualms and help promoting electric drivetrains.

4.2 Australia

Various studies have shown that a carbon-free transition in Australia by 2050 is not only feasible, but would also be economically beneficial.[9, 13] However, its realization faces various challenges such as difficulty in achieving a united policy due to overlapping jurisdiction and competing priorities of federal, state and local governments. In addition, unlike Germany, there is abundance of coal, gas and uranium in Australia making it relatively cheaper and cost competitive source of energy compared to their renewable counterparts. Other major challenges include policy uncertainty which negatively impact investments, technological immaturity & institutional inexperience and more importantly significantly large distance between major supply and demand centers, as evidenced by the losses of up to 11% in distances covered by Australian distribution and transmission networks.[7]

4.3 India

In India, the uneven distribution of energy sources (fossil fuel and CFE) and variability in CFE generation (solar and wind) causes fluctuations in the grid voltage and frequency, thereby posing major challenges to integration of CFE into grid, apart from challenges during transmission and distribution (reverse flow handling, frequency regulation, load balancing, security, etc).[14] The load balancing in the grid due to CFE variability is done by ramping up or down of the coal-fired plants in particular. However, the present coal plants operate at low load factors, and thus over-reliance on them would either lead to ramping down of coal plants to technical minimum level or curtailing of RE output.

In India, the day-ahead scheduling process forms the backbone of grid operation for optimum scheduling and dispatch of the electricity for the next day. Accordingly, forecasting methods are used to predict the demand and generation for the next day. This brings down the variability in CFE generation partially. India is also planning to build Green Corridors for transmission system strengthening and also to enable host states to supply surplus to neighboring states. Some of the other remedies to be implemented to balance 'demand and variable CFE generation' and thus CFE penetration: (i) decentralization of RE plants in small capacities over larger area, (ii) load balancing by conventional energy sources (large-hydro and gas, apart from coal), (iii) forecasting of demand and RE power, and (iv) efficient energy storage systems. Pumped hydro storage and battery-based storage (lead acid, Vanadium Redox batteries) are currently dominating in India.[15-16]

5.0 ROLE AND APPLICATIONS OF ADVANCED MATERIALS

Although the most important challenges considering the transition to a carbon-free energy usage are mostly political based, a technological progress can help and promote the transition to carbon-free, renewable energies. Besides the partially mentioned necessary grid technologies, the material research related topics can be divided in different groups:

Photovoltaic and Solar Thermal Technologies:

Polymer solar cells (PSCs) are a low-cost, reel-to-reel printable and flexible alternative to silicon based photovoltaics. These can be used for outdoor as well as indoor applications and its lightweight and portable nature opens up an array of new applications. Power conversion efficiency of 13% for PSCs have now being achieved taking it a step closer to its commercialization stage.

Advanced research in further developing high performing materials and processes to fabricate plastic solar cells via environmentally friendly solvents such as water will be a game changer, enabling large-scale industrial production of this technology making it accessible at low costs.

Materials research is underway around the world to further improve existing and develop new photovoltaic devices including but not limited to dye sensitized solar cells, inorganic thin film solar cells and lately perovskite solar cells. Nanomaterials such as carbon nanotubes, fullerenes, graphene, quantum dots, semiconducting nanoparticles and conducting polymers continuously play a significant role in the advancement of these solar technologies.

Advanced materials research is also desirable for further development of self-cleaning surfaces and coatings for solar thermal plants and development of new materials for high voltage cables to minimise energy losses during distribution and transmission.

Storage technologies:

Development of large-scale (grid storage) and small-scale (transportation) storage technologies. Here, not only battery technologies are important but also hydrogen-based technologies are important. More recently, pumped hydro energy storage has also attracted lot of research attention as a viable option in Australia, to balance the grid with power generated from solar and wind.

Hydrogen Technologies:

Improve the efficiency factor of the conversion of hydrogen to electric energy and vice versa. Improve storage technologies and reduce the energy necessary to condense the hydrogen gas.

Wind Energy:
In wind energy system, turbine blade is the heart of plant and the blade materials that have drawn maximum attention in recent times are Natural fiber reinforced bio-composites (called as green materials), Carbon nano-tube composites and Thermoplastic polymers.

Nuclear Power:
In a nuclear reactor, the utmost critical component is clad tube encapsulating the fuel. Due to low U-reserves in India, it has been decided to increase the residence time of fuel (to enhance fuel usage) which in turn demanded the development of advanced clad materials. Currently, India has been developing advanced Zr-alloys for water based reactors and Oxide dispersion strengthened alloys for Na-cooled fast breeder reactors. European Union and India has also developed Eurofer-97 and INRAFM steel respectively for the plasma blanket structure in Fusion reactors, in order to withstand intense neutron-irradiation and He embrittlement.

Improving carbon-based technologies:
As outlined above each of the considered countries has at least to bridge several decades using carbon-based energies to ensure and secure the energy needs of its citizens. Therefore material research related to cleaner carbon-based technologies is important to meet the global carbon emission aims.

Others:
Materials related to “Power-to-X” technologies to enable an efficient conversion from electric energy into storable materials like liquids or gases.

6.0 SUMMARY AND RECOMMENDATIONS FOR MATERIAL RESEARCH

In the present report, the current energy scenario and prospects to transition to carbon-free energy (CFE) are discussed for Germany, Australia and India. It is important to mention that fossil fuels (coal, gas oil) currently dominate the energy mix in all the three countries. However, in view of the negative environmental impacts (e.g. CO_2 emissions), all the three countries have drafted policy framework for a gradual transition to carbon-free alternatives to meet energy demands.

The above mentioned transition is required in the three important sectors: electricity, industry and transportation. Probably, one of the key and a major first step to a complete transition to CFE in all energy sectors is obviously the conversion of the electric sector. Here - besides the policy-based issues and subjects that may vary for each country - the integration of the fluctuating and unsteady energy production of renewable technologies and their match to the consumption demands is one essential issue. The need of a stable and digitalized grid, new and better kinds of large scale (electric sector) and small scale storages (transportation, e.g. electric drive concepts) are the difficulties that have to be overcome in all of the considered countries.

Seen from a material science related point of view, especially storage technologies need to further evolve. Besides this, the continuous improvement of all kinds of renewable energies (e.g. wind energy and solar energy) are important. Carbon-based technologies (especially coal in Australia, Germany; Coal and gas in India) are seen as bridge technologies in all the three countries and therefore should further be improved to ensure a more clean transition to carbon-free energies.

7.0 ACKNOWLEDGMENTS

The authors would like to thank the E-MRS and all associated organizations for hosting the Forum for Next Generation Researchers at the World Material Summit 2017 in Straßbourg. Furthermore they want to thank Prof. Dr. Michael Powalla from the Karlsruhe Institute of Technology and Enrico Lang from EnBW AG for patiently answering questions concerning the energy situation in Germany and Europe. Anirudh Sharma wishes to thank Flinders Centre for Nanoscale Science and Technology for financial support. Prasad Reddy would like to thank INAE, India for the travel support and Dr. Amarendra, Director MMG, IGCAR for the extended support and encouragement.

REFERENCES

[1] Statistical Review of World Energy, London, 2016. *https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html*

[2] Heinonen, S.; Karjalainen, J.; Ruotsalainen, J. Towards The Third Industrial Revolution; Finland Futures Research Centre: 2015.

[3] REN21 Renewables 2015 Global Status Report, Paris, REN21 Secretariat.

[4] Energy White Paper 2015; Department of Industry and Science, Government of Australia, 2015.

[5] Australian Energy Update 2016; Department of Inductry, Innovation and Science, Australian Government, 2016.

[6] All India Installed Capacity of Utility Power Stations as on 30th September 2017; *http://www.cea.nic.in/reports/monthly/installedcapacity/2017/installed_capacity-10.pdf*

[7] Byrnes, L.; Brown, C.; Foster, J.; Wagner, L.D. Australian renewable energy policy: Barriers and challenges. Renewable Energy 2013, 60, 711-721.

[8] Energy White Paper 2012; Australian Government, 2012.

[9] Teske, D.S.; Dominish, E.; Ison, N.; Maras, K. 100% Renewable Energy for Australia– Decarbonising Australia's Energy Sector within one Generation. Report prepared by ISF for GetUp! and Solar Citizens, March 2016.; Institute for Sustainable Futures, University of Technlogy Sydney, 2016.

