CFES 2010

Center for Future Energy Systems (CFES)

The NY State Center for Advanced Technologies (CAT) for Energy

www.rpi.edu/cfes

NYSTAR

Rensselaer

Cornell University

CFES Energy Overview

Marty Byrne
Associate Director

June 28, 2010

CFES Technology Focus Areas

- **Emerging Energy Technologies**
  - Renewable energy
    - **Wind, solar cells, solar thermal, thermo and thermophotovoltaic, thermoelectric, wind, bioenergy, energy storage**
  - Fuel cells and hydrogen
    - **Electrodes, membranes, catalysts and reformer, Membrane electrode assembly (MEA), testing and characterization, storage and electrolysis**
  - High temperature superconductivity
- **Energy Efficiency and Conservation**
  - Smart lighting and displays
    - **Solid State Lighting (SSL) LED Systems**
    - **Organic Light Emitting Diode (OLED) displays**
  - Intelligent building façade and design
    - **Dynamic integrated concentrating solar window modules for electricity, heating and shading; integrated wind, air and water**
- **Power Sourcing and Distribution Networks**
  - Grid Integration of Renewable and Distributed Generation (DG)
    - **Technology roadblocks, performance monitoring and policy**
  - Electricity Grid
    - **Distribution grid reliability, power electronics, interconnection**

Obama/Biden Energy Vision

- **Commitment to Renewable Energy Sources**
  - Renewable - 10% 2012; 25% by 2025; 5 year PTC; 60B gal Biofuels
- **Support of Plug-In Hybrid Technology and Infrastructure**
  - Goal of 1 million vehicles by 2015; increase fuel economy mandates
- **Improved Energy Efficiency in Buildings and Appliances**
  - 15% demand reduction; 40% building efficiency within 5 years
- **Improved Electrical Grid**
  - Implement "Smart Grid" technologies including smart meters and smart appliances
- **Investments in CO2 Capture and Sequestration**
  - Clean coal technology demonstration program
- **Commitment to Nuclear Energy and Waste Disposal**
- **Cap & Trade System to Reduce Greenhouse Gases**
  - Reduce CO2 emissions by 80% below 1990 levels ($150B)

Great Hopes for Change and Capital

What is the Definition of Renewable Energy

- Renewable energy is energy generated from **natural resources** such as sunlight, wind, rain, tides, and geothermal heat, which are renewable (naturally replenished)
- Energy that can be **replenished** at the same rate as it is used
- Used to describe energy sources that are replenished by natural processes on a sufficiently **rapid time-scale** so that they can be used by humans more or less indefinitely, provided the quantity taken per unit of time is not too great.
- Energy that comes from sources that can be **replaced,** such as sun, wind, waves, biofuels.
- A source of energy that is replenished by natural phenomena, such as **firewood or the water held behind by a dam** used for hydroelectrical purposes. Conversely, fossil fuels are a non-renewable source of energy.
- There is **no formal definition** for this term. Typical usage defines it as any energy source that is replenished at least as fast as it is used. Standard examples are solar, wind, hydroelectric, and biomass products.
- Energy produced from **virtually inexhaustible resources** such as the sun. For example, solar radiation, biomass, wind, water, or heat from the earth's interior are renewable energy resources.
- Energy obtained from sources that are **essentially inexhaustible** (unlike, for example the fossil fuels, of which there is a finite supply). Renewable sources of energy include **wood, water, geothermal, wind, photovoltaic and solar thermal energy.**
- Energy sources that are, within a short time frame **relative to the Earth's natural cycles, sustainable**, and include **non-carbon** technologies such as solar energy, hydropower, and wind, as well as **carbon-neutral technologies**.

Why Renewable Energy Sources?

US Consumes 18.7M bpd = 785M Gallons/Day
286B Gallons/Year

Fossil Fuel is not limitless – environment is degrading

Why Renewable Energy Sources?

BP Deepwater Horizon Spill – April 20, 2010
50,000 bpd – 2M Gallons/Day
Day 70 - 140M gallons

Why Renewable Energy Sources?

EXXON Valdez 10-14M Gallons

Why Renewable Energy Sources?

- **US Oil demand 18.7M bdp**
- **69% - 13M bpd is converted to gasoline/diesel**
- **US Oil production has declined from 9M bpd in the 1970's to 5M bpd in 2009**
- **In the US 80% of oil production is concentrated in Louisiana, Texas, Alaska and California**
- **US refining capacity is maxed out, susceptible to terrorism and natural disasters**

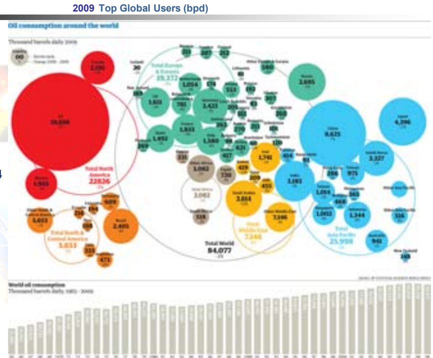
US Gasoline/Diesel CO_2 emissions 2.2B Tons/yr

Why Renewable Energy Sources?

