Center for Future Energy Systems
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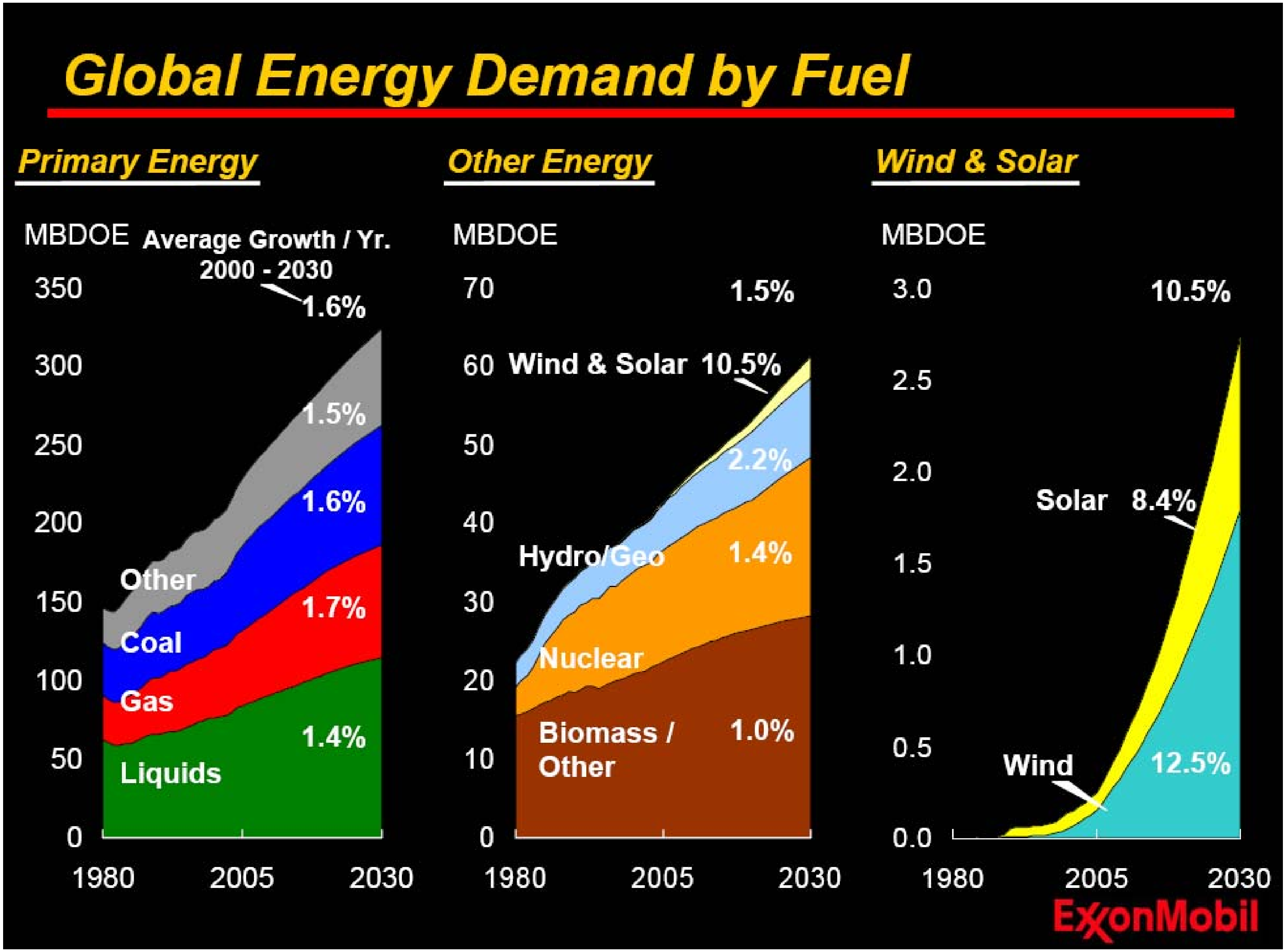
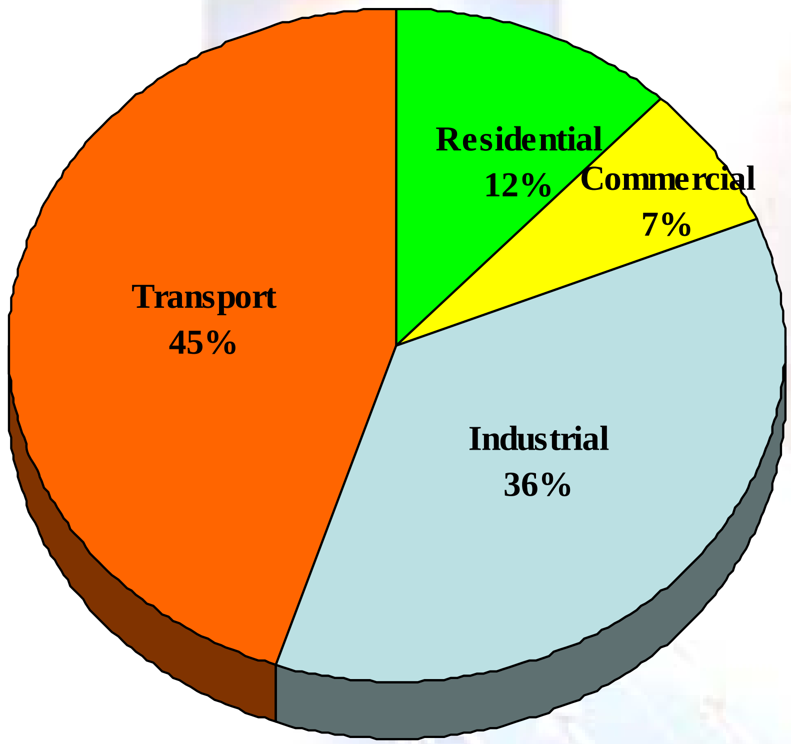
World Energy Consumption (2000 – 2030)



United States Energy Usage by Sector

Net Energy Consumption:
60 Quadrillion Btus



Estimates indicate that over the next 20 years, U.S.'

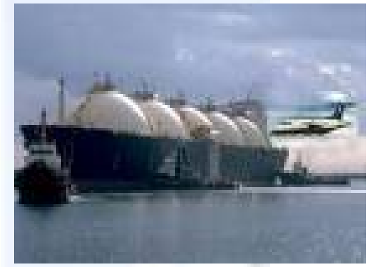
- oil consumption will increase by 33 percent,
- natural gas consumption by well over 50 percent, and
- demand for electricity will rise by 45 percent.

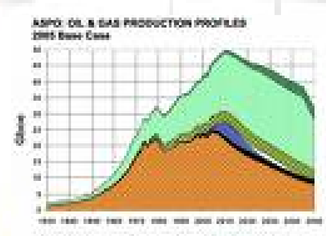
Americans spend over $1 million per minute on Energy

Source: EIA

The Drivers

- **Fuels**
  - Energy Insecurity, Price Volatility, Peak Oil, Environmental Awareness, etc.
  - Federal Policy
- **Electricity**
  - Renewable Portfolio Standards, Electric Utility Deregulation, Aging T&D Infrastructure, Demand and Supply, End-Use Efficiency, Pollution
  - State & local regulation



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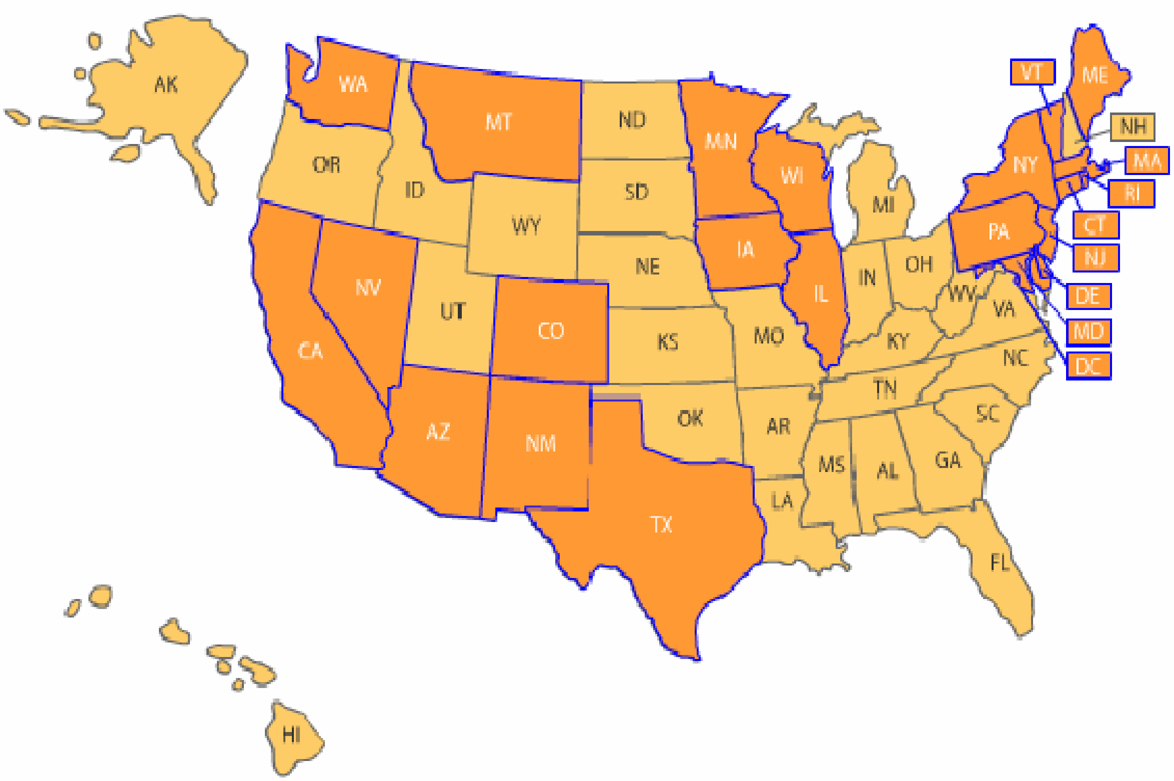
States with Renewable Portfolio Standard