[10] Manish Kumar Hairat, Sajal Ghosh, Renewable and Sustainable Energy Reviews 73 (2017) 1041–1050.

[11] 2017 Energy statistics, Ministry of statistics and programme implementation, Govt. of India, Central Statistics office, New Delhi, India.

[12] 2015 India energy outlook, World energy outlook special report, International energy agency, Paris, France.

[13] Riesz, D. .; Elliston, D.B.; Vithayasrichareon, D.P.; MacGill, A.P.I. 100% Renewables in Australia: A Research Summary; Centre for Energy and Environmental Markets, University of NSW, 2016.

[14] Ashwin Gambhir, Jatin Sarode, Shantanu Dixit, Grid Integration of Renewables in India, 2016, Prayas (Enery Group), Maharashtra, India.

[15] Amit Kumar Rohit, Ksh. Priyalakshmi Devi, Saroj Rangnekar, Journal of Energy storage, 13 (2017) 10-23.

[16] Amit Kumar Rohit, Saroj Rangnekar, Journal of Energy storage, 13 (2017) 447-456.

APPENDIX 1

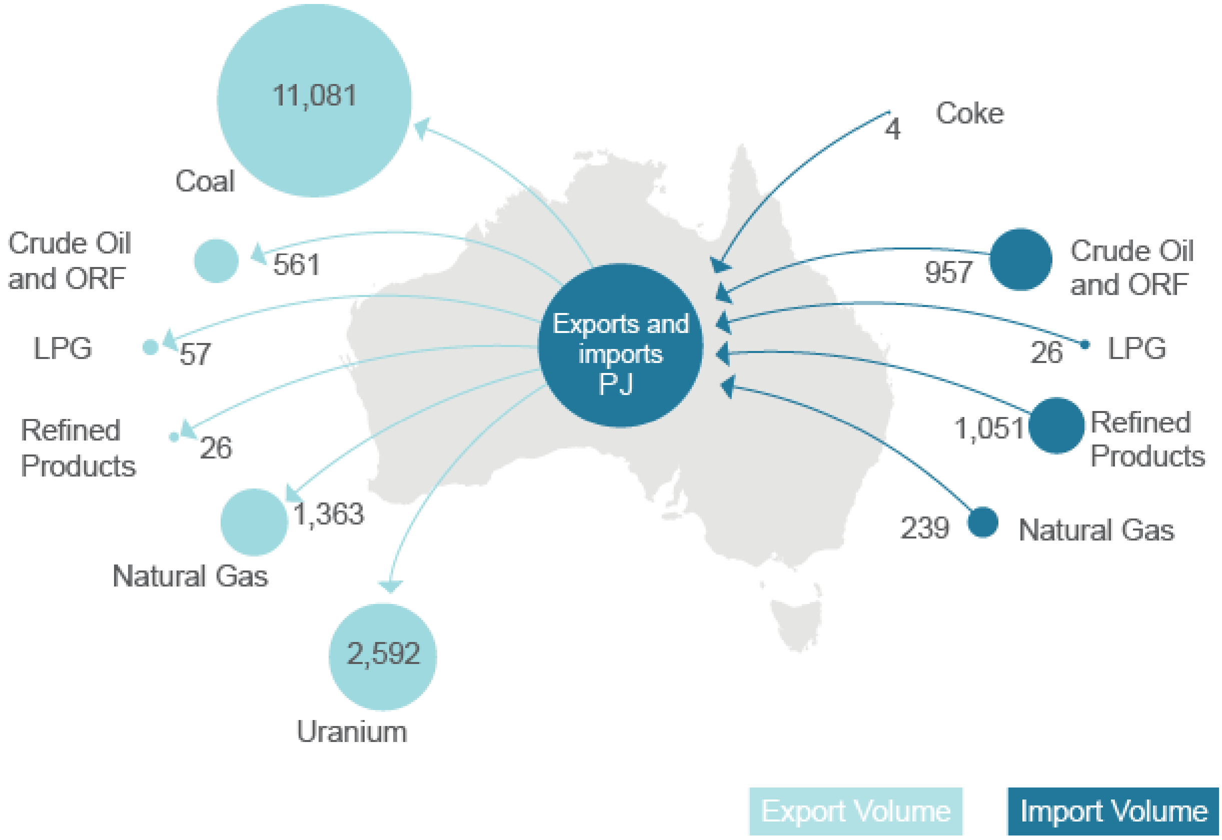
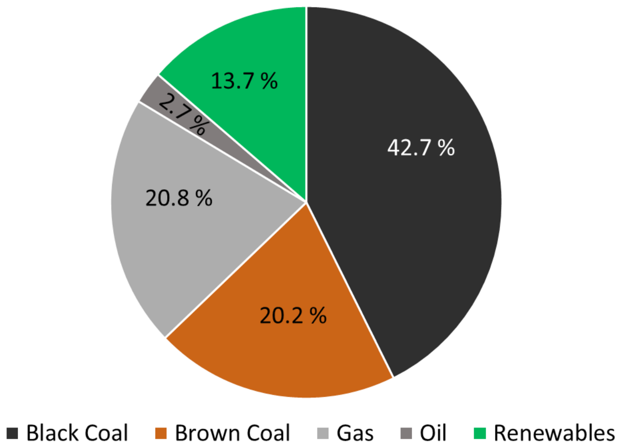


Figure 1: Australian energy trade in 2014-15[4]



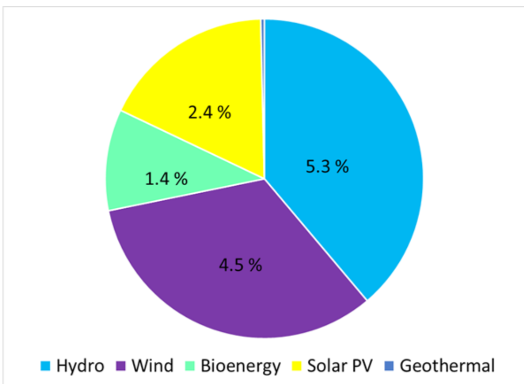


Figure 2: Australian electricity generation by fuel type in 2014- 2015[4]

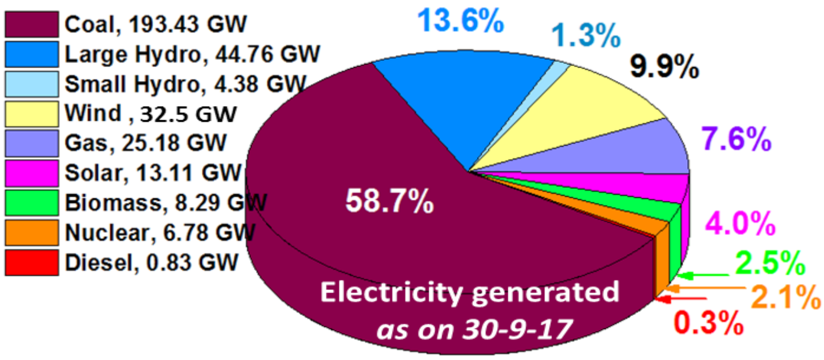


Fig.3: Electricity generation in India by various fuel sources as on 30th September 2017 [6].