2009 Top Global Users (bpd)

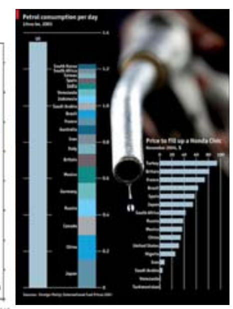
Million bpd

- USA 18.7
- China 8.6
- Japan 4.4
- India 3.2
- Russia 2.7
- Germany 2.4
- Saudi 2.6
- Canada 2.2
- S Korea 2.3
- Brazil 2.4
- France 1.8
- Mexico 1.9



Liquid Fuel Global CO_2 emissions 10B Tons/yr

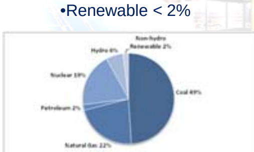
Why Renewable Energy Sources?



Why Renewable Energy Sources?

- **US Electrical Capacity is 1,100 GW, NYS 43 GW**
- **Electricity Sources (CO_2 emission impact)**

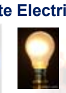
Coal 49% (2.2B Tons/yr)	NYS 14%
Nuclear 19% (104 plants)	NYS 29%
Natural Gas 22% (1.3B Tons/yr)	NYS 22%
Hydro 7%	NYS 17%
Petroleum 2% (.2B Tons/yr)	NYS 16%
Renewable < 2%	NYS 2%



US Generates 4B Tons/yr of CO_2 emissions

Why Renewable Energy Sources?

- **US Nameplate Electrical Capacity is 1,100 GW (1.1 TW)**
- **100 W**

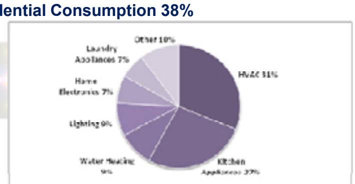


- **1000 W (kW)**
- **1,000,000 W (MW)**

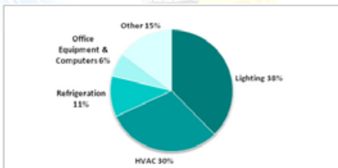
- **1,000,000,000 W (GW)**
- **1,000,000,000,000 W (TW)**

Use of Electricity (EIA)

•Residential Consumption 38%



•Commercial Consumption 36%

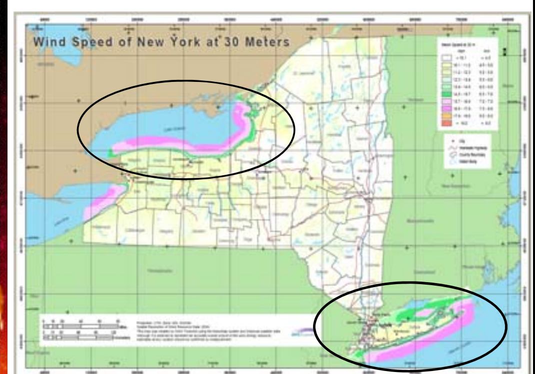


Renewable Energy Sources

•Wind – Wind farms, Distributed wind
•Hydroelectric
•Ocean Energy – thermal, wave, tidal
•Solar PV – Residential, Commercial, Utliity, CPV
•Solar Thermal – CSP - parabolic, dish, CST - flat plate, tube
•Solid Biomass – Direct Fired, Co-fired, Gasification
•BioFuels – Ethanol, Biodiesel, Chemicals
•Biogas – Anerobic Digestion, Landfill gas
•Geothermal
•Hydrogen Fuel Cells
•Waste Heat Generators

Wind Energy

Wind Energy



Renewable Energy Alternatives

Global Wind Power – 159 GW; US 35 GW

Renewable Energy Alternatives

Cape Wind Farm Project – 350 MW; 75% Cape Cod 175,000 homes

Renewable Energy Alternatives

Wind Power

- Use natures forces – substantial reduction in CO2 emissions
- 2009 installed global capacity 159 GW versus 5 GW in 1995
- 2009 fastest growth rate since 2001, 32%
- Estimated 2015 capacity of 290 GW per EER, 1000 GW 2020
- Wind energy leaders: 121 GW

USA	35 GW	39%
Germany	26 GW	8%
China	25 GW	100%
Spain	19 GW	15%
India	11 GW	
Italy	5 GW	

CFES 2009 - 2010 Projects

Wind Turbine Performance Advancements – Miki Amitay

- **Wind turbine blade active vibration and flow control - GEGR**
  Phase II project work to enhance synthetic jet actuators to actively control the flow of air over a turbine blade
- **Advanced vertical axis wind energy design – Aerocity LLC**
  testing of advanced vertical axis wind turbines to improve design and power output

Wind Turbine Control and Stability – Jian Sun

- Stability and control of cluster converters connected to weak grid - GE




CFES 2010 Wind Workshop

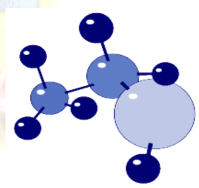
Turbine Design, Control and Monitoring & Power Conversion and Grid Integration

- Miki Amitay (RPI), *Performance Enhancement of Wind Turbine Blades Using Flow Control*
- Luciano Castillo (RPI), *Wind Turbine Array and Turbulence*
- Jason Vollen (RPI), *Potentials of Flow Control in the Built Environment: Building Integrated Wind*
- Dan Walczyk (RPI), *An Overview of Composite Wind Turbine Blade Manufacturing*
- Tom Walter (Mechanical Solutions Inc.), *Predictive Health Monitoring for Wind Turbine Generators*
- David Torrey (AEC), *Generator Options in Small & Medium Turbines*
- Ronghai Qu (GE), *Development and Challenges of Permanent Magnet Wind Generators*
- Jian Sun (RPI), *Enhancing Wind Turbine Control by Local Energy Storage*
- Mark Embrechts (RPI), *Design of Capacitor Batteries for Temporary Power Storage for Windmills*

What is Ethanol & How is it Produced?