Ex: New York's PSC adopted RPS in Sept 2004

Main Tier

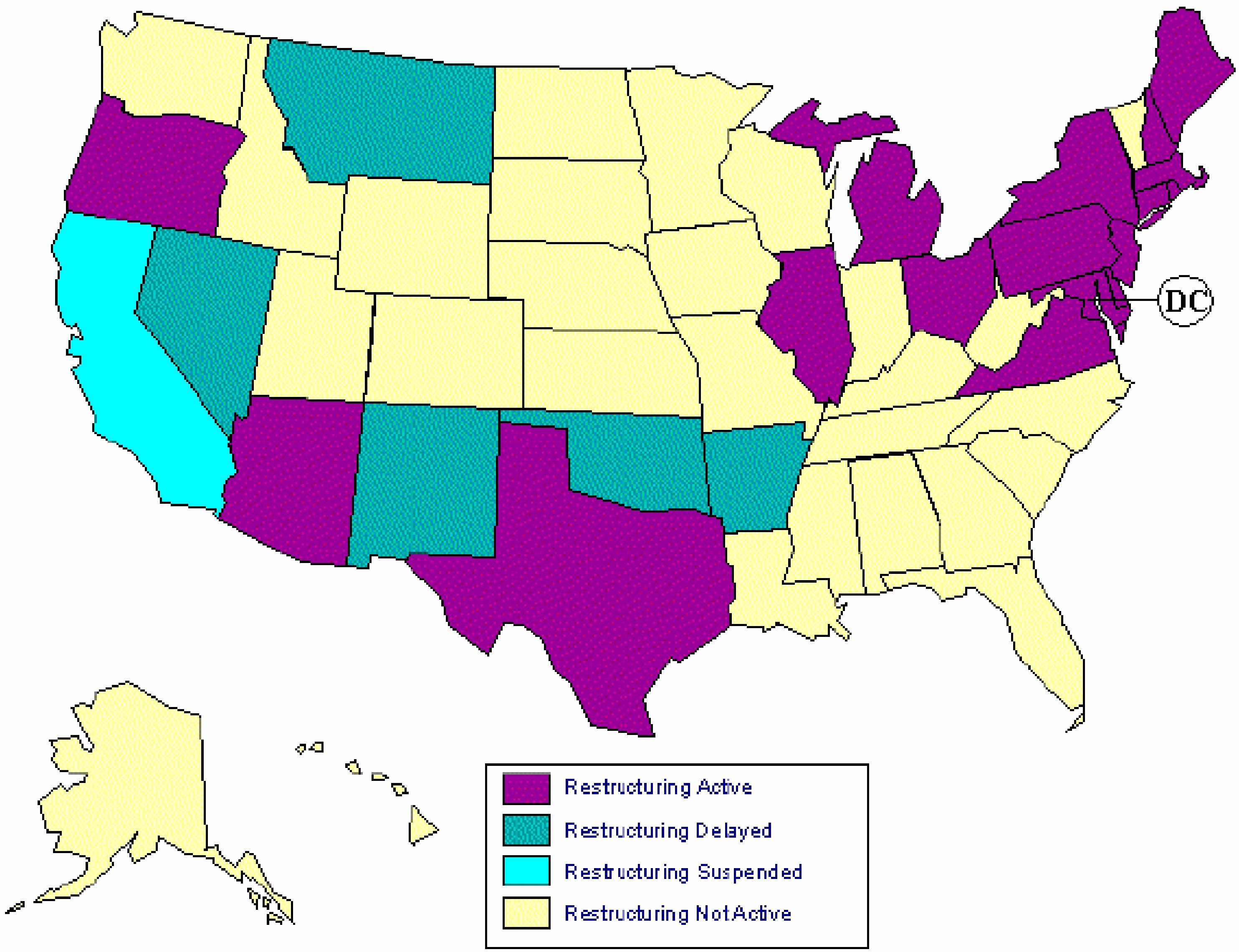
3,583 MW @ 0.38 CF 11,988,888 MWh/yr
Wind, Biomass, Biofuel, etc
Total Funds: $762 million (2006-'13)

Customer Tier

44 MW @ 0.61 CF 239,778 MWh/yr
Solar PV, Small wind, Fuel Cells, and Farm ADG
Total Funds: $130 million (2006-'13)

State	Amount	Year
Arizona	15%	2025
California	20%	2017
Colorado	10%	2015
Connecticut	10%	2010
District of Columbia	11%	2022
Delaware	10%	2019
Hawaii	20%	2020
Iowa	105 MW	
Illinois	25%	2017
Mass	4%	2009
Maryland	7.5%	2019
Maine	10%	2017
Minnesota	1,125 MW	2010
Montana	15%	2015
New Jersey	6.5%	2008
New Mexico	10%	2011
Nevada	20%	2015
New York	25%	2013
Pennsylvania	18%	2020
Rhode Island	15%	2020
Texas	5,880 MW	2015
Vermont*	10%	2013
Washington	15%	2020
Wisconsin	2.2%	2011

Status of Electric Utility Deregulation



Electric Utility Deregulation

"You got to be very careful If you don't know where you're going, because you might not get there," Yogi Berra

- Fundamentally a half-hearted effort
  - ISO/RTO bureaucracies
  - ISOs operate both grid and market
  - Utilities own distribution network and customer account
  - Consumer participation too weak
- Policies/programs such as LMP, SCR/DR, Capacity Payment, Transmission Congestion Contracts Mitigation Payment

- The promise of lower prices – what low prices?
- The promise of choice – what choice?
- The Promise of new technology – what new technology?

Wind Power - Options

- **Small Wind**

  Pros: State and federal incentives, offsets retail price, netmetering

  Cons: High-cost, difficult to site, low efficiency, low capacity factor

- **Large Wind**

  Pros: State and federal incentives, mature technology, competitive price

  – Cons: Siting/Permitting, land lease, Interconnection, intermittency ($0 bid)

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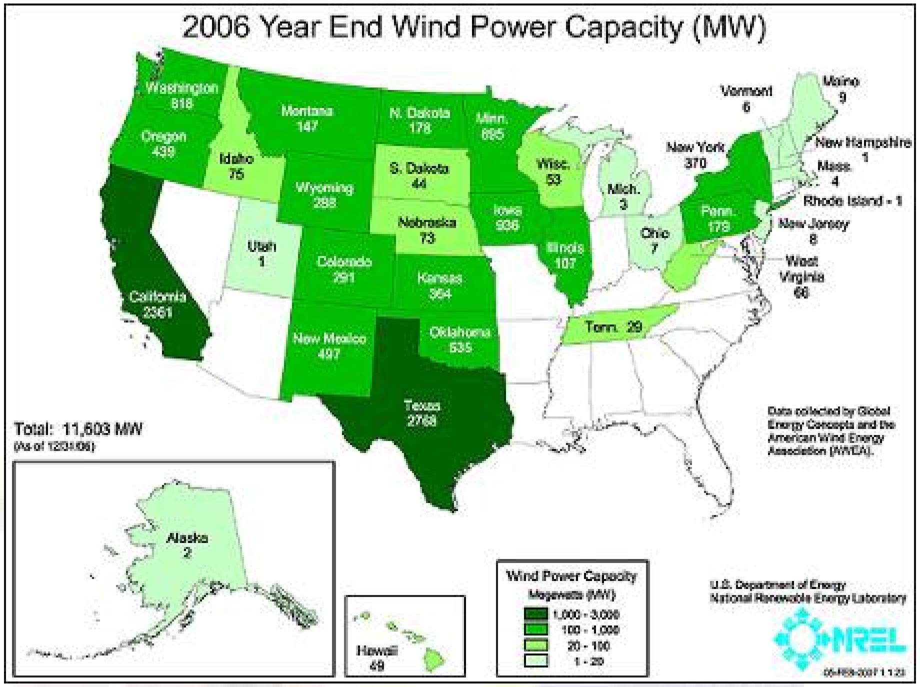
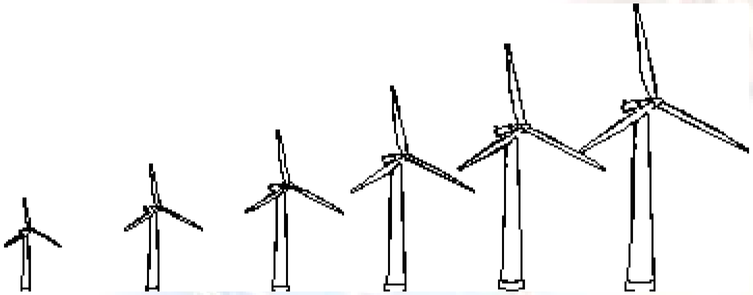
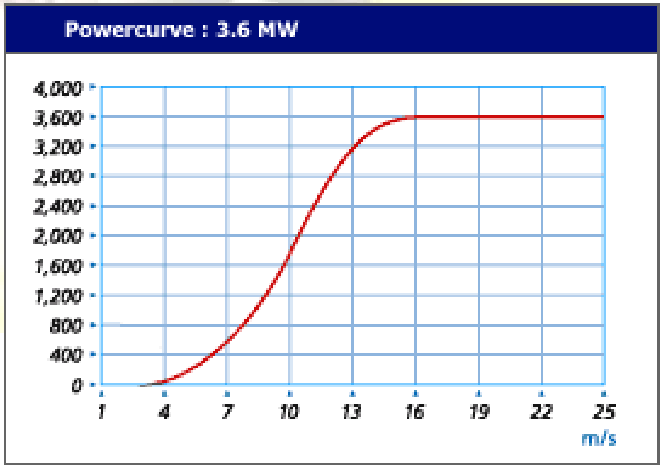
Wind Power

- The US has an installed wind power capacity of 11,600 MW (globally 74 GW)
- Long-term technical potential of wind energy is believed to be 5 times current global energy consumption or 40 times current electricity demand.
- This would require covering 12.7% of all land area with wind turbines - with 6 large wind turbines per square kilometer.