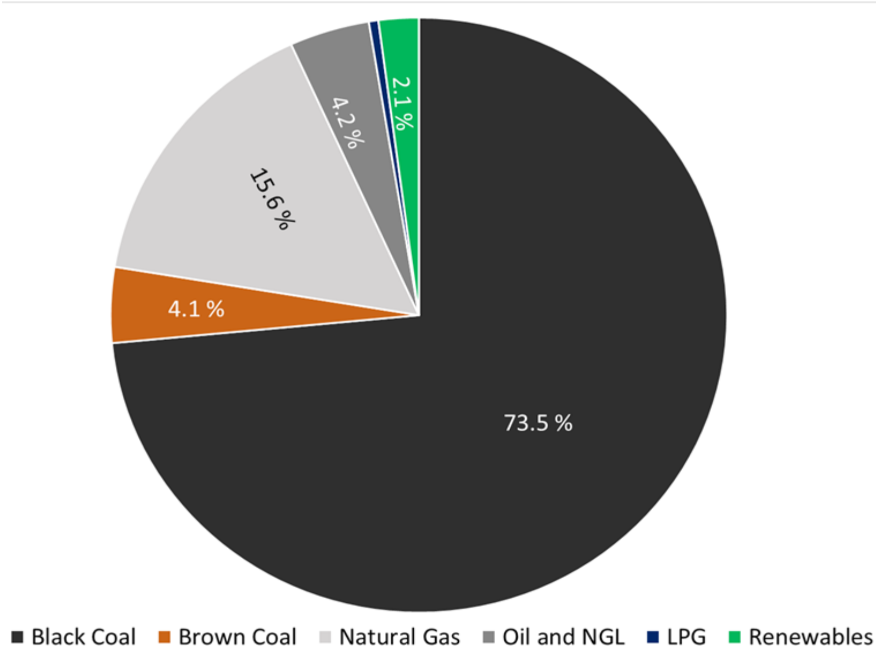


Figure 4: Australia's total energy production from different sources in 2014-15.[4]

Table 1.0: Estimated potential of Carbon free energy sources in India and projected target capacities [10-12, 14]

	FUEL SOURCE	POTENTIAL	PREVIOUS/CURRENT STATUS OF INSTALLED CAPACITY	INDIA'S TARGET CAPACITY
1	Small hydro	20 GW	2.8 GW (project capacity < 10 MW) in 2014	5 GW by 2022 (with 25 MW plant capacity)
	Large hydro^	128 GW	42 GW in 2014, 44.1 GW in 2017	
2	Solar	750 GW (upon of usage of 3% wasteland)	3.7 GW in 2014, 13.1 GW in 2017	100 GW by 2022
3	Wind	302 GW (with a hub height of 100 m)	32.5 GW in 2017	60 GW by 2022
4	Nuclear	Not applicable as it depends on source of fuel	5.8 GW in 2014, 6.78 GW in 2017	17.3 GW by 2024, 25% of nation's electricity by 2050

	FUEL SOURCE	POTENTIAL	PREVIOUS/CURRENT STATUS OF INSTALLED CAPACITY	INDIA'S TARGET CAPACITY
5	Geothermal	10.6 GW	The commercial deployment of power plants from these sources is not yet materialized.	
6	Ocean energy	Waves : 40 GW, Tides : 9 GW, Thermal gradients: 180 GW		

^ Large hydro energy, though renewable, is not a very clean source of power like solar and wind.

REMARK: DETAILED CONCLUSION AND RECOMMENDATION FOR INDIA

India has to exploit all the resources of energy including conventional fossil fuels (coal, gas, oil, bioenergy) and carbon-free energy sources to bridge the demand-supply gap at least upto 2040 whereby RE/CFE sources could contribute to 40-45% of the energy demand in electricity sector. As coal contributes nearly 50% of the electiricity demand in the near future, the coal-fired plants should be based on cleaner coal technologies like super and ultra-supercritical combustion technologies to minimise emissions with high thermal efficiency. In contrast to hydel power, solar and wind power would become the preferrable low carbon options of India. Apart from these, nuclear power has to increase to augment the energy demand and also to support the base-load power demand. Further, to increase RE intergration, flexible coal plants are mandatory. For large-scale integration of RE/CFE India is yet to equip with efficient energy storage technologies, smart-grid solutions and better forecasting methodologies.

RENEWABLE ENERGY POTENTIAL IN AUSTRALIA

A recent report by a group of researchers at the University of New South Wales (UNSW) along with the Australian Energy Market Operator (AEM), showed that 100% renewable electricity portfolios is potentially feasible in Australia with competitive costs with alternative energy sources that may be available in 2030.[A]

At the Institute of Sustainable Futures (ISF), University of Technology, Sydney researchers have also studied the feasibility of switching 100% to renewables in a time bound manner. This research was based on one of the main models used for Germany's "Energiewende" project and analysis three scenarios:

(a) 'Reference scenario'- assumes the continuation of status quo as a reference

(b) 'Renewable scenario'- renewable energy replaces the existing energy sources by 2030 in the stationary power sector, while industries and transportation sector continues to use fossil fuels.

(c) 'Advanced Renewable scenario'- power sector is fully decarbonized by 2030 and by 2050 fully renewable energy supply system is developed.

The outcomes of this study shows that decarbonizing Australia and utilizing 100% renewable energy as the primary energy source is not only possible and technically feasible (Figure 5 and 6), but also promises surplus energy as the combined renewable energy potentials exceed the future energy projections by an order of magnitude.[B] More importantly, going 100% renewable is also economically beneficial.

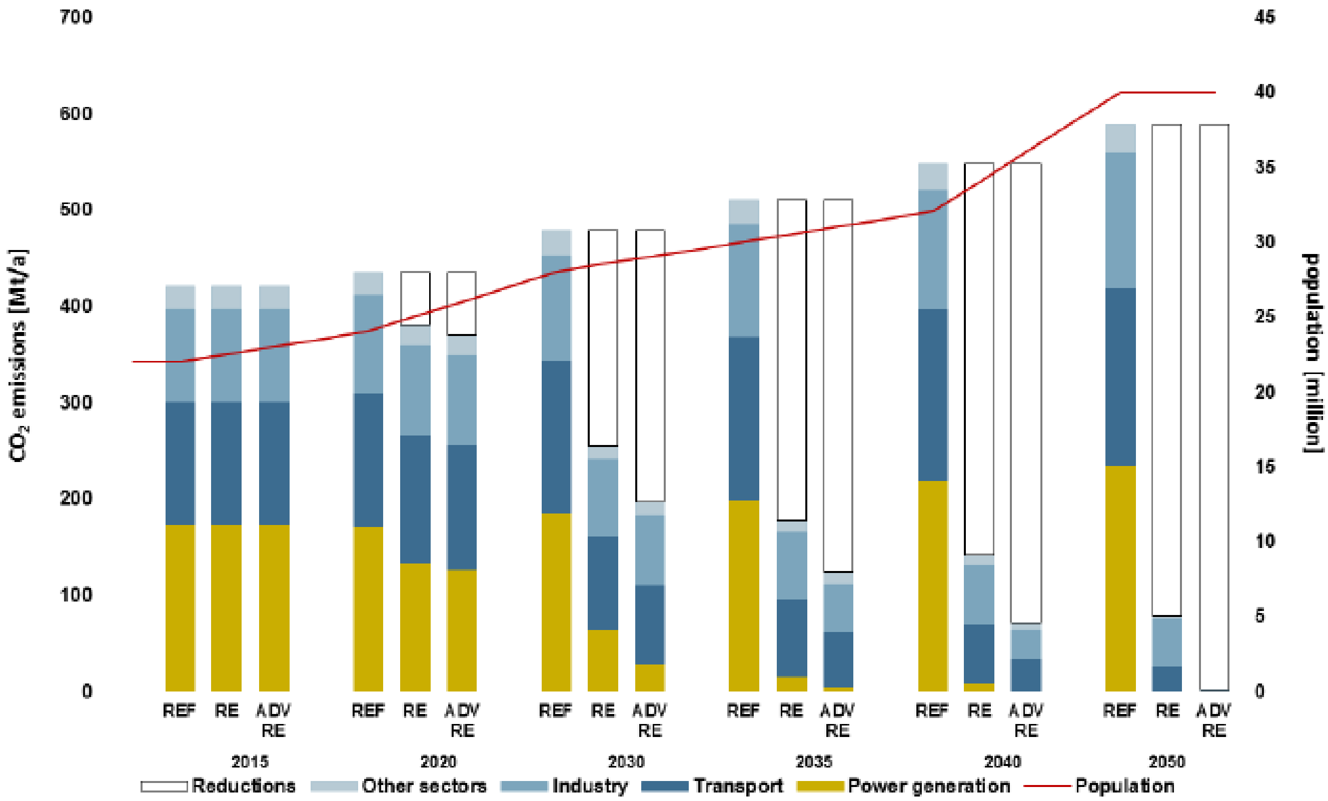


Figure 4: Energy related CO_2 emission from different sectors, in three different scenarios.[8]

Once technical hurdles are overcome, compared to the 'reference scenario', 'renewable scenario' would save $40 billion by 2030 and by 2050, total energy costs are projected to be only around $65 billion per year as compared to $180 billion per year projected for the 'reference scenario'.