- **What is Fuel Ethanol?**
  - Ethanol (ethyl alcohol or grain alcohol) is a clear, colorless liquid with a characteristic odor. In dilute aqueous solution, it has a somewhat sweet flavor, but in more concentrated solutions it has a burning taste. Ethanol, CH_3CH_2OH, is an alcohol, a group of chemical compounds whose molecules contain a hydroxyl group, -OH, bonded to a carbon atom.

- **Wet Corn Milling**
  - Large "chemical" plant
  - Ethanol is one byproduct
- **Dry Corn Milling**
  - Dedicated ethanol production
  - Small to medium size range
  - Fastest growing market segment
- **Cellulosic Ethanol**
  - Emerging process
  - Enables wide range of feedstocks



Renewable Energy Alternatives

Ethanol

- Clean burning gasoline replacement fuel?
- Ethanol - used in all engines up to 10%
- E85 blends – only 3% of US vehicles
- Corn represents 98% of feedstock today
- 2009 ethanol production – 36B gals (50% exports)
- 100+ US plants
- 29B gallons required to get 10% blend

New Technology – Cellulosic Ethanol

Renewable Energy Alternatives

Biodiesel

- Clean burning diesel replacement fuel? Meet ASTM D6751
- Biodiesel can be used in compression engines from 4-20%; also useable in oil burners
- Soybean oil represents 80% of feedstock today
- Canola, palm, corn, animal fat, cooking oils
- 2009 Biodiesel production capacity-2B gals
- 110 US plants (15-23% utilization)
- Congress mixed on $1 tax credit

New Technology - Algae Biodiesel

Renewable Energy Alternatives

Solar Photovoltaic

- **Global PV installed capacity 2009 - 22 GW (49%)**
- **Global annual PV production 7 GW (52%)**
- **90% is grid connected**
- **10% - residential power, commercial lighting, gate openers, telecommunications, consumer electronics**
- **Global solar sales up 41% in 2006 to $17B, $69B by 2016**
- **Clean Edge predicts 10% solar share possible by 2025**
- **Solar installations: PV 8%, thermal 2%**
- **Solar panel price parity by 2015**
- **Global Thin Film Solar cell development – 10% Market**
- **Thin film technology is the future of PV cost parity**

State/Federal level mandates will drive grid demand

Renewable Energy Alternatives

- **Hydrogen Fuel Cell Market**
- **Stationary Market – Power Plants (300KW – 50MW)**
  - UTC 275 PureCell (CT) – supply Freedom Tower in NYC
  - FuelCell Energy Inc. DFC (CT) – Industrial & Commercial
- **Mobile Market – Car, Bus, Scooter, Bike (50KW – 100KW)**
  - Toyota – FCHV with range of 516 miles
  - Honda – FCX Clarity introduced in CA June 2008
  - GM Equinox, Ford Explorer
- **Portable Market – Laptops, PDA's, Cellphone (100W – 500W)**
  - Jadoo XRT and N Gen – portable power packs
  - Voller Emerald APU – PEM technology
  - Medis Technologies (NY) – Alkaline technology

Challenge is to solve hydrogen production and infrastructure

NYSTAR CAT Program Results

The NYSTAR - Center for Advanced Technology (CAT)

-Encourage collaboration between research institutions and industry
-Promote and facilitate technology transfer
-Leverage state resources to attract funding

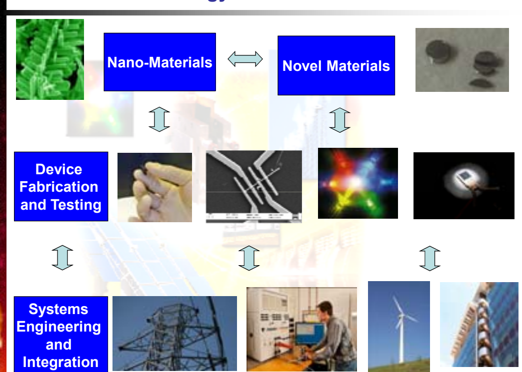
Since 2000, NYS has invested $109M in all CATs resulting in total economic impact of over $4B, including:

- over 5,000 jobs created or retained
- over $1.6B in increased sales by company partners
- over $700M in company cost savings

The investment return for each dollar invested in the CATs is > $30.00. NYSTAR CATs have worked with over 500 companies across the State.