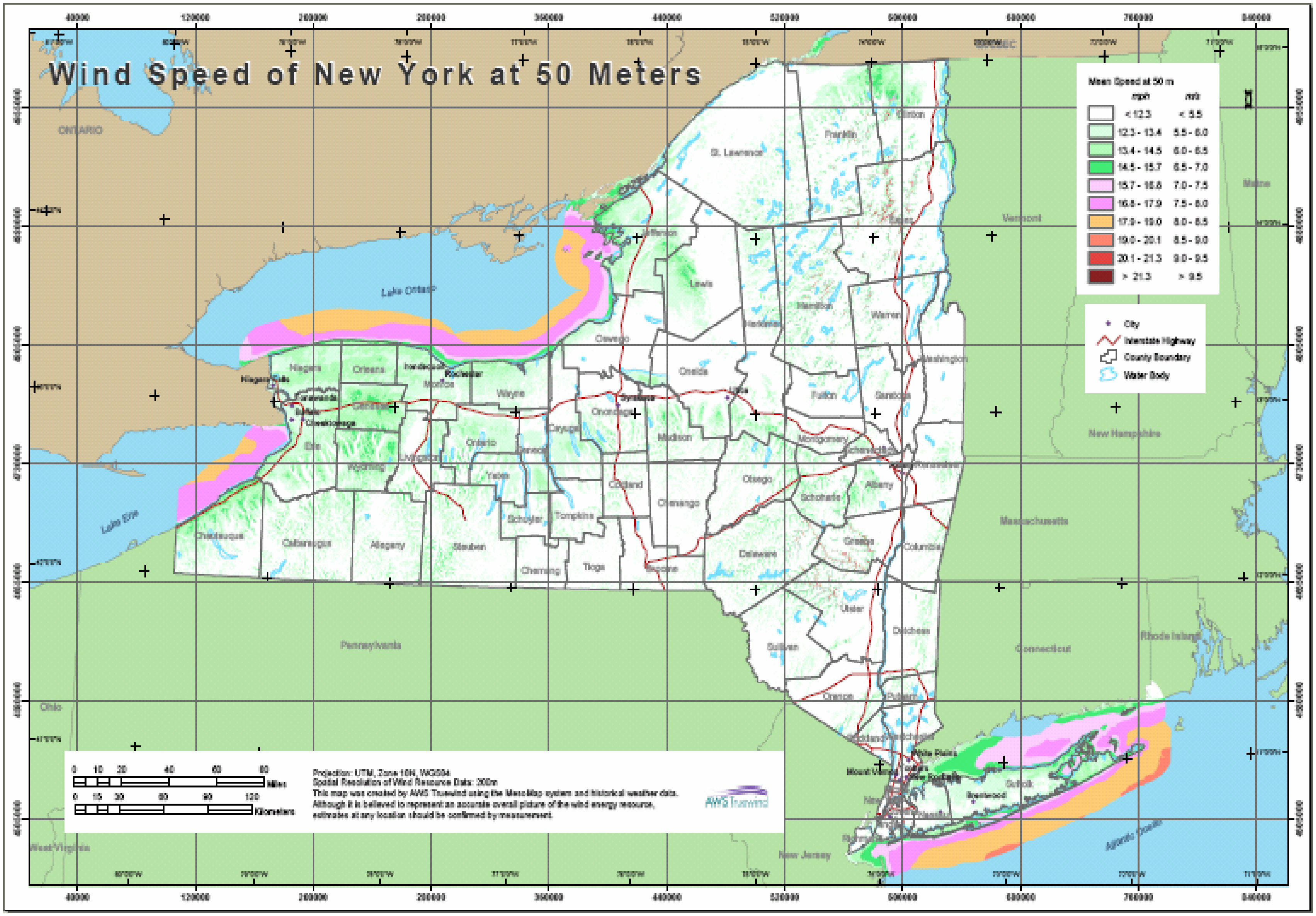




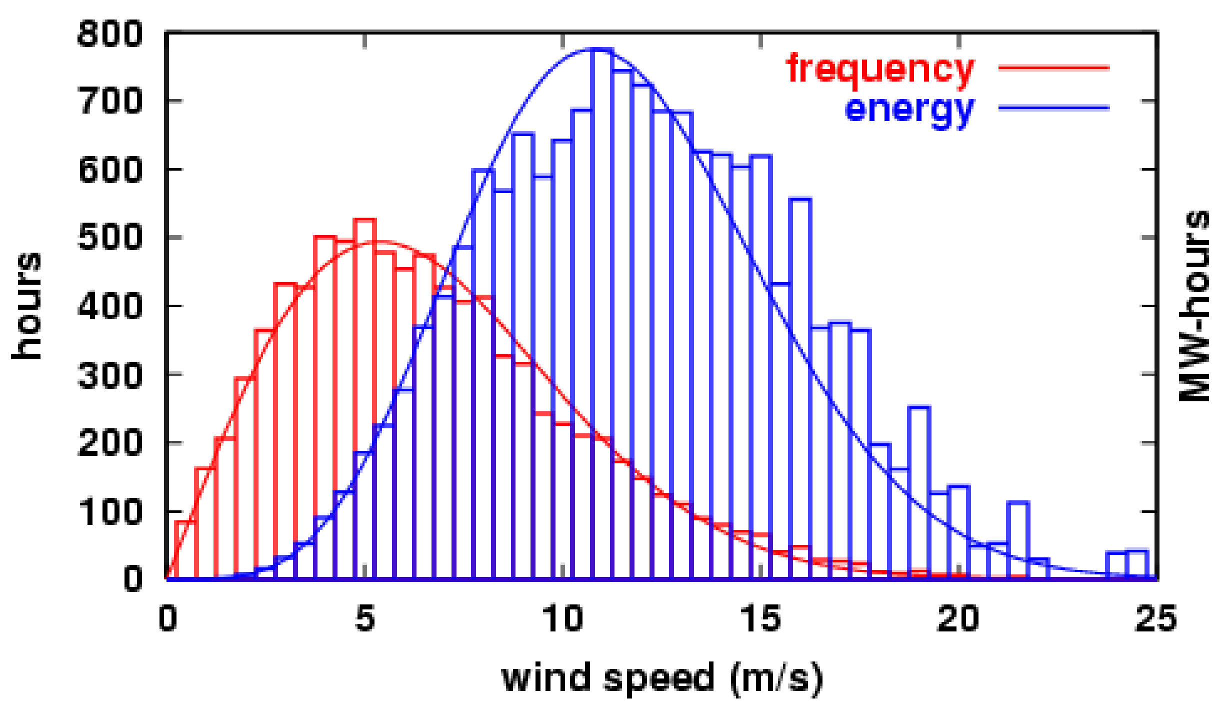
	1981	1985	1990	1996	1999	2006
Rotor (meters)	10	17	27	40	50	104
Rating (KW)	25	100	225	550	750	3,600
Annual MWh	45	220	550	1,480	2,200	15,000