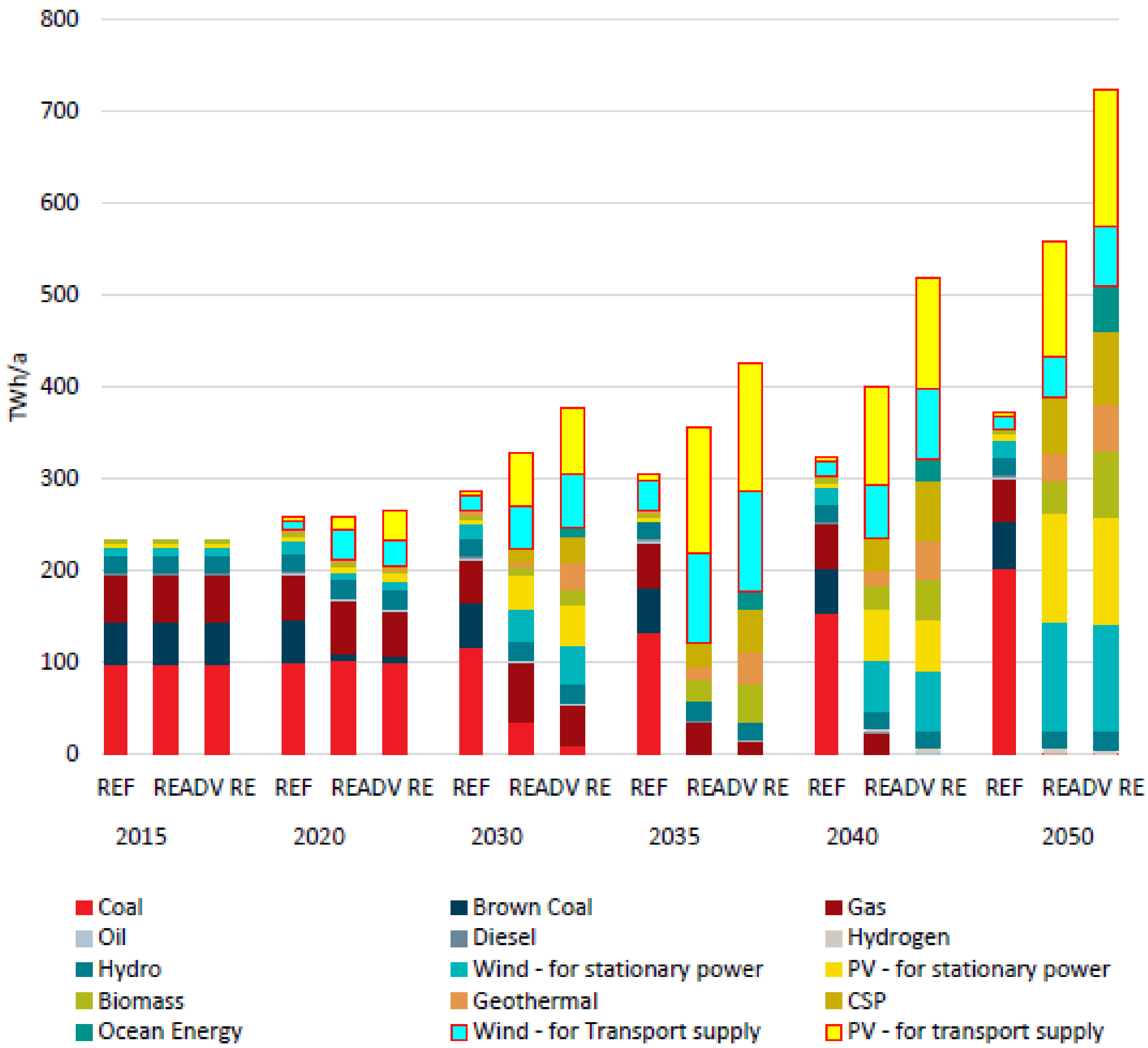


Figure 6: Projection of electricity generation by different technologies, based on the three scenarios[B]

(A) Riesz, D.J.; Elliston, D.B.; Vithayasrichareon, D.P.; MacGill, A.P.I. *100% Renewables in Australia: A Research Summary*; Centre for Energy and Environmental Markets, University of NSW: 2016; *http://ceem.unsw.edu.au/sites/default/files/documents/100pc%20RE%20-%20Research%20Summary-2016-03-02a.pdf*

(B) Teske, D. .; Dominish, E.; Ison, N.; Maras, K. *100% Renewable Energy For Australia– Decarbonising Australia's Energy Sector within one Generation. Report prepared by ISF for GetUp! and Solar Citizens, March 2016.*; Institute for Sustainable Futures, University of Technlogy Sydney: 2016

APPENDIX E

Nanocomposite Hydrogels and Their Therapeutical Potential

Yanhua Cheng[a], Thaís N. Barradas[b], Manjunatha Pattabi[c]

[a] State Key Laboratory for Modification of Chemical Fibers and Polymer Materials, College of Materials Science and Engineering, Donghua University, Shanghai 201620, P. R. China

[b] Federal Institute of Education Science and Technology of Rio de Janeiro – Department of Pharmacy – Brazil.

[c] Materials Science Department, Mangalore University, Mangalagangothri 574 199, India

1 - INTRODUCTION

Hydrogels are three-dimensional systems constituted by water-soluble polymeric networks that contain chemical (covalent) or physical (secondary forces, crystallite formation or chain entanglement) crosslinks, which are prerequisites for gelation. This three-dimensional network features high affinity for water and, due to the crosslinks or physical bonds, it swells in an aqueous environment, a phenomenon that gives the hydrogels their final form [1-3]. Hydrogels have been pointed as versatile materials because of their unique properties in medical and pharmaceutical field [2-5].

The dispersion of nanoparticles (NP) (i.e., dendrimers, micelles, polymeric NP, liposomes, inorganic NP) in a gelled matrix constitutes systems that can be considered composite hydrogels, since they are composed of nanometric structures entrapped in a hydrogel matrix, (as in a “plum pudding”) [3,6,7]. Figure 1 presents these systems in a simplified manner, where D1 and D2 represent the diffusion coefficients of the drug from the secondary release vehicle and the hydrogel, respectively [8].

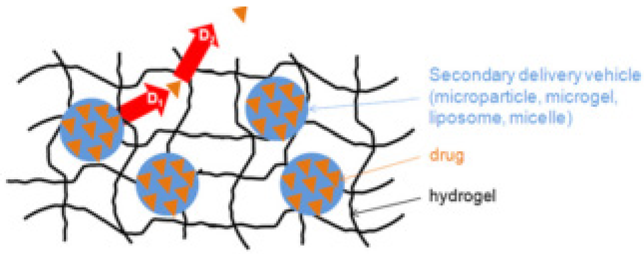


Figure 1: “Plum pudding” model for hydrogels composite with bioactive compunds encapsulated in a secondary release vehicle such as NP [8].

In these systems, NP are trapped into a three-dimensional hydrogel network which increases its stability against the formation of supramolecular aggregates. In addition to being able to control the rate and time of drug release, optimizing the therapeutic effects [3,9]. Such therapeutic improvement is also related to adhesive properties provided by hydrogel-forming polymers, which increases drug residence time at the therapeutic site. This phenomenon favors pharmacological activity of the active principle by ensuring the intimate contact of the particles with the target tissue [9].

There are at least three different drug release patterns from hydrogels according to how they were introduced into the gelled matrices: (i) drug release can be based on the diffusion phenomenon, which regulates the movement of molecules through the polymeric matrix; (ii) external stimuli can also regulate drug release, as they induce swelling of stimulus-responsive hydrogels that react to certain external conditions such as pH and temperature; (iii) localized enzymatic degradation of gel-forming polymers can trigger release of bioactive compounds [9-11].