(Source: NYSTAR)

CFES Energy Thrust and Platforms



CFES Partnership Focus

- **Business**
  - Sponsored Company Research Agreements
  - Identify RPI resources/expertise for project management
  - Collaborative research proposals
  - Technical consultation
  - Identify state and federal funding opportunities
  - Support technology transfer and licensing
  - Business plans
- **Research**
  - Materials development
  - Device fabrication
  - Device and material characterization
  - System integration and design

CFES Partnerships

- **Active Collaborating Partners**
  - At RPI
    - New York State Center for Polymer Synthesis
    - Fuel Cell and Hydrogen Research Lab,
    - Center for Automation Technology and Systems (CATS)
    - The Lighting Research Center (LRC)
    - Smart Lighting Engineering Research Center
    - Computational Center for Nanotechnology Innovations
  - Cornell University
    - Cornell Center for Materials Research (CCMR) and the Fuel Cell Institute (CFCI), Energy Materials Center (emc2)
  - Brookhaven National Lab
    - Center for Functional Nanomaterials (CFN) and Condensed Matter Physics and Materials Science (CMPMS)
  - Clarkson University
    - Center for Advanced Materials Processing (CAMP)
  - Alfred University
    - Center for Advanced Ceramic Technology (CACT)

CFES Industry Partners

APPLIED MATERIALS
Ford
CUSTOM ELECTRONICS INC
PEMEAS
STARFIRE SYSTEMS
GE
Inverters Unlimited Inc.
PrecisionFlow Technologies
Durable Systems

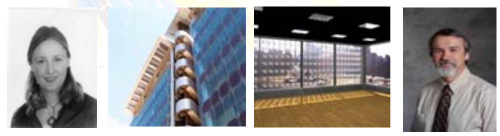
W.A.C. LIGHTING
ZEISS
SuperPower
Kodak
Advanced Energy Conversion
PRIMET
CORNING
SENSITRON SEMICONDUCTOR
Troy Research Corp

plug power
RPC Photonics
evident
GM
Crystal IS
Anteon
Applied NanoWorks
X-ray optical systems

CFES 2009 - 2010 Projects

Center for Architectural Science and Ecology (CASE) Anna Dyson, Michael Jensen (MANE)

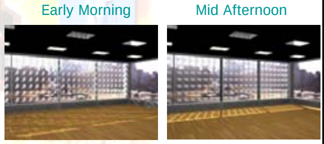
- **R&D of next generation building energy systems – SOM**
  Investigate next generation integrated building systems – wind, active phyto-remediation system for indoor air quality, on-site water purification, building thermal air control
- **Dynamic Shading Window System with integrated concentrator (IC) DOE**
  The IC solar façade 10 X 10' curtain wall prototype is being fabricated for testing of thermal and electrical performance.
  HelioOptix has been granted exclusive worldwide license.
- **DOE Building Hub – Building Energy Sustainability Systems Laboratory-BESSL**
  The project will pursue pioneering integrated systems of systems, including heating, ventilation and air-conditioning, lighting, building integrated renewable energy, building envelope, water heating, energy supply and distribution, appliances, electronics and other energy consuming devices



Dynamic PV Concentrator Modules: Design & Architecture

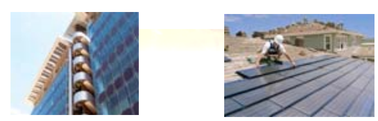
Prototype test facility used for testing PV cell and system performance

Early Morning | Mid Afternoon



Views from an animation of the tracking movement of the miniaturized concentrator PV system installed in a building façade.

IC Solar Facades:
Section 2: Market Trends for BIPV



Prototype #2: Pole Scheme Actuating Assembly (2003 - 2004)

Funding:
"Concentrating Photovoltaic Energy Systems for Integrated Intelligent Building Envelope"
NYSERDA PON 629, 3/2002-3/2008
Award: $218,997
Cost Share (Industrial and RPI): $191,745
Funding to build and test power output on the first "Proof of Concept" Prototype

Turntable Prototype #5: Glass Frame (2006-2008)

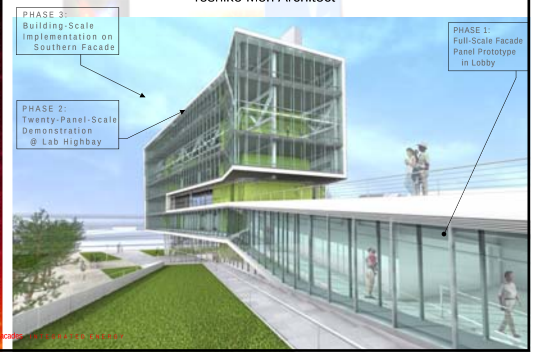
Building Applications: Full Scale Demonstration 2008-9

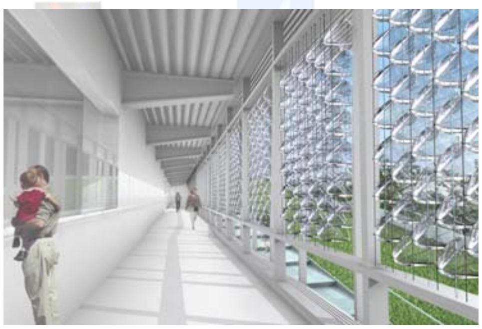
Syracuse Center of Excellence
in Environmental and Energy Systems