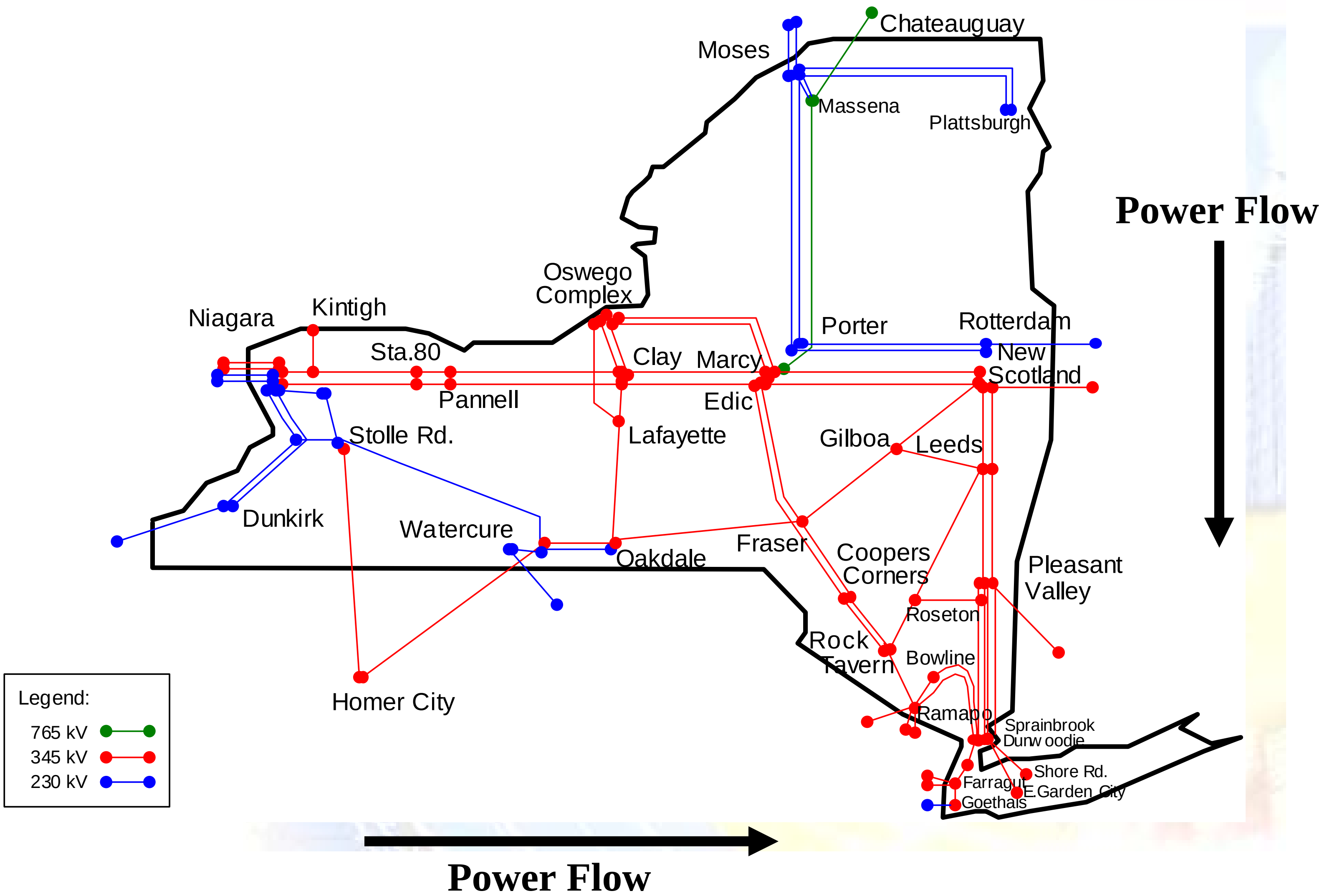
New York Wind Speed Map



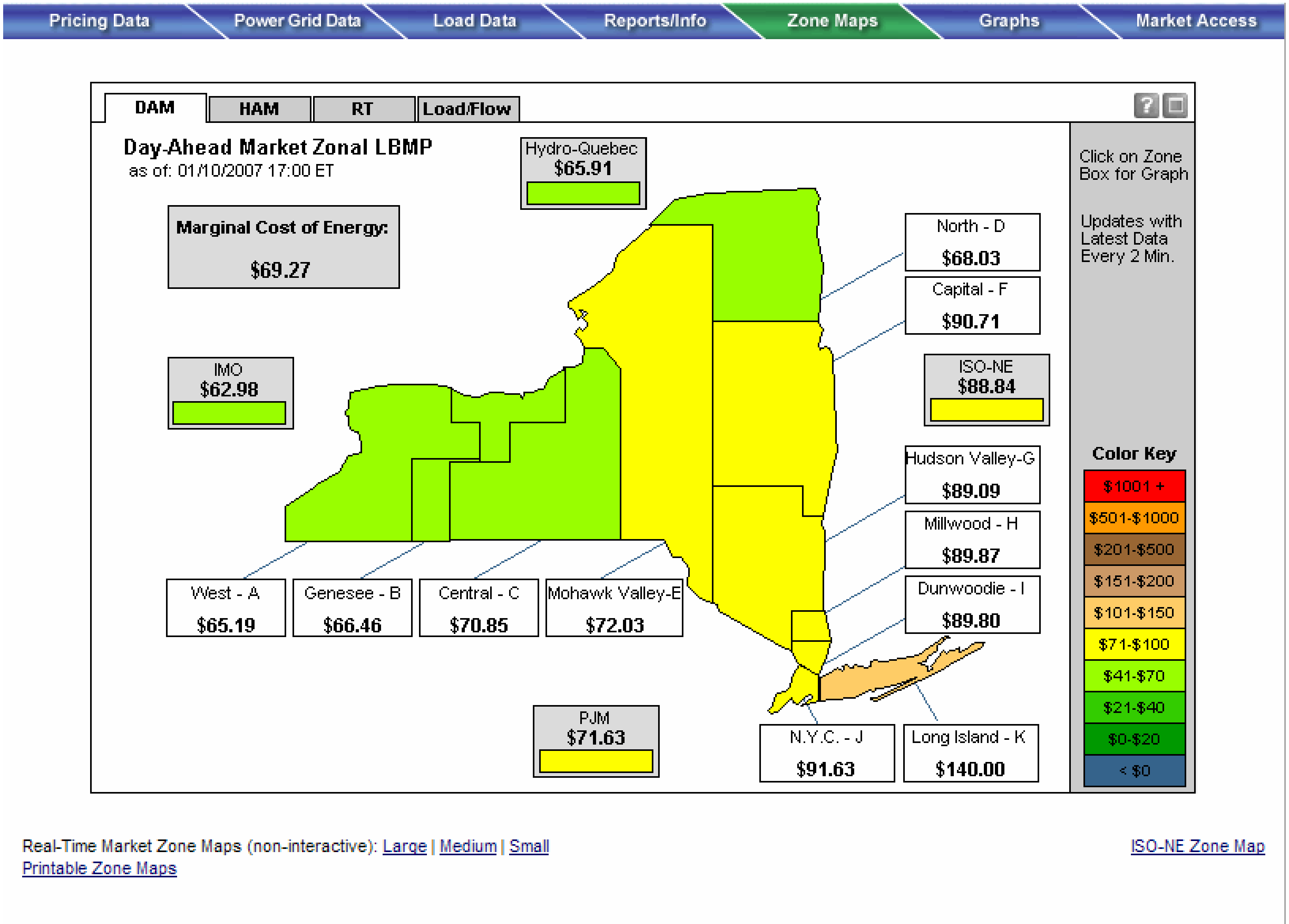
- In 2006, worldwide capacity of wind-powered generators was 74 gigawatts, their production was less than 1% of electricity used
- Wind energy accounts for 23% of electricity use in Denmark, 4.3% in Germany and around 8% in Spain.
- Globally, wind power generation more than quadrupled since 1999.
- Wind power is used in large scale wind farms for electrical grids and as small individual turbines for providing electricity in isolated locations.



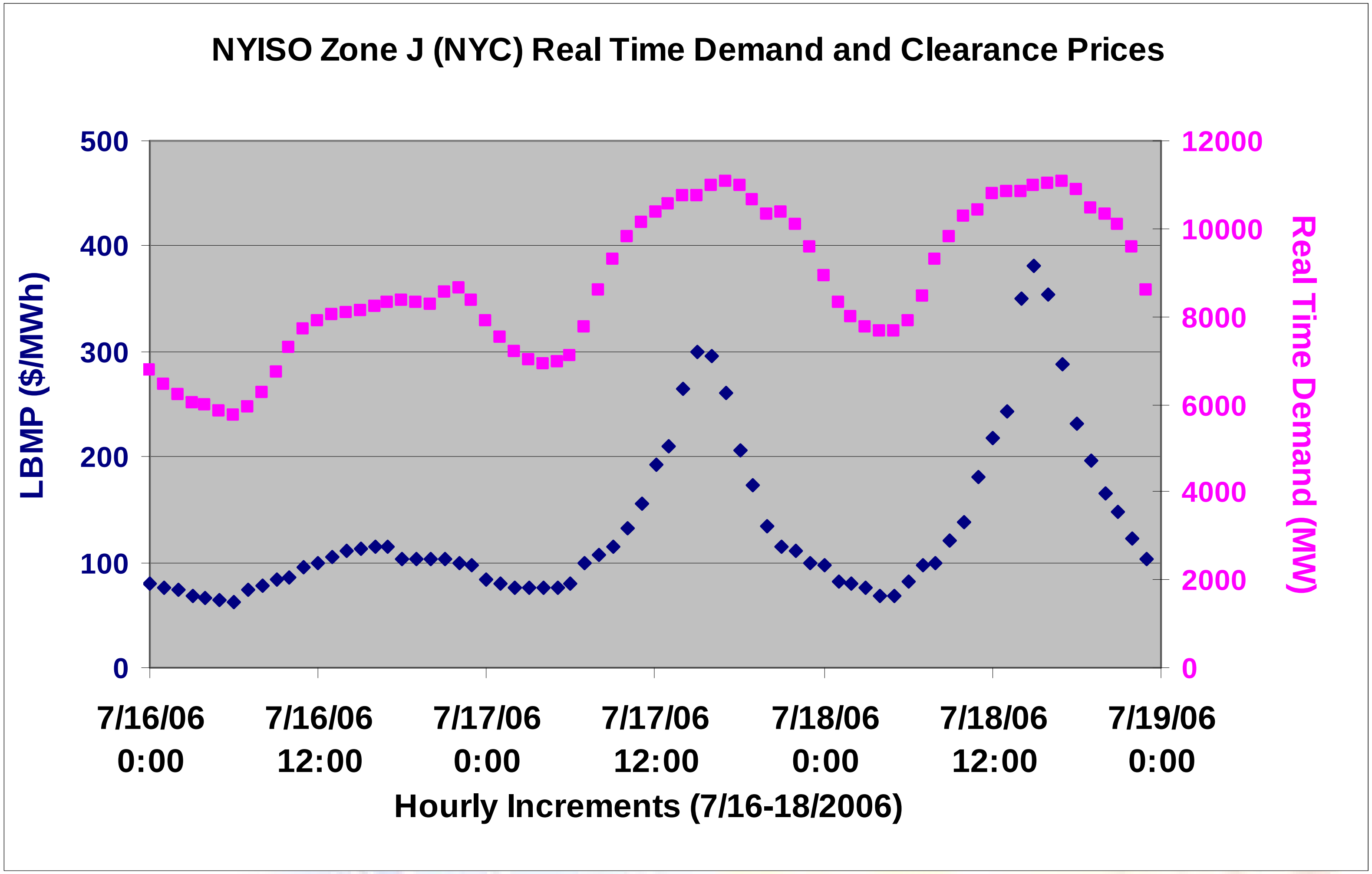
New York State Electricity Flow



NYISO – Eleven (11) Electric Power Control Zones



Demand and Price Relationship

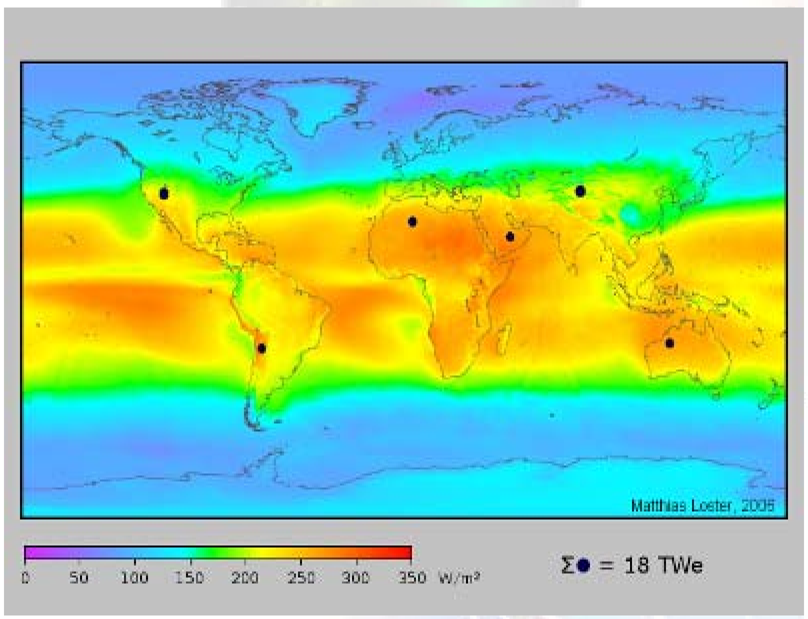


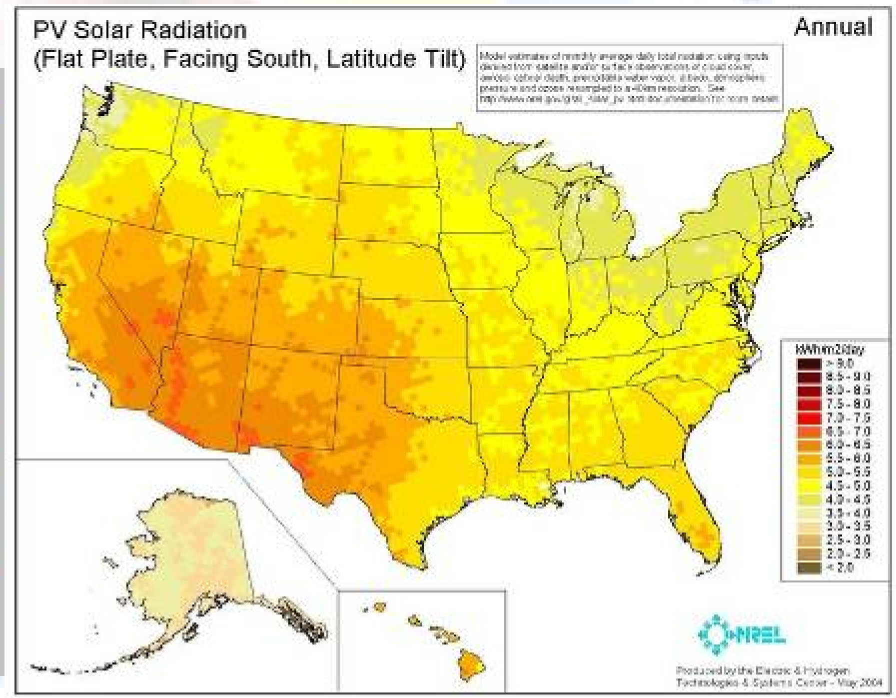
Real time demand and location based marginal price (LBMP) for NYISO Zone J Control Area on a day of record-setting demand (July 17, 2006) and the preceding and following days.

Solar/Photovoltaic Energy

- Solar power is the technology of obtaining usable energy from the light of the Sun. Sun provides approximately 1 kw/m^2 on earth's surface.
- Solar energy has been used in many traditional technologies for centuries and has come into widespread use where other power supplies are absent, such as in remote locations and in space.
- Solar energy is currently used in a number of applications:
  - Heating (hot water, building heat, cooking)
  - Electricity generation (photovoltaics, heat engines)
  - Desalination of seawater.
- A solar cell (or photovoltaic cell) is a semiconductor device that converts photons into electricity. Fundamentally, the device needs to fulfill only two functions: photogeneration of charge carriers (electrons and holes) in a light-absorbing material, and separation of the charge carriers to a conductive contact that will transmit the electricity. This conversion is called the photovoltaic effect.