2 – SILVER NANOPARTICLES

Antimicrobial potential of silver NP have been well recognised long ago. The toxicity of silver nanoparticles is much less than the ionic silver, makes silver nanoparticles attractive for antimicrobial applications. Various studies show that silver NP have very high activity against gram-positive and gram-negative bacteria, viruses like HIV [12,13]. When resistance to drugs developed by certain bacteria like tuberculosis, malaria is a serious threat for human health and silver nanoparticles can be a potential solution. While the synthesis of silver nanoparticles by various means is established, their therapeutic potential is not exploited. The incorporation of siver nanoparticles in to the hydrogels, and the delivery of the nanoparticles at the desired point is yet to be investigated. The toxicity of silver nanoparticles also has to be studied systematically and seriously, as there are conflicting results [12,13].

3 – STUMULI-RESPONSIVE NANOPARTICLES

Stimuli-responsive nanocarriers are able to deliver drugs in response to specific stimuli, either endogenous variation (such as pH,[14] enzyme concentration, and redox gradients[15]) or exogenous stimuli (including temperature,[16] magnetic field,[17] ultrasound intensity,[18] light[19] and electric pulses[20]). It should be noted that for endogenous variations, the precise control of drug delivery is difficult because of the uncontrollable specific microenvironments and individual differences in the human body.[21] In addition, although drug release with exogenous stimuli *in vivo* is feasible, it is difficult to attain precise drug release control due to the large-scale area of exogenous stimuli, usually causing undesirable side effects. Therefore, it is worthwhile to further develop drug-release technologies, ideally with more benign side effects.

Cancer poses a great threat to human health and life. It is well known that near-infraed (NIR) light can penetrate the skin/tissue to irradiate optically sensitive nanoparticles *in vivo*.[19,22] Lately, NIR laser-induced photothermal ablation therapy (NIR-PAT) has attracted much interest as minimally invasive therapeutic methodology for cancers. A prerequisite for the development of NIR-PAT is to obtain photothermal nanoagents. So far, different kinds of agents have been developed, including polymer nanoparticles,[23] noble-metal nanomaterials (such as Ag, Au, Pd),[24-25] carbon-based nanomaterials,[26] and semicondutors nanomaterials.[27] Our group has developed several semiconductor photothermal nanoagent materials, including $Cu_{2-x}S$ and WO_{3-x} based nanoagents for the photothermal ablation of cancer cells in vivo.[28, 29] Nevertheless, it should be pointed out that the NIR-PAT will cease immediately if the NIR laser irradiation is shut off.

To further improve the therapeutic effects from chemotherapy or NIR-PAT, the combination of chemotherapy and NIR-PAT has attracted increasing attention. Incorporating photothermal nanoagent materials into stimuli-responsive hydrogels to form the nanocarriers, resulting nanocapsules with doped anticancer drug allow the application of photothermal therapy and drug release simultaneously, which can be switch off/on by an external vivo NIR laser (Figure 2).[30] The nanocapsusles can be injected into the tumor and close to cancer cells, under irradiation with a 915-nm laser, cancer cells can be efficiently destroyed; the tumor growth inhibition can be easily envisioned.

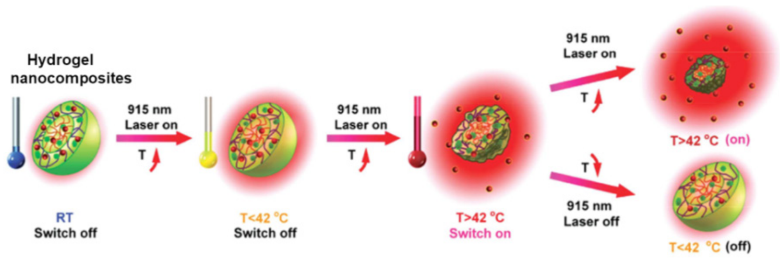


Figure 2. Intelligent durg release switched "on" or "off" by an external vivo NIR laser.

4 – PERSPECTIVES

Nanocarriers when entrapped into hydrogel matrixes can combine both improved efficacy and controlled release, resulting in novel and better products that can provide a solution to the increase of bacterial resistance to common antibiotics or yet give birth to innovative strategies to cancer treatment. Photothermal nanocarriers are considered promising materials for cancer treatment due to their ability of delivering active compounds to the site of interest with minimal toxicity to healthy tissues. Given the benefits of combining phototermal nanoagents with hydrogelled matrices, different promising opportunities cancer treatment are emerging that shall ultimately lead to improved cancer management. Thus, nanocomposite hydrogels are considered advantageous materials by combining favorable therapeutic efficacy characteristics and enhanced penetration attributed to NPs with the prolonged drug release properties provided by hydrogels.

REFERENCES

[1] BHATTARAI; GUNN; ZHANG. **Advanced drug delivery reviews**, v. 62, n. 1, p. 83–99, 2010.

[2] YU *et al*. **Journal of Applied Polymer Science**, v. 103, n. 1, p. 125–133, 2007.

[3] GAHARWAR; PEPPAS; KHADEMHOSSEINI, **Biotechnology and Bioengineering**, v. 111, n. 3, p. 441–453, 2014.

[4] ULLAH, *et al*. **Materials Science and Engineering C**, v. 57, p. 414–433, 2015. Disponível em:

[5] SONG, *et al*. **Journal of Biomedical Nanotechnology**, v. 11, n. 1, p. 40–52, 2015.

[6] KHADEMHOSSEINI; DEHGHANI. **Biomaterials**, v. 32, n. 36, p. 9719–29, 2011.

[7] GUO; ZHOU. **Polymers and Polymer Composites**, v. 21, n. 7, p. 449–456, 2013.

[8] HOARE; KOHANE. **Polymer**, v. 49, n. 8, p. 1993–2007, 2008.

[9] ZHU, *et al*. **International journal of pharmaceutics**, v. 378, n. 1–2, p. 152–8, 2009.

[10] JEONG; KIM; BAE. **Advanced drug delivery reviews**, v. 54, n. 1, p. 37–51, 2002.

[11] VAN TOMME; STORM; HENNINK. **International journal of pharmaceutics**, v. 355, n. 1–2, p. 1–18, 2008.

[12] PATTABIA and PATTABI. **Materials Science Forum** v. 754 pp 131-142, 2013.

[13] ELECHIGUERRA *et al*, **Journal of Nanobiotechnology**, v. 3, n. 6, 2005.

[14] DENG;. ZHEN; HU; WU; XU; CHU, ***Biomaterials*** **2011,** *32*, 4976-4986.

[15] ZHU; KATE; TORCHILIN, ***ACS Nano*** **2012,** *6*, 3491-3498.

[16] CHEN; LIANG; CHEN; WANG; CHENG; LIU; XIA; SUNG, ***ACS Nano*** **2013,** *7*, 438-446.

[17] JENKINS; PICKARD; GRANGER; CHARI, ***Acs Nano*** **2011,** *5*, 6527-6538.

[18] RAPOPORT, KENNEDY, SHEA, SCAIFE, NAM, ***J. Controlled Release*** **2009,** *138*, 268-276.

[19] SHANMUGAM,SELVAKUMAR, YEH, ***Chem. Soc. Rev.*** **2014,** *43*, 6254-6287.

[20] KIM, JEONG, PARK, ***J. Am. Chem. Soc.*** **2011,** *133*, 5206-5209.

[21] MURA, NICOLAS, COUVREUR, ***Nat. Mater.*** **2013,** *12*, 991-1003.

[22] CHEN, ZHANG, SUN, HU, WANG, ***Adv. Funct. Mater.*** **2009,** *19*, 3815-3820.

[23] SHENG, HU, ZHENG, ZHAO, LIU, GAO, GONG, GAO, ZHANG, MA, CAI, ***ACS Nano*** **2014,** *8*, 12310-12322.

[24] HUANG, TANG, MU, DAI, CHEN, ZHOU, RUAN, Z. YANG, N. ZHENG, ***Nat. Nanotechnol.*** **2011,** *6*, 28-32.

[25] NAM, LA, HWANG, HA, PARK, WON, JUNG, BHANG, MA, CHO, JIN, HAN, SHIN, WANG, KIM, CHO, YOO, KIM, KIM, ***ACS Nano*** **2013,** *7*, 3388-3402.

[26] TSAI, CHANG, CHENG, SHANMUGAM, CHENG, SU, YEH, ***ACS Nano*** **2013,** *7*, 5330-5342.

[27] LI, YANG, REN, QU, QU, ***Adv. Mater.*** **2012,** *24*, 1722-1728.