IC Solar Facades INTEGRATED ENERGY

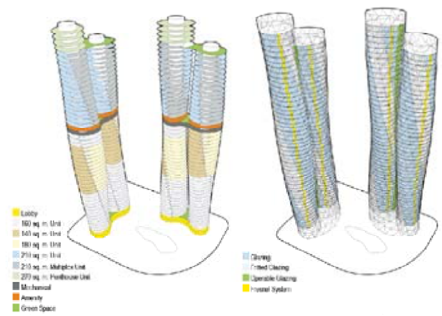
Syracuse Center of Excellence

Toshiko Mori Architect





Building Applications



RPI Building Hub Team

Multidisciplinary Problem Solving

Integrated Systems Research (Group S):
- *Adaptive building envelopes (ABE);* ***Anna Dyson, Jason Vollen SoA***
- *Distributed environmental control systems (DECS);* ***John Wen - ECSE***
- *Integrated on-site CHCP systems. Wayne Bequette* ***CHME***

Enabling Technology Development & Demonstration (Group T):
- *Intelligent controls for coordinated operations (ICO);* ***John Wen - ECSE***
- *Lighting* ***Narendran - SoA;*** *Smart lighting* ***Bob Karlicek - SoE***
- *Energy storage, waste heat recovery;* ***Michael Jensen - MANE***
- *Smart Grid integration; demand response;* ***Jian Sun, Joe Chow - ECSE***

Strategically Targeted Fundamental Research (Group F):
- *Advanced materials research;* ***Robert Hull – MSE; Shengbai Zhang - SoS***
- *Multi-scale building simulation models* ***A. Messac, M. Shephard - MANE***

Buildings account for 40% of total US energy

RPI Building Hub Team

Advanced Materials Research

- Thermochromic powders – tungsten doped VO for smart glass
- Nano-insulation materials
- Low cost single-crystal solar cells on glass
- Nano-photonic crystals to capture diffused light
- Solar cells that capture IR and UV lights
- Thermoelectric energy conversion – replace refrigerants
- Multifunctional materials for the ABE – porous concrete, eco-ceramics
- Phase-change thermal storage – reradiate heat at night
- Electrochemical storage – thin film batteries and supercaps
- Improved air and water membrane systems
- Optimized solid state lighting, overcome green gap

CFES 2009 - 2010 Projects

Advanced Lighting Technologies

- **Polarized LED's, study of titania loaded encapsulants – TRC**
  Develop polarizable LEDs for backlighting of LCD; development of encapsulation materials with high refractive index
- **Green LED's based on nanophosphors – Auterra**
  Develop phosphor based green LED with 50% more light output
- **Integrated lighting systems - WAC Lighting**
  Showcase the viability of LED technology



RPI Lighting Research Center - LRC

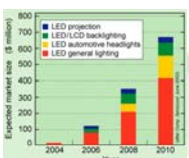
Slide 44

- **Renssealer's Lighting Research Center: World's leading research and education center for lighting**
  - 22 years of proven record of innovation in the development and effective use of lighting
  - Long-standing industrial partners for market transformation and field demonstration activities
  - State-of-the-art NIST traceable lighting laboratory and measurement equipments
  - Strengths: Technology, Human factors and Design
    - Over 50 Faculty, staff, and students to support lighting activities



Solid-State Lighting

All-semiconductor-based illumination devices



- **About 25% of all electrical energy used for lighting**
- **SSL is factor 20 / 5 times more efficient than incandescent / fluorescent lighting**
- **Electrical power savings 1.50 PWh (PetaWh; Peta = 10^{15})**
- **Fossil fuel savings 16.6 Quad* (thermal energy of fuel)**
- **Carbon emission / CO_2 emission reduction 259.7 Mtons / 952.1 Mtons**
- **Alleviate need for 133 power stations***
- **Reduction of waste, hazardous Hg, and reduction of pollution (SO_2)**
- **Solid-state lighting is an environmentally benign technology**

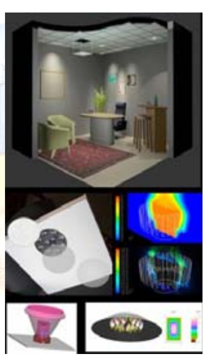
Project - Daylighting

Slide 46

- **Improved fenestration (window and skylight) designs and configurations.**
- **Active electric lighting systems to better respond to changing daylight conditions**
- **PV-integrated skylight system**
  - optimum size and shape of the skylight or light scoop to allow maximum daylight penetration while minimizing glare, heat loss/gain as well as ease of installation;
  - most efficient type and configuration of glazing;
  - best roofing materials, color, and integration options;
  - most effective means of incorporating PV panels into the skylight structure


Project- Energy Efficient Solid-State Lighting: Innovative DC-Power Grid for Building Interiors

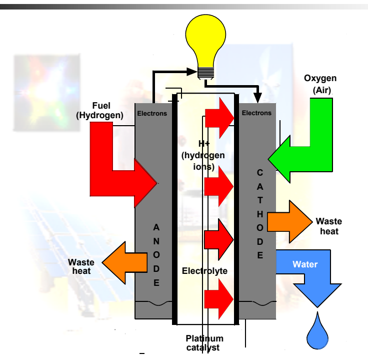
- **A modular direct current (dc) grid system**
  - To support innovations in solid-state lighting, active controls, renewable energy technologies and maximize energy savings
  - To allow for easy reconfiguration of lighting as space and buildings needs change
  - To combine grid power and on-site generated PV power for energy savings and load shedding needs (no energy storage)
- **Building materials integrated solid-state lighting systems**
  - Novel, highly efficient, cost effective
- **Modelling, prototyping, system integration**
  - lighting, electronics and electric power, optics, mechanical and thermal