- Solar power systems installed in the areas defined by the dark disks could satisfy the world's current total primary energy demand (assuming a conversion efficiency of 8%). That is, all energy currently consumed, including heat, electricity, fossil fuels, etc., would be produced in the form of electricity by solar cells. The colors in the map show the local solar irradiance averaged over three years from 1991 to 1993 (24 hours a day) taking into account the cloud coverage.

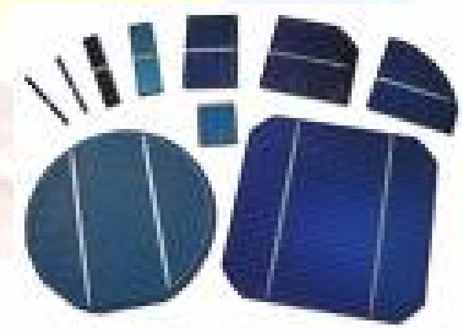


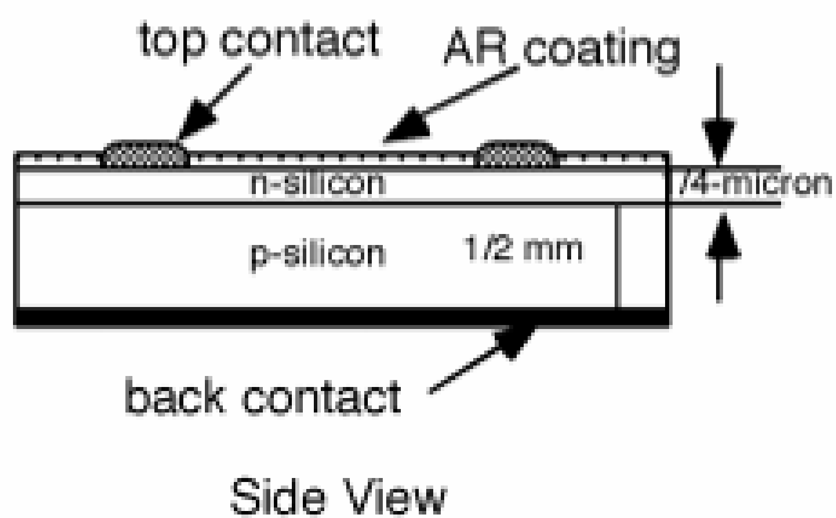


Photovoltaic Technologies - Silicon

Silicon cells all have the same general construction

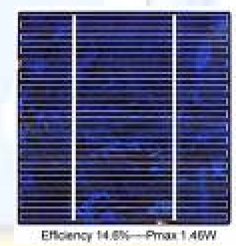
- **p-type silicon, typically boron (bottom)**
- **n-type silicon, typically phosphorus (top)**
- **Anti-reflective coating (TiO2, Si3N4)**
- **Metal contacts**

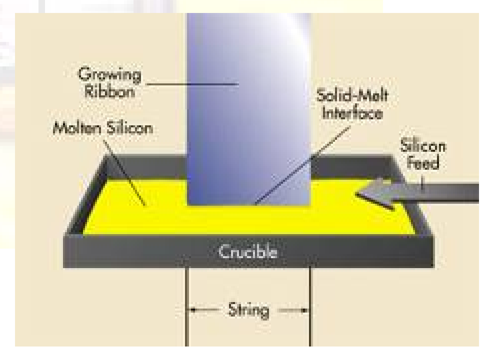




Photovoltaic Technologies - Silicon

- **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 and most expensive among all silicon technologies
- **Poly-Crystal**
  - Ingots cast in bricks
  - Ingots cut to produce wafers
  - Pros: Ingots can be cut into square wafers and 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

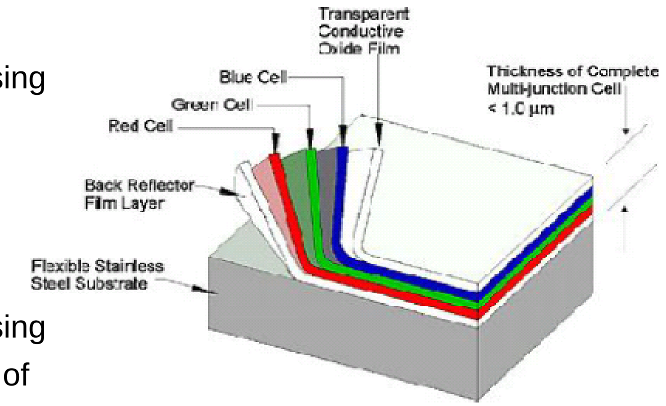




Photovoltaic Technologies – Thin Film

Amorphous Silicon

- CVD using silane and hydrogen
  - ➢ Pros: Less material, flexible cells, and roll-to-roll processing
  - ➢ Cons: Lower efficiency



Copper Indium Gallium Selenide (CIGS)

- Flexible metal substrates offer an alternative to wafer-Si based cells
  - ➢ Pros: Less material, flexible cells, and roll-to-roll processing
  - ➢ Cons: High-manufacturing costs, Indium (over a quarter of world's In)

Cadmium Telluride (CdTe)

- CdTe p-type layer w. CdS n-type layer and ITO conducting layer
  - ➢ Pros: Less material, flexible cells, and roll-to-roll processir
  - ➢ Cons: Cadmium

III-V Triple Junction Concentrator Cells

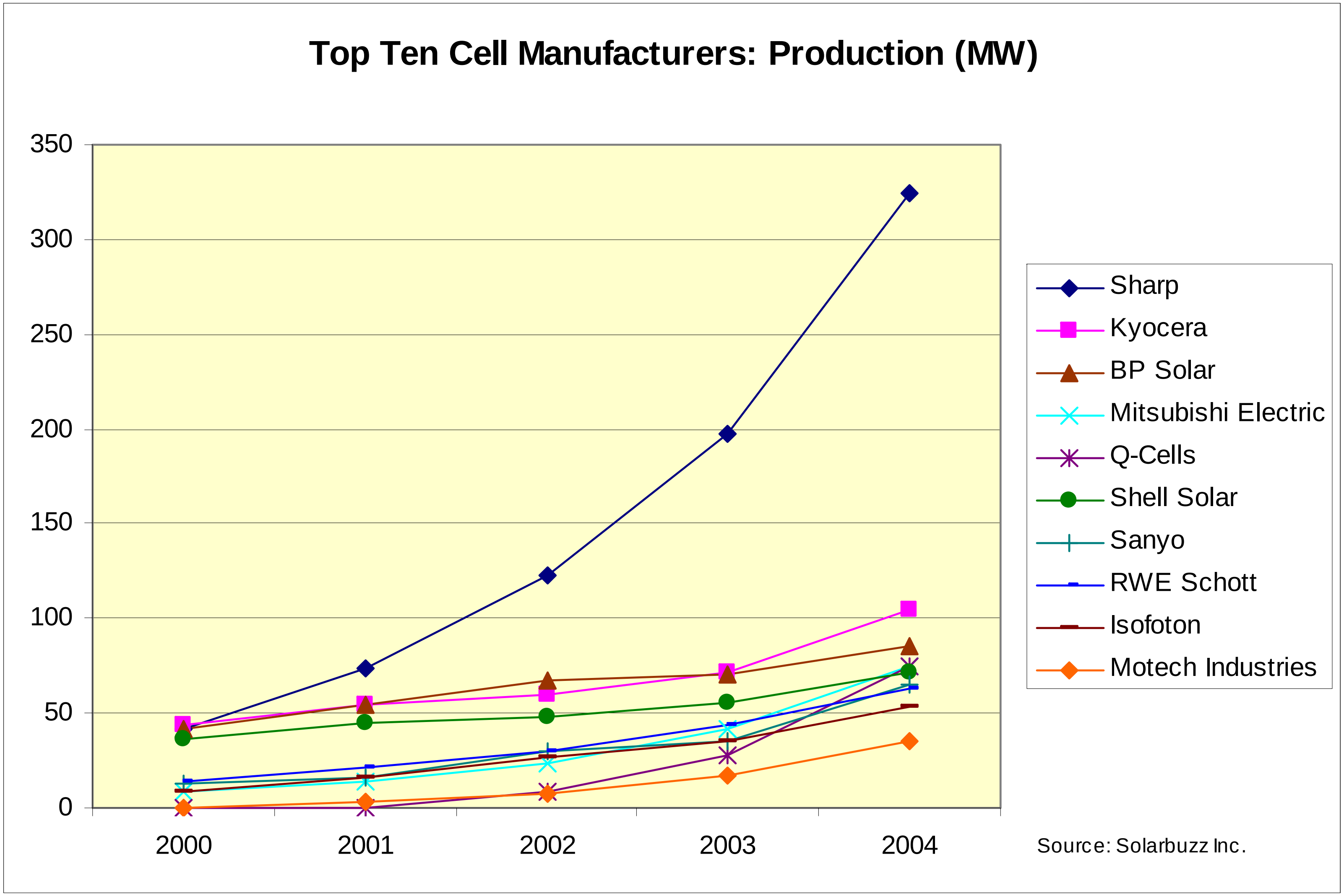
- Metalorganic vapor phase epitaxial growth on Germanium substrate
  - ➢ Pros: High efficiency (39%)
  - ➢ Cons: High-manufacturing costs, smaller cells

Polymer/Organic

- Thin-films of organic semiconductors
  - ➢ Pros: Low materials costs and roll-to-roll manufacturing
  - ➢ Cons: Low efficiency and degradation