[28] ANTARIS, ROBINSON, YAGHI, HONG, DIAO, LUONG, DAI, ***ACS Nano*** **2013,** *7*, 3644-3652.

[29] TIAN, HU, ZHU, ZOU, CHEN, YANG, LI, SU, HAN, LIU, ***J. Am. Chem. Soc.*** **2013,** *135*, 8571-8577.

[30] MENG, WEI, WANG, XIA, CHEN, WANG, ZHU, ***Adv. Mater.*** **2016,** *28*, 245-253.

APPENDIX F

The Current Status of Smart Grid Development: Social, Political and Economic Perspectives

Kassio Papi Silva Zanoni[a], Zhao Yong[b], Pierre Denis[c]

[a] University of Sao Paulo, Physics Institute of Sao Carlos, Brazil
[b] Institute of Electrical Engineering, Chinese Academy of Sciences, Beijing, China
[c] Ulm University, Germany

1 INTRODUCTION: TRADITIONAL VERSUS SMART ELECTRICITY GRIDS

In our traditional electrical system, energy is generated in large power plants responsible for base-load generation, typically via gas, coal, oil or nuclear energy. Transmission grids interconnect unidirectionally the power plants to large consumer zones and distribution grids carries energy to medium/small consumer centers. The balance between power production and consumption – which varies significantly across days and through years – is roughly controlled by the bulk power plants that distribute energy according to predictions of demand.

Recently, many renewable energy technologies have emerged as environment-friendly alternatives to combustion-based energy generation. However, success in these areas heavily depends on other ancillary sectors. For example, in order to accommodate the intermittent (and only partially predictable) availability of renewable sources into the electrical system, the traditional electrical grids need radical changes towards smarter technologies.

A smart grid is an electricity grid that efficiently distributes power by combining large and smaller power generator centers with energy management to balance out production and consumption. The distribution is controlled on real time and in situ, in an interconnected grid with complex information interaction among the different domains involved. Therefore, smart grids deliver electricity more cost-effectively, with lower greenhouse-gas emissions and with active involvement of the customers.

The main components of an ideal smart grid are: i) the bulk generation, with large power plants from variable sources (preferably renewable); ii) a monitored transmission super grid, with many interconnections (possibly international) that allow power-exchange to improve power stability; iii) a distribution grid, with small and medium local generators (e.g. small wind turbines and solar panels) integrated in a bidirectional power flow; iv) the final customers that interact with the electricity supplier in a two-way communication channel that collect data and carry information, allowing real-time demand/response balance; v) small-to-huge widespread storage systems (e.g. batteries and hydrogen fuels) that provide the integration of intermittent renewable sources.

Herein, we provide a global overview of the current state-of-the-art and future perspectives of the smart grid development and the social, political and economic motivations on each continent.

2 GLOBAL OVERVIEW ON SMART GRIDS

2.1 Africa

The entire continent has very good solar and wind resources, however most African countries lack basic electricity infrastructure. In fact, in 2009, ~585 million people had no access to electricity in sub-Saharan Africa [1]. Therefore, the installation of microgrids is a solution to bring electricity specially for isolated communities.

South Africa is at an early stage of implementing smart grids and several pilot models have been proposed, addressing issues such as cost, security and sustainability. Researches on pilot projects are mainly focused on five priority areas within the electricity distribution industry, identified by the Department of Energy [2]. To achieve a larger renewable generation, South Africa hosted renewable energy auctions in 2010 for independent power producers (IPP); in April 2016, ~6.4 GW has been procured by 102 IPPs and, in October 2016, ~2.8 GW of the procured capacity had already started operations (total of 53 IPPs), with all the projects connected and delivering power to the grid [3].

In April 2016, Ghana had a 20 MW solar photovoltaic plant connected to the electricity grid, the largest within Africa [4]; another 20 MW solar project has been awarded by the US Trade and Development Agency to a Ghanaian solar company in the north of Ghana [5]. In March 2017, the just elected Ghanaian government resumed plans to promote large-scale solar and wind energy generation and distribution [6].

In June 2017, The New Yorker reported the competition among American startups to bring electricity to hundreds of thousands of people in the sub-Saharan Africa, in remote places that the grid failed to reach, for example in Ghana, Ivory Coast and Tanzania [7]. Such entrepreneurs install solar microgrids and home-based solar systems that run on a panel installed on each individual house, with a low yet promising current generation. For most cases, this is the first access to electricity in a lifetime.

2,2 Asia

Smart grid development in Asia is not balanced. While South Korea and Japan are world leaders on smart grids, Pakistan, Bangladesh and India still suffers with very tight the electricity supplies.

South Korea (along with Italy) was recognized as a leading country on smart grids at the G8 Summit in July 2009, and promoted the International Energy Agency Implementing Agreement for a Co-operative Programme on Smart Grids (ISGAN) around the world. In January 2010, the South Korean government formulated the “National Roadmap for Smart Grids” to promote R&D, industrialization and improvement of related technologies, with the aim of building a nationwide smart grid system by 2030. The South Korean government completed the installation of smart meters for 1/2 of the domestic households by 2016 and achieved the purpose of saving power consumption by recording and testing statistically accurate data. KEPCO has announced a plan to invest U$ 7.2 billion by the year of 2030 to upgrade transmission and distribution systems and replace smart meters [8,9].

In August 2013, Japanese companies Toshiba and Tokyo Electric Power co-financed the setup of a new company to carry out research on technologies of smart meters, batteries and other equipment to system operation and maintenance. Toshiba acquired the world’s largest maker of smart meters, Langger (originally from Switzerland). Toshiba also carries out verification experiment projects on the summer dynamic response of smart meters in New Mexico, USA [10-12].

China pays close attention to the field of smart grid in particular the development of UHV grid [13]. According to the overall plan of Chinese smart grid construction, China will build a smart grid with a UHV power grid as the backbone network by 2020. The total investment for smart grid in China will be 58 billion U.S. dollars from 2009 to 2020 [14], focusing on utilization of renewable energies. Smart grid technologies are also promoting an electricity reform in China, with the power grid enterprises changing their ways of development/management and the electricity users changing their consumption behaviors. to ensure effective interactions between the smart grid and users to meet diverse energy demands [15-16].

In recent years, the economic and urbanization in Southeast Asia has led to a rapid growth of electricity demand. Some emerging economies, such as Philippines, Indonesia, Thailand and Malaysia, have recently started to formulate concrete road maps for smart grid technologies and manage electricity more efficiently [17,18]. Pike Research estimates that total smart grid revenue in Southeast Asia is expected to grow steadily at a compound annual growth rate (CAGR) of over 10% by 2020, and primarily due to the investment in power transmission, distribution network upgrades and deployment of smart meters [19].

Pakistan, Bangladesh and India have enjoyed sustained and steady economic growth in recent years. Although the installed capacity of electric power is also growing rapidly, the electricity supply in these countries is still very tight. For example, Pakistan had a total installed power generation capacity of 23.5 GW in 2012, but still had a shortage of 6.3 GW of electricity. Smart grids are an alternative to increase the efficiency of power supply and the guaranteed rate of supply in these countries [20-22].

2.3 Europe

There are two major motivations that justify the need for smart grid implementation in the European Union. On one side, when coupled with smart meters, smart grids can provide real time consumption information to the suppliers and consumers. Consequently, dynamic price contracts could be offered to the consumer, inciting them to consume when the price and the demand is at its lowest [23]. On the other hand, some of the state members have invested in volatile renewable energies such as air turbines and photovoltaic systems.

Germany, for example, plans to reduce its CO_2 emission by 40% by 2020 and by 80 % by 2050 in comparison to its emission in 1990 [24]. In addition, the relative percentage of renewable energy on gross electricity consumption should be above 35 % by 2020 and above 80% by 2050. To facilitate this transition, the energy consumption should decrease by 50% by 2050 in comparison to its level in 2008. In 2016, the wind and the solar represented respectively 12.3% and 5.9% of the annual energy sources in the country [25]. Fluctuations are however important and the energy percentage of the solar can reach values higher than 50 % on some days [26].