Collaboration

- **Rensselaer's Lighting Research Center is presently working with industry to accelerate the development of energy efficient solid-state illumination systems and widespread use in lighting applications.**

How Does A Fuel Cell Work

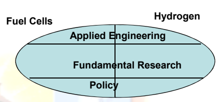


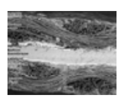
Fuel Cells Compared

Type/Operating Temp	Applications	Comments
Alkaline 80 –100 C	Space	Used by NASA on space missions. Efficiencies can reach 70%. Reliable but expensive.
Proton Exchange 80 – 100 C	Premium power and Transportation	Field units in demonstration. Limited Commercialization. El. efficiencies reach 40%. Limited heat recovery. Potential for low cost.
Phosphoric Acid 200 – 220 C	Stationary power and large vehicular (buses)	Most mature and commercially available. In use at hospital, hotel, school, airport terminal, and small utility plants. Efficiencies reach 40% and 70% with cogeneration.
Molten Carbonate 600 – 650 C	Distributed Power and small-scale utility	Commercially available. In use at WWTPs and commercial buildings. Efficiencies approach 50% and 80% with cogeneration.
Solid Oxide 750 – 1000 C	Stationary and utility power & Transportation	Currently in demonstration (100 kW). Efficiencies approach 55% and 80% with cogeneration. Various designs and Applications.

Research Themes

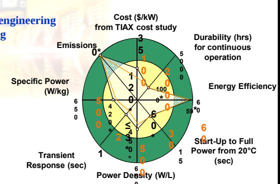
Fuel Cells
- PEM (PBI & PFSA)
- SOFC
- MCFC
- PAFC
- AFC
- Micro





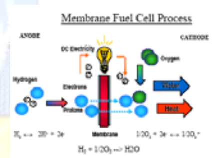
Basic/fundamental research
- Polymers and membranes
- Electrodes & catalysts (architecture & oxygen catalysis)
- Materials – plates, GDL's, solid state ionic conductors
- Imaging
- Modeling
- Controls – advanced sensing, systems engineering
- Manufacturing/mechanical engineering
- Bio-fuel cells

Hydrogen
- Electrolysis, separation, purification
- Hydrogen storage
- Photo-electrolysis



Primary Goals and Objectives

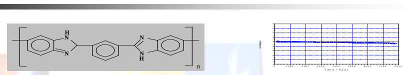
- Coordinate and facilitate fuel cell and hydrogen research at RPI
- Establish working relationship with our CAT Partners – Cornell, Brookhaven
- Develop a broad portfolio of activities from basic to applied research
- Develop industrial partnerships



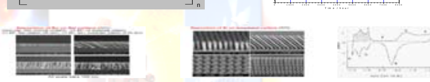
Building upon the existing strengths at RPI

Fuel Cell Activities

PBI



Electrodes & Catalysts



Nano-based Composites

Imaging (NIST)

Polymer Modeling

CFES 2009 - 2010 Projects

Fuel cell and Hydrogen Research Lab – Dan Lewis

- **Investigation of SOFC barrier coatings - GEGR**
  Two year project on Cr-evaporation from metal-oxide and spinel interconnects and coating optimization studies

- **Degradation studies of SOFC – ENrG**
  Provide cell test support and post-mortem analysis on industry standard fuel cells to determine failure modes



CFES Projects – Energy Materials

- Develop high energy density Ultracapacitors, IOXUS – Ramanath NY BEST PON 1704 Award
- Nano-engineered anode architectures for Li Ion batteries - RPI Koratkar, Lu – NY BEST PON 1704 Award
- Silicon based technology for highly efficient TPV energy conversion Applied Materials – Lin
- Development of GaSb, InGaSb thin film TPV for SiC – Durable Systems – Dutta
- Ultra-High ZT nano-structured BiTe for high efficiency refrigeration devices – Ramanath, Borca-Tasciuc
- Testing and evaluation of advanced carbon materials for flexible Li ion batteries – Paper Battery – Pethuraja, Ramanath
- Naanofluidic power generation using CNT and graphene nanomaterials – Advanced Energy Consortium – Koratkar, Shi

CFES Projects

Synthesis and Characterization of Nano-structured Materials for Energy Conversion and Storage

Projects:

- Branched nanorods for thermoelectric power generation and heat pumps
- Silicon nanorod anodes for Li-ion rechargeable batteries
- Flexible nanocomposite thin film energy storage devices
- Biaxial thin film semiconductor CdTe on glass
- High heat flux nanowires for TE devices

Photovoltaics

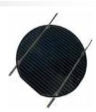
- Photovoltaics (PV) or solar cells are semiconductor devices that directly convert sunlight into direct current (DC) electricity
- Groups of PV cells are electrically configured into modules and arrays
- With power conversion equipment, PV systems can produce alternating current (AC) and can operate in parallel with, and interconnected to, the utility grid.