Conformal Solar Cells

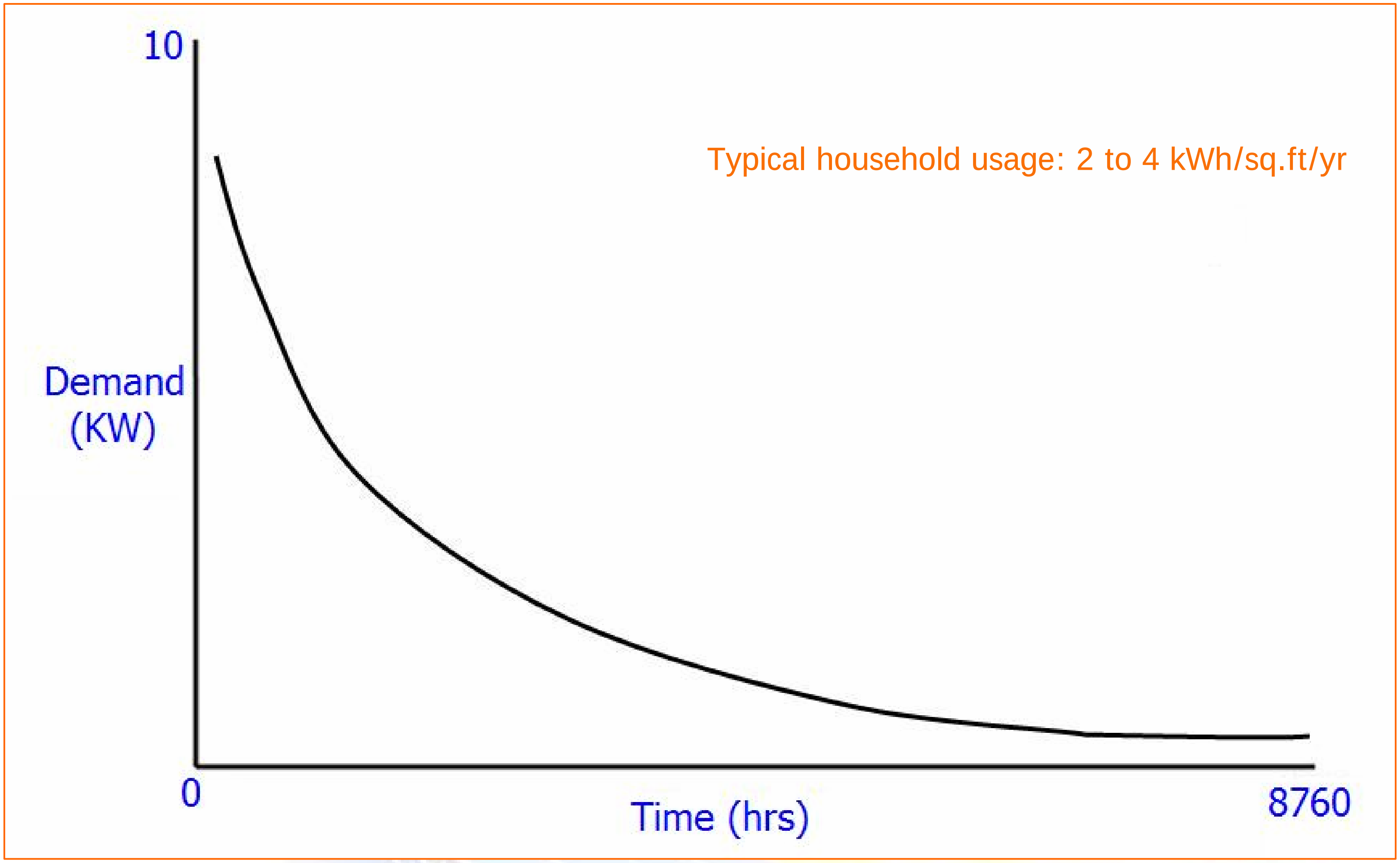
Major Players



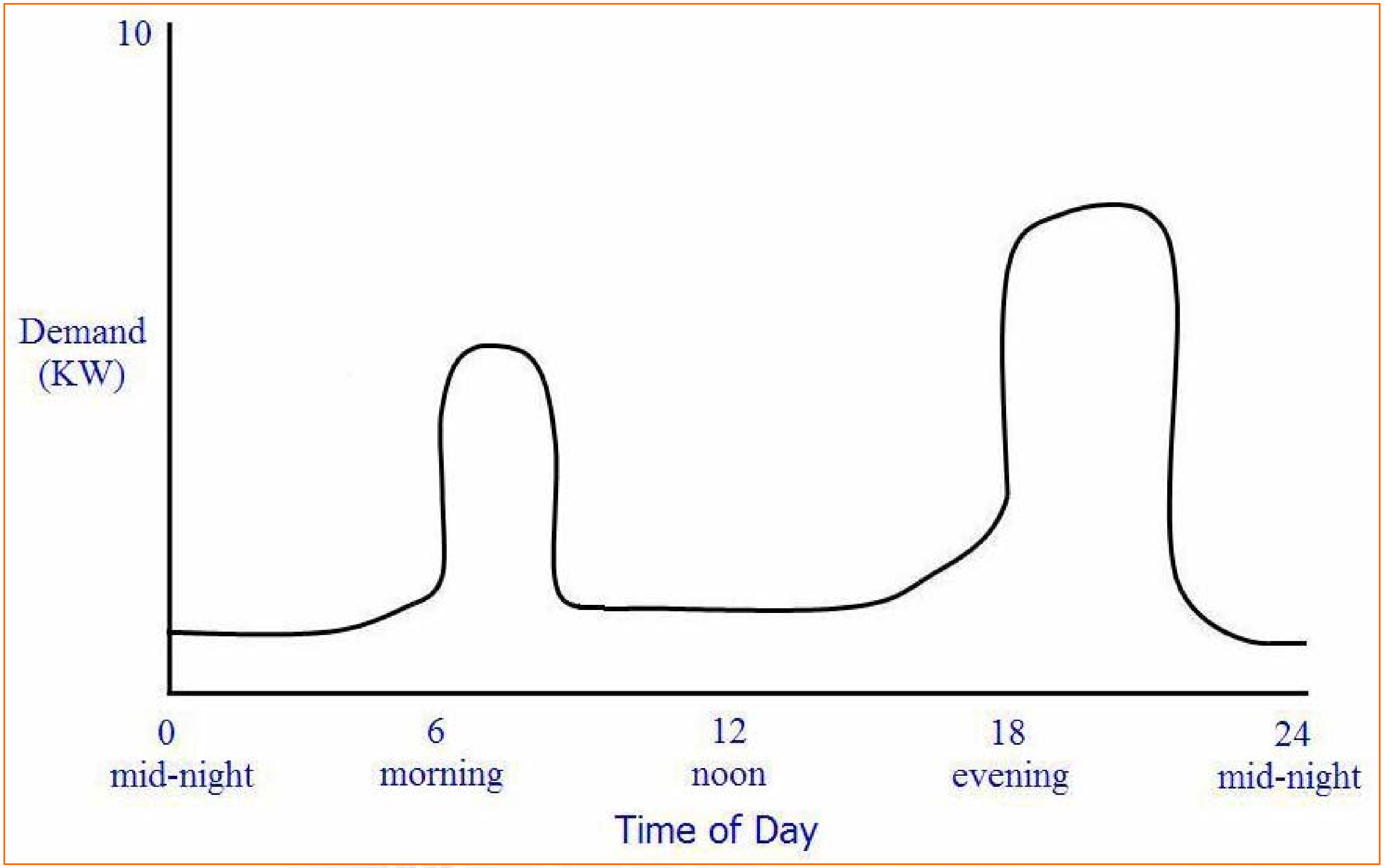
Grid Connected

- Residential (1-10kW)
- Commercial (10-1,000kW)
- Utility (>1MW)