The need to reduce the energy consumption and the implementation of an always increasing percentage of volatile energy sources make smart grids necessary in a short term. In the EU, the investment in smart grids reached a peak in 2012 with 936 million € [27]. Investments have decreased since that time to reach only 472 million € in 2015. The investments are separated in two categories: R & D and demonstrations in real conditions. The number of R & D projects was in 2015 twice that of demonstration projects. However, demonstration projects represent the largest part of the investments [27]. Technological solutions are still required for enabling the full potential of smart grids. For example, the development and enhancement of storage systems could allow the excess of energy produced in time of lower needs to be used at times of higher needs, which is particularly important with renewable energies [28]. Overall in the EU, private investments represent the highest source of financing [27]. It is particularly true in countries such as the United Kingdom and France. In other countries like Germany and Italy, national investment represents still a large part of the financing. In average, the financing from the European Commission is approximately the same as the financing from the states. European funding plays a crucial roles in countries where the state funding is lower such as Bulgaria, Romania and Slovakia. The European commission is also working on a set of rules to allow the exchange of data beneficial to the suppliers while guaranteeing a high level of data privacy [23]. Moreover, efforts should be made to prevent the vulnerability of smart grids to cyber-attacks [29].

2.4 LATIN AMERICA

Power thefts are very common in Latin America and can represent a loss up to 30% in energy production at some regions, especially in favelas, where illegal hook ups and an organized black market costs economies billions each year [30]. To decrease energy thefts is the main motivation for the establishment of a smart grid system in this continent, specially based on meticulous metering. Eight of the ten countries in the continent already have pilot projects in place, with Brazil leading the way [31].

Brazil is currently the largest electricity market in the region, corresponding to 42% of the total consumed energy in South and Central America, mainly from renewable sources, being the 3rd largest hydroelectric producer and the 9th in installed wind power capacity. Brazilian regulation also creates incentives for installing small solar panels in residences [31]. Still, the regulatory framework for smart grid deployment was finalized only in 2012 [32], when Brazil alone lost approximately 15% of its energy production to theft [30]. Eight main smart grid projects are already operating in important urban and touristic destinations in the south and southeast regions, and they cover: an energy management through smart meters inside consumer units; a consumer awareness program and consumers that produce their own electricity through small photovoltaic panels; in-loco energy storage systems; an upgrade of public lighting, telecommunications and grid automation [33].

Beyond Brazil, countries such as Colombia, Ecuador, Chile and Argentina are receiving significant investments to modernize their grids, mostly aiming at decreasing power thefts. In the next 8 years, South America will invest $22.6 billion in smart metering, $7.2 billion in distribution automation and $8.3 billion in other market segments [32]. In Chile, for example, the leading candidate in the 2017 presidential elections has proposed to go 100% renewable by 2040 [34].

In Mexico, the Federal Electricity Commission accounted thefts that exceeded 30 percent in some regions of the country. To counterbalance, new regulations specify that the Mexican Secretariat of Energy develop a smart grid program ever three years, like the one published in 2016 establishing improvements in power quality as well as in energy and operational efficiencies, integration of clean energy, and facilitation of customer engagements. Moreover, 2 million smart meters are expected to be installed by 2019, and American companies see it as a top emerging market for U.S. smart-grid technology exporters [35].

2.5 NORTH AMERICA

In the United States, a federal policy known as Energy Independence and Security Act of 2007 created a Grid Modernization Commission and granted support for smart grids by investing around U$ 500 million from 2008 to 2012 to establish smart grid capabilities. Later, the American Recovery and Reinvestment Act of 2009 granted U$ 4.5 billion for the development, deployment, and worker training of smart grids and the in-consumers-home installation of 2.5 million smart meters, 1 million energy displays, 170,000 smart thermostats, and 175,000 other load control devices towards a reduction in the energy consumption. Nowadays, a total of 5.9 million smart meters is deployed, with a projected nonresidential smart meter penetration rate of 71.7% by 2020 [36]. In 2017, investments in the smart metering segment is predicted to reach U$ 1.2 billion [36]. A study by Chen et al. showed that “a majority of US residents supported smart meter technology and were willing to adopt this technology” [37]. In 2011, renewable energy contributed to 11.7 % (also accounting hydroelectric power) of total national energy production, surpassing energy from nuclear powers. In 2016, wind and solar energies alone corresponded to 5.6 and 0.9% of the total energy produced [38]. However, nowadays, irresponsible acts from notorious politicians and the conservative media have been misleading consumers regarding the benefits of the smart grid implementation and the urgent necessity for renewable and sustainable energy generation [39].

In Canada, a research and technology organization associated to the Canadian natural resources ministry called CanmetENERGY is leading the field of clean energy and smart grids, with division in five main topics: “using the current network infrastructures in an optimal way; improving the quality of service; ensuring the integrity of the network; reducing the cost of isolated networks; optimizing the electricity production” [40]. The ministry is currently calling for projects in smart grid demonstrations and deployments, which will invest U$ 100 million from 2018 to 2022 to “support larger sale demonstrations of promising near-commercial smart grid technologies, and deployment of proven smart grid integrated systems to reduce GHG emissions, better utilize existing electricity assets and foster innovation and clean jobs” [40]. In 2016, Canada had solar and wind power generating capacities of 2.7 and 11.9 GW, respectively, being the 13th and 8th among the world largest producers.

In 2013, U$ 105 billion worth of energy was traded in the bilateral relationship between US and Canada. According to Mallet et al., there are differences in the way smart grids are shown in American and Canadian journals [41]: “The Canadian smart grid newspaper content focuses more on implementation and describing people’s experiences with smart meters, while the U.S. content focuses more on commercial opportunities with more reference to private sector actors and various technological components beyond smart meters. (...) This suggests that cultural differences at the national level be a further contextual lens helpful to policy makers and technology proponents as they embark upon energy system change initiatives.”

2.6 OCEANIA

New Zealand is an interesting case to study the potential of smart grids coupled with volatile energy sources. Indeed, 80% of the energy generation of the country originates from renewable energies such as hydro and geothermal sources [42]. Moreover, its metering infrastructure is already very advanced and covers 62% of the households. The wind energy represents 5% of the energy produced. The part of the solar energy is still relatively low but increases rapidly since 2012. These two energy sources are among the most volatile and present important challenges for power quality. Additionally, due to its geographical location, New Zealand cannot rely on importation to complete its electricity demand. In this context, the GREEN Grid research program was recently initiated to evaluate the possibilities of cost reduction and the challenge for power quality and safety that a smarter and greener grid represents. The results of this study could be of high interest for larger countries which plan to transition to smart grids at a higher scale. Preliminary results recommend the better geographical distribution of wind turbines and the use of hot water cylinder to reduce the problem of energy volatility. A particularity of New Zealand concerns its high number of electricity distribution businesses. Additionally, there has been very little pressure from the state for standardization. As a result, a high diversity of meter types and data access arrangements was initially present. To allow a better coordination in between the sector players, the government sponsored the establishment of the “Smart Grid Forum”. Recently, most of the smart grid systems have converged on two different technologies.

In Australia, the “Smart Grid, Smart City” project was undertaken to evaluate the possible cost reduction originating from the implementation of smart grids [43]. In 2009 and 2010, $500 million were allocated to the project from public and private funds. The tests occurred at different locations to be the most representative of the different climates and demographic characteristics present in Australia. The results of the study show that the highest potential in cost reduction lies in a more advanced fault detection, isolation and restoration. As an example, in September 2016, a storm in South Australia damaged the electrical network, and almost the entire state lost its electricity supply [44]. Progress in fault detection would reduce the duration of future outages in unaffected network sections. It was estimated that up to $14.41 billion could be saved through to 2034 by better fault detection and isolation [43]. The potential of smart meters, with or without dynamic tariffs, was examined by the study. Without dynamic tariffs, the costs required to install smart meters would be more important than the potential benefits. However, when paired with dynamic tariffs, a net benefit of $1 billion could be realized through to 2034. This comes from the fact that the customers will be more likely to consume electricity in period of lower needs. The Australian state of Victoria is the only state has already completed the main part of the smart meter rollouts. It is however expected that the other states will follow soon, within the next 2 or 3 years [45]. Both Australia and New Zealand are definitively committed to a larger smart grid implementation since it is predicted that they will spend together around $6 billion in smart grid infrastructure from now to 2027. The state of South Australia is particularly interested in these investments to reduce the risk of a new blackout. A new energy plan ambitions the installation 100 MW of battery energy storage in this region.