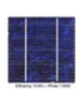
PV Cell Technologies

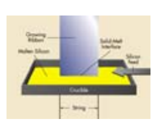
- **II-VI Oxide Semiconductor Cells**
  - (ZnMnTe/Zn/ZnO)
- **III-Nitride Based Tandem Cells**
  - (GaN /AlN)
- **3D Cells using Semiconductor Nanostructures**
  - II-VI, III-V, IV-IV quantum dots
- **III-V Bulk Semiconductor Cells**
  - GaSb, GaInSb, GaInAs

Photovoltaic Technologies - Silicon

- Silicon
  - Single Crystal
    - Ingots drawn using Czochralski process
    - Ingots cut to produce wafers
    - Pros
      - Highest efficiency silicon cells
    - Cons
      - Ingots are cylindrical leading to round wafers
      - Most costly among all silicon technologies
  - Poly-Crystal
    - Ingots cast in bricks
    - Ingots cut to produce wafers
    - Pros
      - Ingots can be cut into square wafers
      - Less costly to produce than single crystal
    - Cons
      - Lower efficiency than single crystal
  - Ribbon
    - Films drawn from molten silicon
    - Pros
      - Lower silicon losses
    - Cons
      - Slow growth rates

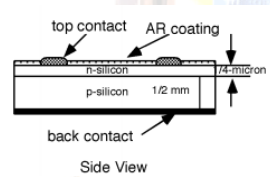


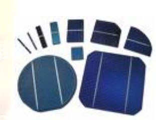




Photovoltaic Technologies - Silicon

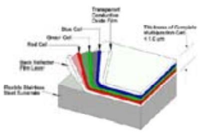
- Silicon cells all have the same general construction
  - p-type silicon, typically boron (bottom)
  - n-type silicon, typically phosphorus (top)
  - Anti-reflective coating (TiO2, SiN)
  - Metal contacts

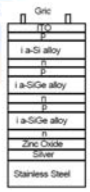




Photovoltaic Technologies – Thin Film

- **Amorphous Silicon**
  - Typically deposited by chemical vapor deposition from silane and hydrogen gas
  - Pros
    - Less material usage
    - Roll-to-roll manufacturing
    - Flexible cells
  - Cons
    - Lower efficiency





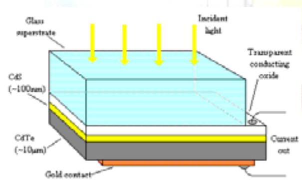
Photovoltaic Technologies – Thin Film

- **Copper Indium Gallium Selenide (CIGS)**
  - Unlike basic silicon solar cells which have a simple p-n junction, CIGS cells are heterojunction cells
  - Pros
    - Less material than crystalline silicon
    - Roll-to-roll manufacturing possible
    - Flexible
  - Cons
    - High manufacturing costs
    - Lower efficiency than silicon

Thin-Film Space Solar Cell Schematic & Photograph

Photovoltaic Technologies – Thin Film

- **Cadmium Telluride (CdTe)**
  - CdTe is p-type layer
  - CdS is n-type layer
  - ITO (Indium Tin Oxide) is top conducting layer
  - Pros
    - Small amount of raw materials
  - Cons
    - Cadmium

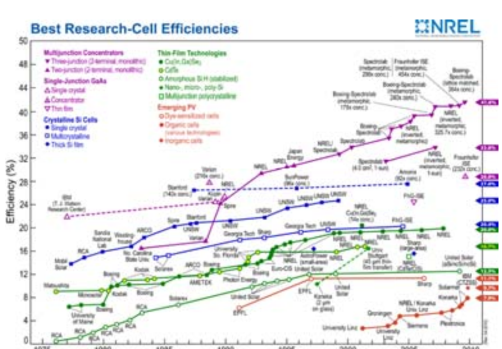


Photovoltaic Technologies – Organic/Polymer

- **Relatively new technology**
- **Built from thin-films of organic semiconductors**
- **Pros**
  - Very low materials costs
  - Roll-to-roll manufacturing possible
- **Cons**
  - Low efficiency
  - Degradation

Conformal Solar Cells

PV Cell Efficiency



CFES 2009 - 2010 Projects

Distributed Generation (DG) Test Bed - NYSTAR funded project to investigate impact of DG on the grid

RPI – Project Mgt - Grid simulator/test bed hardware/software

- **PACE** – Policy overviews on facilitating role of DG, compensating DG owners, design of fair tariffs and incentive programs
- **IUI** – Fuel cell inverter, solar panel system array and inverter
- **AEC** – Design and delivery of wind generator and inverter
- **Sensitron** – Power factor control method (PFC) and FPGA
- **RPC** – Optimized thin film LED test rack, driver performance studies

Building block for Smart Grid and PMU Lab, Smart Grid course development

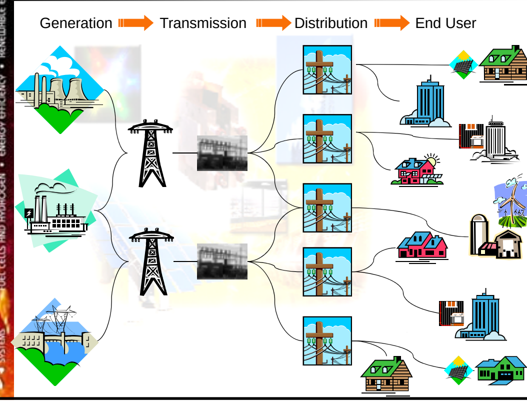
Impact of Renewable Generation on the Grid