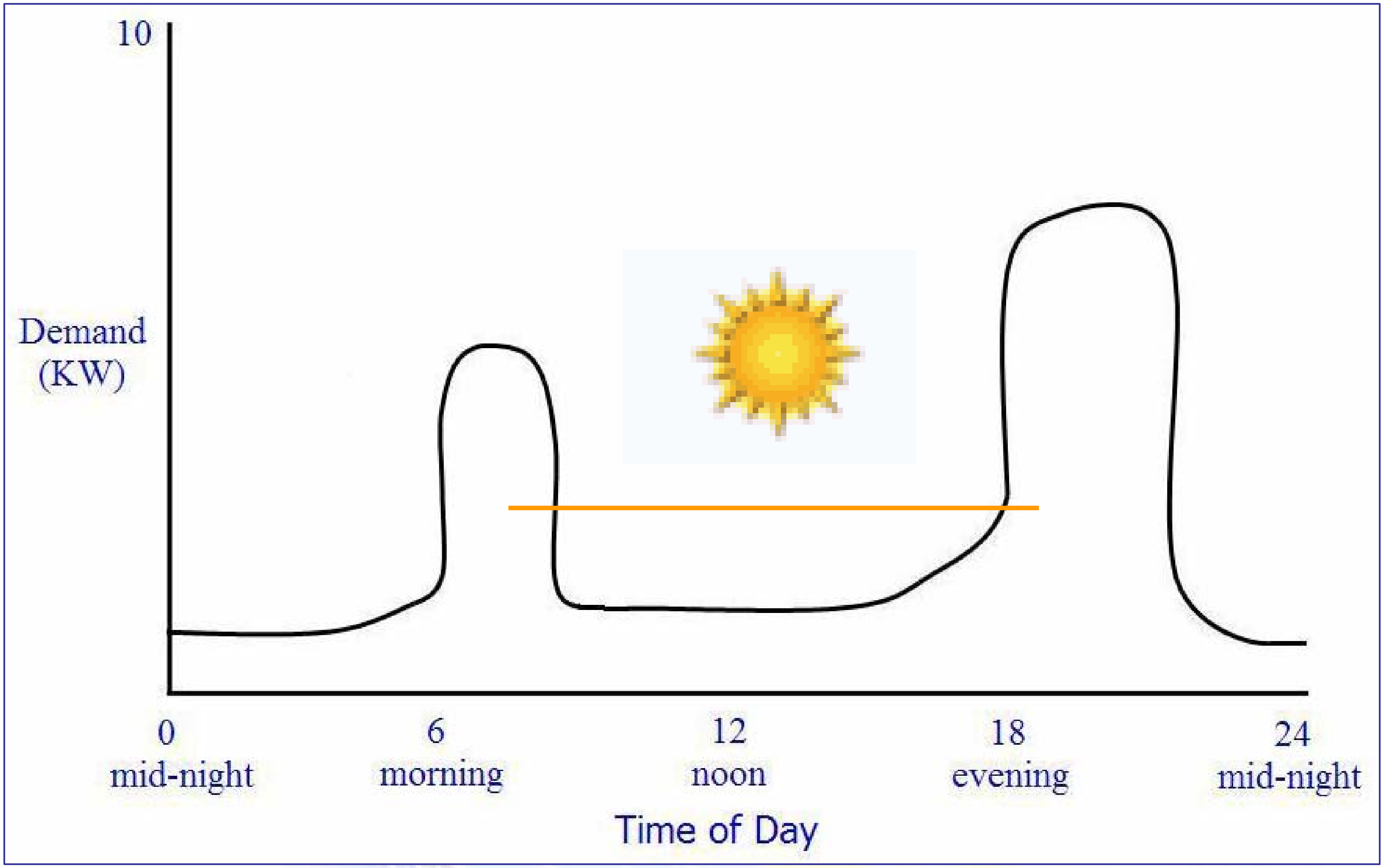
Annual Household Electricity Usage



Typical Household Daily Demand Profile



Typical Household Daily Demand Profile



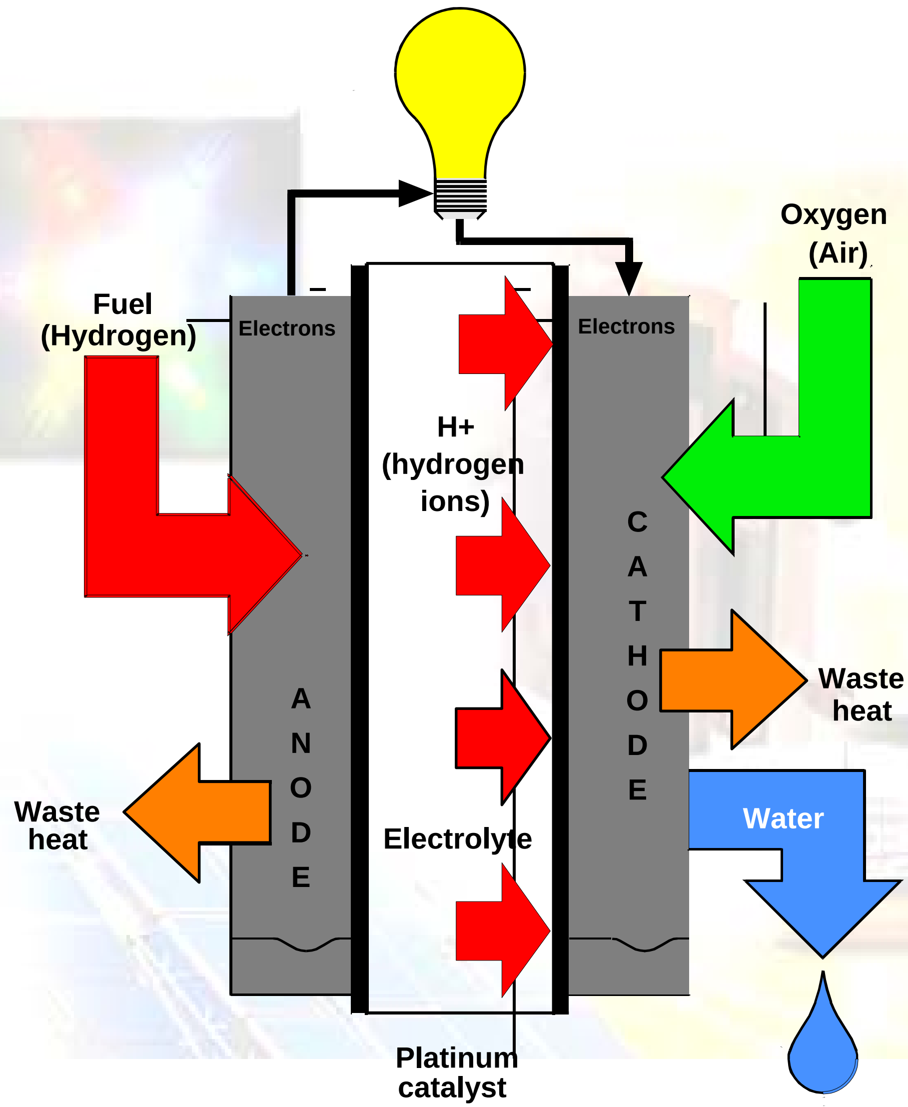
Photovoltaic Development Needs

- To reduce the cost of Photovoltaic cell processing by an order of magnitude
- To fabricate thin-film PV cell structures with cell efficiencies > 25%
- To develop innovative process methodologies to bridge the gap between processes optimized for microelectonics (ex: CVD, Plasma depositon) and those traditionally used for large area processing (ex: solgel, dip coating, screen printing)

New Areas of Thrust - Gaps

- **Devices**
  - synthesize III-Nitride, GaAs-based, II-VI - based thin films and nanostructures for broad spectrum solar energy absorption;
  - Design and develop optimal matrices to embed nanostructures (ex: nanostructured carbons interpenetrated with poly-3(hexyl)thiophene (P3HT) for low-cost photovoltaic devices)
  - inorganic nano-structures such as PbSe-TiO2 based Graetzel cells
- **Processes**
  - development of nano-particle precursors for fabrication of low cost, high- efficiency multiple band-gap stacked thin film thermo-photovoltiac devices
  - development of low-cost techniques and approaches for growing structures and devices
  - development of low-cost large area process methods such as solgel and screen printing to replace the currently used processes optimized for microelectronics
- **Characterization**
  - characterize the electrical, optical, microstructural, and morphological properties of the materials and devices fabricated.

How Does A Fuel Cell Work



Types of Fuel Cells

Type	Applications	Comments
 Alkaline	80 – 100 C Space	Used by NASA on space missions. Efficiencies can reach 70%. Reliable but expensive.
 PEM	80 – 100 C Premium power and Transportation	Field units in demonstration. Limited Commercialization. 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. El efficiencies reach 40% and 70% with cogeneration.
 Molten Carbonate	600 – 650 C Distributed Power and small utility	Commercially available. In use at WWTPs and some commercial buildings. El efficiencies approach 50% and 80% with cogeneration.
 Solid Oxide	900 – 1000 C Stationary and utility power & Transportation	Currently in demonstration (100 kW). El Efficiencies approach 60% and 85% with cogeneration. Various designs and Applications.

Fuel Cells & Applications

Cell / Fuel Type	PEM	PBI	PAFC	MOFC	SOFC	DMFC
Natural Gas	S & T	S & T	S	S	S & T	
Methane (LFG/ADG)	S		S	S	S	
Propane	S					
Methanol	P	P				P
Ethanol			S	S	T & P	
LPG/Diesel			T	T	T & P	
Hydrogen	S & T	S & T				P
JP – 8					P	

S: Stationary, T: Transportation, P: Portable

Fuel Cell Installations

Wind, PV vs. Fuel Cells

	Wind	Photovoltaic	Fuel Cells
Primary Application	Supply Side	Behind the Meter with Net-metering	Supply Side
Available Size Range	1000 to 3500 kW	1 to 100s kW	200 – 1000 kW
Tariff/Potential Revenue	\$0.05 - \$0.08 /kWh	\$0.10 - \$0.15 /kWh	\$0.05 - \$0.08 /kWh
Fuel Costs	None	None	\$0.02 - \$0.03 /kWh
Co-Products (value)	None	None	Heat (\$0.02 /kWh±)
Market Readiness	Commercially Available	Si-based: Commercial CIGS, others – Early Stages	PAFC, MCFC – Commercial PEM, SOFC – Emerging
Major Technological Challenges (/R&D needs)	Efficiency, capacity factor, storage (generally applied)	Efficiency, Process Optimization, manufacturing scale-up	Membranes, catalyst, system engineering, BOP
Cost target	\$1000 /kW	\$1000 - \$1500 /kW	\$500 - \$1000 /kW
Emissions	None	None	CO_2 at fuel source
Capacity Factors	20 – 30%	10 – 20%	90% +

The Future Electricity Distribution Grid of New York State – A Test Bed Validation ($1.5 Million)

- New York and 30 other states have adopted Renewable Portfolio Standards (RPS) mandating significant amounts of power to come from renewable resources (Ex: NYS: 25%)
  - A good portion of that is likely to come from small scale inverter based generators (PV, Small wind, ADG, Fuel Cells, etc) connected to the utility distribution grid
  - Electrical implications from the high penetration and diversity of distributed resources on the utility distribution grid need to be examined.
- Establish a DG-Test Bed to understand the operational characteristics of the distribution grid under a high degree of DG penetration
  - Stability and dynamic behavior of utility distribution grids with small system inertia - the feasibility of installing DE storage devices to counter balance natural intermittency, system stability and power quality will be studied.
  - Power quality interactions among inverter-based DG, particularly relating to harmonics and voltage sags and surges, will be examined.
  - New DG control features that meet IEEE 1741 will be developed and tested.

The Test-Bed Will Enable

- The Test Bed on which system-level issues related to grid integration of DG can be tested and evaluated on
  - Grid compatibility of DG in terms of steady-state power flow control, power quality, grid transient, as well as switching between grid-connected and standalone operation
  - Dynamic interactions of DG with the grid; patterns of such interactions over a wide frequency range and their effects on grid stability and power quality
  - Effects of inverter-based DG harmonics and common-mode EMI currents on grid protection devices, such as false trigging of neutral current protection relays
  - Dependency of DG interactions with the grid on grid characteristics and DG control
  - DG response to abnormal grid characteristics in terms of grid impedance, voltage and frequency variation, power quality problems, as well as grid fault conditions
  - Effects of rectification loads such as electronics, solid-state lighting, and variable-speed motor drives on grid stability and power quality, particularly on grids with high penetration of DG; and
  - Grid-friendly load control techniques, such as active power factor correction, active load shading, adaptive load power management; effectiveness of such techniques on grid stability and power quality.

Superconductivity

- **Nearly zero electrical resistance at low temperatures**
  - Low Temperature Superconducting (LTS)
    - Metallic – Niobium based
    - Require cryogenic cooling/liquid Helium
  - High Temperature Superconducting (HTS)
    - Ceramic – BSCO, YBCO, etc.
    - Superconducting at 77 K (Liquid Nitrogen Temp.)
    - Difficult to process into defect-free wires
- **High Temperature Superconducting (HTS) Products**
  - power generators - increase efficiency by 0.45% (nearly one-half of the remaining generator losses)
  - large motors – motors consume half of country's electric energy
  - transformers – eliminate nearly 80% (all I2R) of transformer losses (saving $250 M+ for NYS)
  - power lines (underground) - increase power delivery by a factor of 3 to 5 in the same diameter duct and enable two-way power transmission in the future

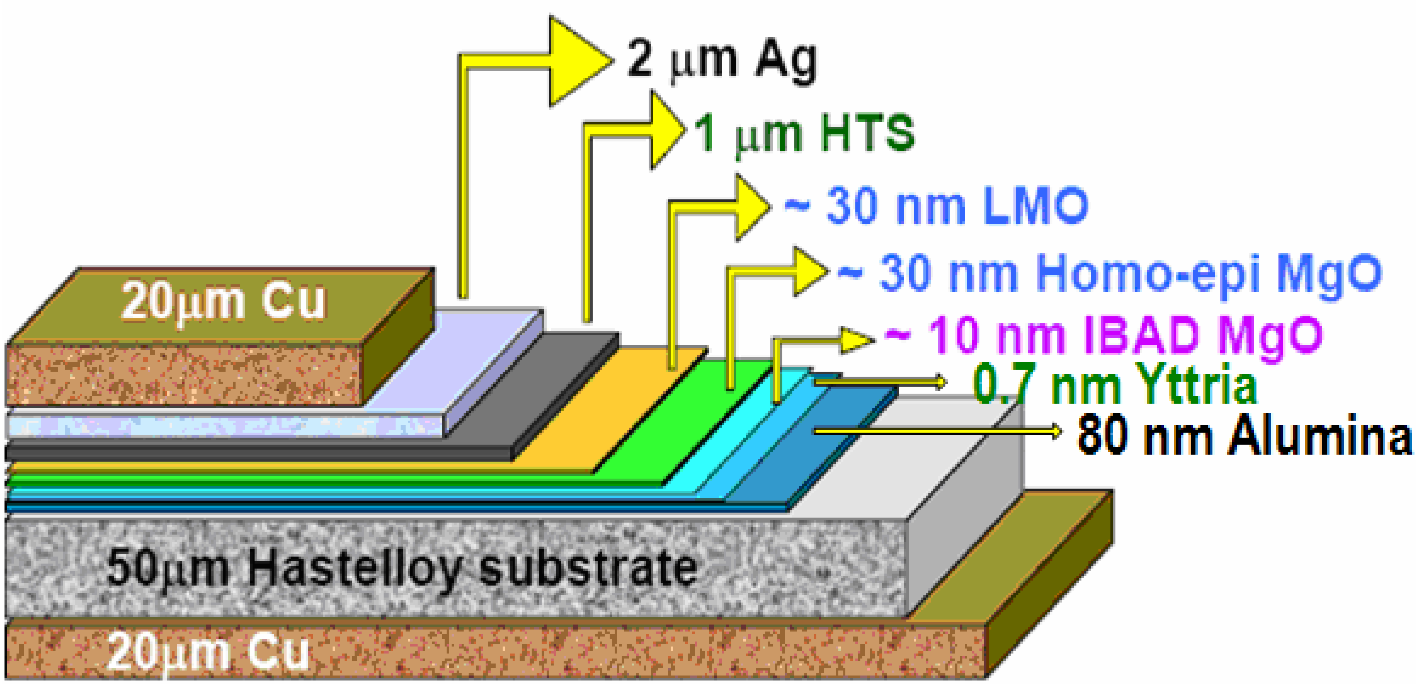
High Temperature Superconductivity (HTS)