FINAL PERSPECTIVES

In conclusion, initiatives for changing the energy system are usually motivated by cultural, economic and/or social differences, which provide further contextual lens for proposing future policies and technologies. In this sense, the challenges for implementing smart grids in less developed regions are: outdated infrastructure for electricity supply, transmission and distribution; lack of integrated communication platforms; high-cost of deployment; compatibility of old equipment; lack of specific regulatory policies; lack of human skills [46]. For example, a study in Brazil showed that consumers do not care about sustainability and are not aware about smart grids neither approve new technologies [33]. On the other hand, the challenges for implementing smart grids in more developed regions are: the complex integration of volatile renewable energies; the high level of cyber-security required; the financial risks perceived by the private investors. In these countries, the most important factors for investors concern the maturity of the current technology and the always evolving business models [41].

REFERENCES

[1] Welsch, M. et al. Smart and Just Grids for sub-Saharan Africa: Exploring options; Renew Sust Energ Rev 20 (2013) 336.

[2] In *http://www.doe-irp.co.za/content/IRP2010_updatea.pdf*. Accessed in October 2nd, 2017.

[3] In *http://www.ipp-renewables.co.za/#page/303*. Accessed in October 2nd, 2017.

[4] In *https://cleantechnica.com/2016/04/17/ghanas-largest-solar-pv-project-just-connected-to-the-grid*. Accessed in October 2nd, 2017.

[5] In *https://www.pv-tech.org/news/ustda-provides-more-than-us860000-for-ghana-solar-project*. Accessed in October 2nd, 2017.

[6] In *https://www.pv-magazine.com/2017/03/30/ghanas-new-government-relaunches-solar-program*. Accessed in October 2nd, 2017.

[7] In *https://www.newyorker.com/magazine/2017/06/26/the-race-to-solar-power-africa*. Accessed in October 2nd, 2017.

[8] Lee, S.S. et al. Northeast Asia Interconnection and Virtual Power System Simulator Design; In IEEE Power System Society 2011 General Meeting, USA (2011).

[9] Lee, S.S. et al. Northeast Asia Interconnection-Based Integration of DG, DR, HVDC, and Nuclear Load-following under Smart Grid in the South Korean Power System; In IEEE Power & Energy Society 2012 General Meeting, U.S.A (2012).

[10] Ela, E. and O'Malley, M. Studying the variability and uncertainty impacts of variable generation at multiple timescales; IEEE Trans. Power Sys. 27 (2012) 1324.

[11] Bouffard, F. and Ortega-Vazquez, M. The value of operational flexibility in power systems with significant wind power generation; In IEEE PES Conference, USA (2011).

[12] Bouffard, F. and Galiana, F.D. An electricity market with a probabilistic spinning reserve criterion; IEEE Trans. Power Sys. 19 (2014) 300.

[13] Zhenya, L. Global Energy Interconnection. Beijing: China Electric Power Press (2015).

[14] Ming, Y. et al. Dynamic Economic Dispatch with Equal Response Risk Constraints, Automation of Electric Power Systems 33 (2009) 14.

[15] Ningning, L. et al. Unit commitment considering expected customer interruption cost; In IEEE 11th International Conference on Probabilistic Methods Applied to Power Systems, Singapore (2010).

[16] Ming, Y. Novel Solution to Dynamic Economic Dispatch Considering Customer Interruption Costs; Proceedings of the CSEE 29 (2009) 103.

[17] Lannoye, E. et al. Evaluation of power system flexibility; IEEE Trans. Power Sys. 27 (2012) 922.

[18] Ma, J. Evaluating and Planning Flexibility in Sustainable Power Systems; IEEE Trans. Sust. Ener. (2013) 200.

[19] Dingyao, X. et al. Power source flexibility evaluation considering renewable energy generation uncertainty; Electric Power Automation Equipment 35 (2015) 120.

[20] Calderaro, V. et al. Optimal decentralized voltage control for distribution systems with inverter-based distributed generators; IEEE Trans. Power Syst. 29 (2014) 230.

[21] Khatod, D.K. et al. Evolutionary programming based optimal placement of renewable distributed generators; IEEE Trans. Power Syst, 28 (2013) 683.

[22] Zhang, D. An optimal and learning-based demand response and home energy management system; IEEE Trans. Smart Grid 7 (2016) 1790.

[23] The European Commission, Proposal for a directive of the European parliament and of the council on common rules for the internal market in electricity, Brussels (2017).

[24] Fifth “Energy Transition” Monitoring Report, The Energy of the Future (2015).

[25] In *https://1-stromvergleich.com/strom-report/strommix/*. Accessed in October 9, 2017.

[26] In *https://www.reuters.com/article/us-climate-germany-solar/germany-sets-new-solar-power-record-institute-says-idUSBRE84P0FI20120526*. Accessed in October 9, 2017.

[27] The European Commission, JRC science for policy report, Smart grid projects outlook (2017).

[28] Smart grids in Germany, Fields of action for distribution system operators on the way to Smart Grids.

[29] Vineetha, C.P. and Babu, C.A. Smart grid challenges, issues and solutions, IEEE Int. Conf. Intell. Green Build. Smart Grid, Taiwan (2014).

[30] In *http://www.power-technology.com/features/featuresmart-grid-energy-theft-power-brazil-latin-america*. Accessed in October 3rd, 2017.

[31] In *https://cleantechnica.com/2015/08/11/south-american-investment-smart-grid-infrastructure-reach-38-1-billion-2025*. Accessed in October 3rd, 2017.

[32] In *http://www.renewableenergyworld.com/articles/2012/09/brazil-update-aneel-finalizes-the-regulatory-framework-for-smart-grid-deployment.html*. Accessed in October 3rd, 2017.

[33] Di Santo, K.G. et al. A review on smart grids and experiences in Brazil; Renew Sust Energ Rev 52 (2015) 1072.

[34] In *http://www.independent.co.uk/news/world/americas/chile-electricity-renewable-100-per-cent-by-2040-climate-change-sebastian-pinera-presidential-a7961571.html*. Accessed in October 3rd, 2017.

[35] In *https://www.export.gov/article?id=Mexico-Smart-Grid*. Accessed in November 13th, 2017.

[36] In *https://www.statista.com/topics/1125/smart-grids/*. Accessed in November 13th, 2017.

[37] Chen, C. et al. Between the technology acceptance model and sustainable energy technology acceptance model: Investigating smart meter acceptance in the United States; Energy Res Soc Sci 25 (2017) 93–104.

[38] In *https://www.eia.gov/tools/faqs/faq.php?id=427&t=3*. Accessed in November 13th, 2017.

[39] In *http://reneweconomy.com.au/smart-grid-dumb-media-conservatives-hit-peak-stupid-over-demand-response-30092/*. Accessed in November 13th, 2017.

[40] In *http://www.nrcan.gc.ca/energy/electricity-infrastructure/smart-grid/4565*. Accessed in November 13th, 2017.

[41] Mallet, A. et al. Electric (dis) connections: Comparative review of smart grid news coverage in the United States and Canada; Renew Sust Energ Rev (2017) In press. DOI: 10.1016/j.rser.2017.06.017

[42] Stephenson, J et al. Smart grid research in New Zealand – A review from the GREEN Grid research programme, Renewable and Sustainable Energy Reviews 82 (2018) 1636–1645. DOI: 10.1016/j.rser.2017.07.010

[43] In *https://utilitymagazine.com.au/smart-grid-smart-city-the-future-of-australias-electricity-networks/*. Accessed in November 15th, 2017.

[44] In *https://www.export.gov/article?id=Australia-smart-grid*. Accessed in November 15, 2017.

[45] In *http://www.powerengineeringint.com/articles/2017/03/australia-and-new-zealand-to-invest-6-1bn-in-smart-grid-technologies.html*. Accessed in November 15, 2017.

[46] Zikalala, D.P. et al. Prospects and challenges of implementing smart grid technologies in South Africa; RPG 2015 (2015). DOI: 10.1049/cp.2015.0374.

European Materials Research Society
BP 20
F 67037 Strasbourg cedex 2, France
Tel +33 (0)3 88 10 65 43
Fax +33 (0)3 88 10 63 43
emrs@european-mrs.com
www.european-mrs.com