- Renewable energy generation sources represent a considerable number of units when compared with the total
- Unfortunately, they represent a small percentage of the total MWh generated
- These renewable energy sources are small when compared with traditional central station generation sources
- Typically, these generation sources are located at the point of use and are defined as distributed generation (DG)

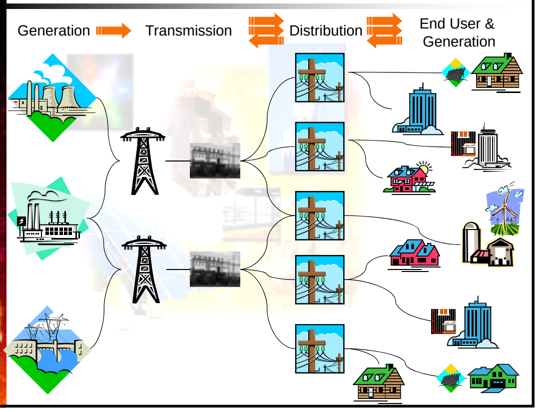
Energy Source	Number of Generators	Percent of Total Units
Coal	1,522	9.1%
Petroleum	3,753	22.3%
Natural Gas	5,467	32.5%
Other Gases	102	0.6%
Nuclear	104	0.6%
Hydro	4,143	24.7%
Renewables	1,671	9.9%
Other	45	0.3%
Total	16,807	

Energy Source	Percent of MWh	Average Unit Size (MW)
Coal	49.7%	221
Petroleum	3.0%	17
Natural Gas	18.7%	80
Other Gases	0.4%	22
Nuclear	19.3%	1015
Hydro	6.5%	23
Renewables	2.3%	14
Other	0.1%	21

Current Electric Power System



Electric Grid of the Future



Implications of DG on Grid

- Net metering regulations exist in 41 states and are applicable to most renewable technologies
- Many renewable generation technologies produce direct current (DC) power which requires power electronics to invert output to alternating current (AC)
- Several of the renewable technologies, such as photovoltaics and wind are intermittent sources
- As these renewable energy sources are “behind the meter”, utilities do not have control of these generators

Electrical implications of a high penetration and diversity of distributed resources on the utility distribution grid needs to be examined

CFES 2010 DG Test Bed Project

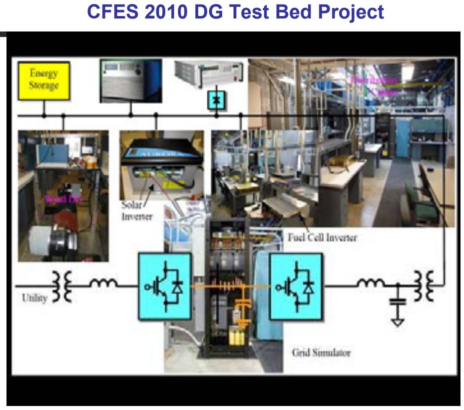
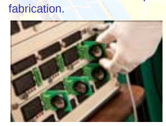


Fig. 1: The distributed generation test-bed currently under development at RPI.

CFES Energy Materials and Device Lab (EMDL)

Solar and Battery Test Stations - suite of tools for fabricating, processing, characterizing and testing a variety of materials and device structures for new energy applications. Broadly, the facilities can be divided into five test stations:

- **Photovoltaic test bench**
  - Efficiency, power factor, current-voltage and spectral response/quantum efficiency from 350 nm to 1800 nm.
- **Battery and Ultracapacitor fabrication and testing station**
  - Coin cell fabrication in programmable glove box, charge/discharge cycle testing, cyclic voltammetry and impedance spectrometry.
- **Spectrophotometric facility**
  - Absorption, transmittance and reflectance of light from 175 to 17000 nm.
- **BET/Sorption analysis facility**
  - Physisorption, chemisorption, vaporsorption, BET surface analysis, mass spectrometer, and hydrogen storage characteristics of nanoporous materials.
- **Rapid wet chemical processing**
  - Environmental controlled spin coater, dip coater for low cost energy device fabrication.



Energy Initiatives on Campus

- **Solar**
  - 46 kW re-installation of fixed photovoltaic (PV) system on Fieldhouse – new data acquisition package scheduled Spring 09 - ***SunViewer***
  - 4 kW fixed and sun tracking system installed on East Campus Athletic complex
  - DG Test Bed installation on Jonsson Engineering

- **Wind**
  - 10 kW three blade wind turbine installed on the east side of campus. Power is transmitted to the campus power grid. New data acquisition package – Fall 10

- **Biodiesel**
  - Rensselaer is currently in the process of designing and installing a biodiesel processing facility that will convert the waste cooking oil from the Dining Halls into a useable fuel for campus vehicles.

CFES Outreach

- **CFES Industrial Outreach (Sponsor)**
  - Workshop on Next Generation Wind Power - May 12, 2010
  - New Energy New York - Aug 2010
  - World Energy Conference - September 2010
  - Advanced Energy Conference - Nov 2010
- **Business**
  - Sponsored Company Research Agreements
  - Identify RPI resources/expertise for project management
  - Collaborative research proposals
  - Technical consultation
  - Identify state and federal funding opportunities
  - Support technology transfer and licensing
  - Business plans
- **Research**
  - Materials development
  - Device fabrication
  - Device and material characterization
  - System integration and design

CFES Outreach

THANK YOU

Questions?