Develop new photolithographic etching techniques to produce striated 2G (YBCO) HTS tape

- ➢ Reduces ac losses in 2G HTS materials

• Identify and demonstrate use of process alternatives to copper electroplating and enable direct application of copper over HTS (eliminating silver layer)

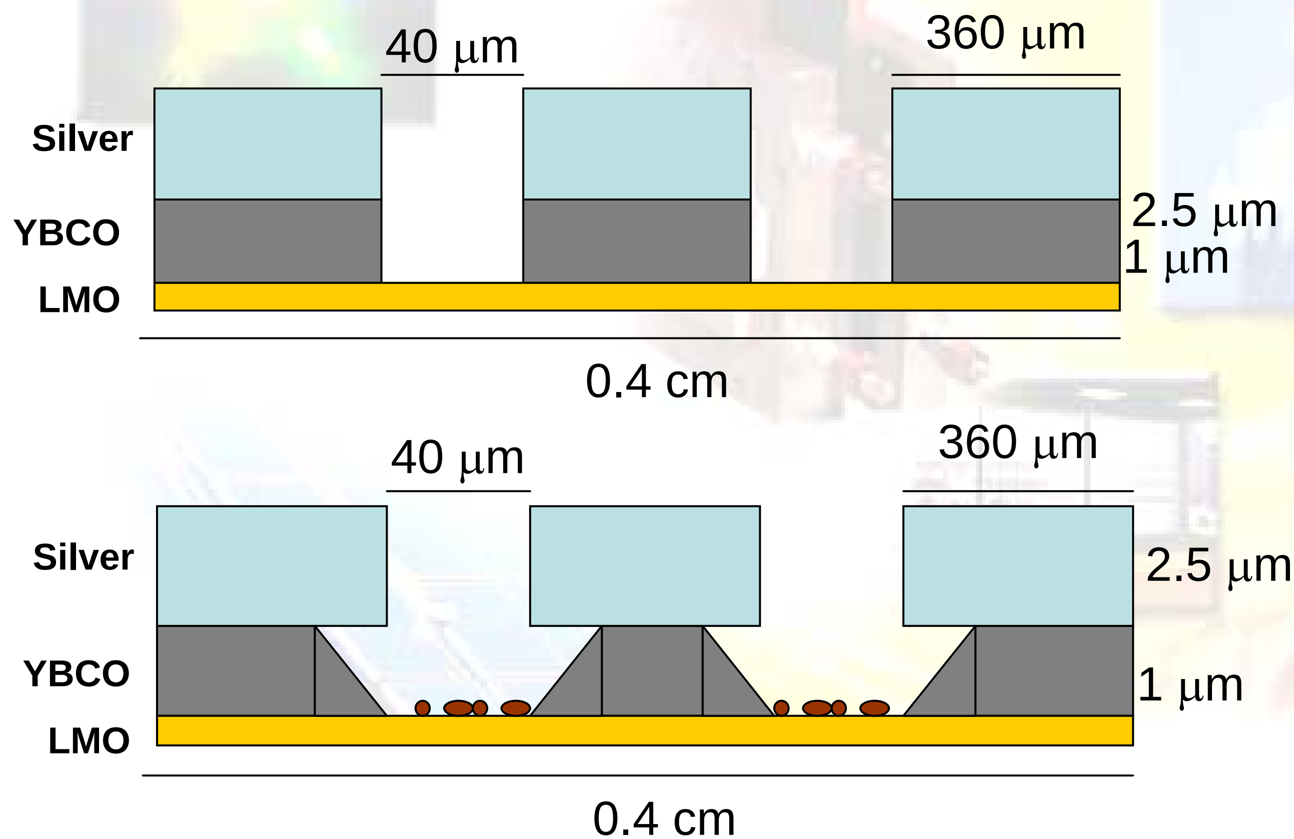
- ➢ The project supports processes that are suitable for the roll-to-roll manufacturing of 2G HTS tape.



Picture: Courtesy of SuperPower

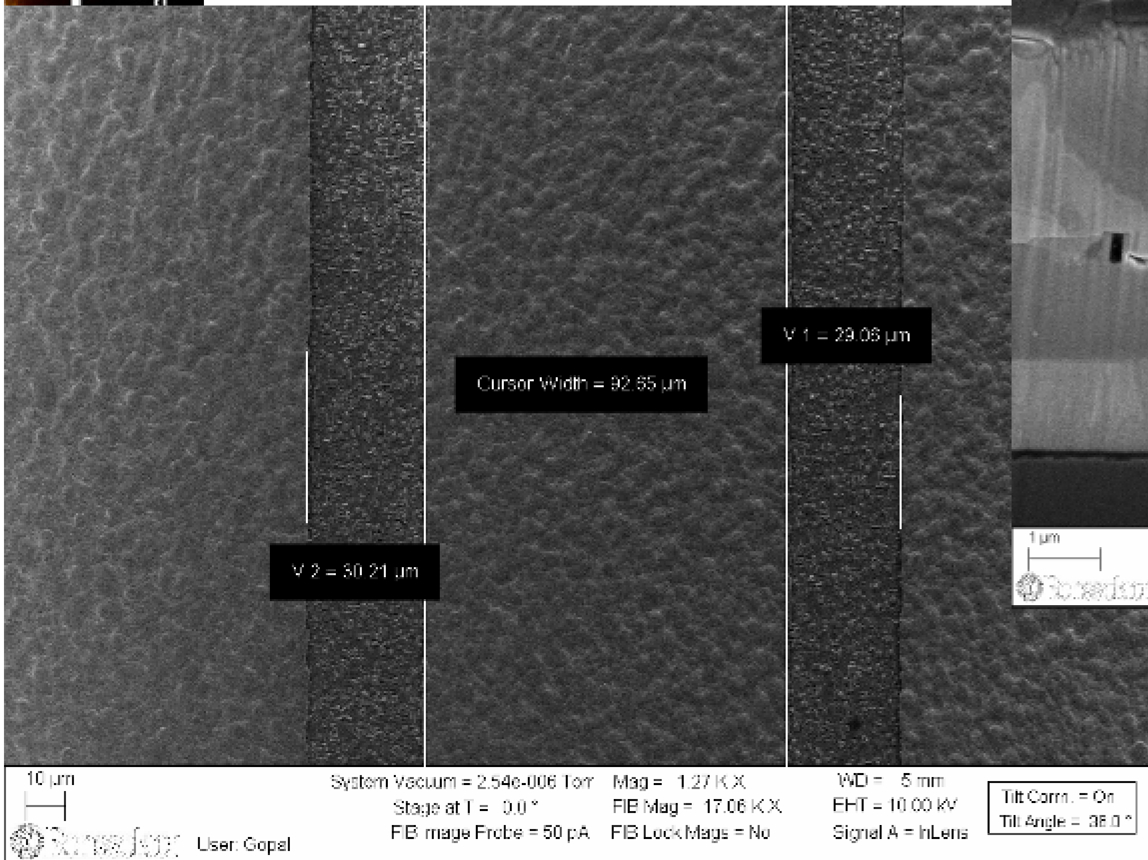
HTS - AC loss

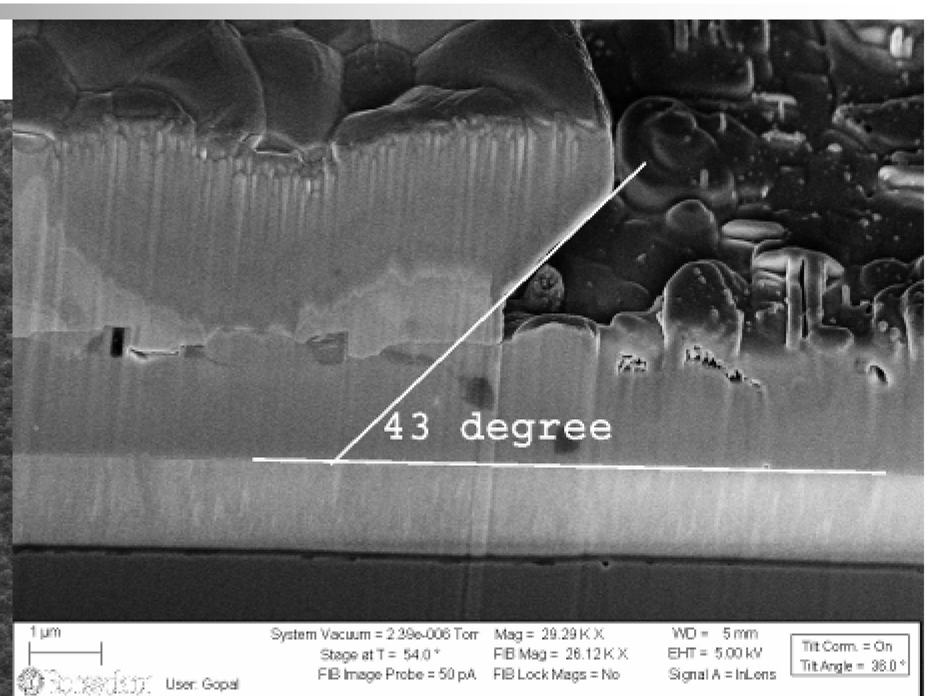
- Current in a superconductor generates a magnetic field around the conductor, which is called the self-field. With the alternating current, the alternating self-field penetrates the superconductor during each current cycle. Even if there is no external magnetic field, the variation of the self-field inside the material causes a hysteresis loss, which is called self-field loss
- One promising approach to reduce the hysteresis loss is to divide a wide tape into several narrow superconducting stripes separated by non-superconducting barriers.

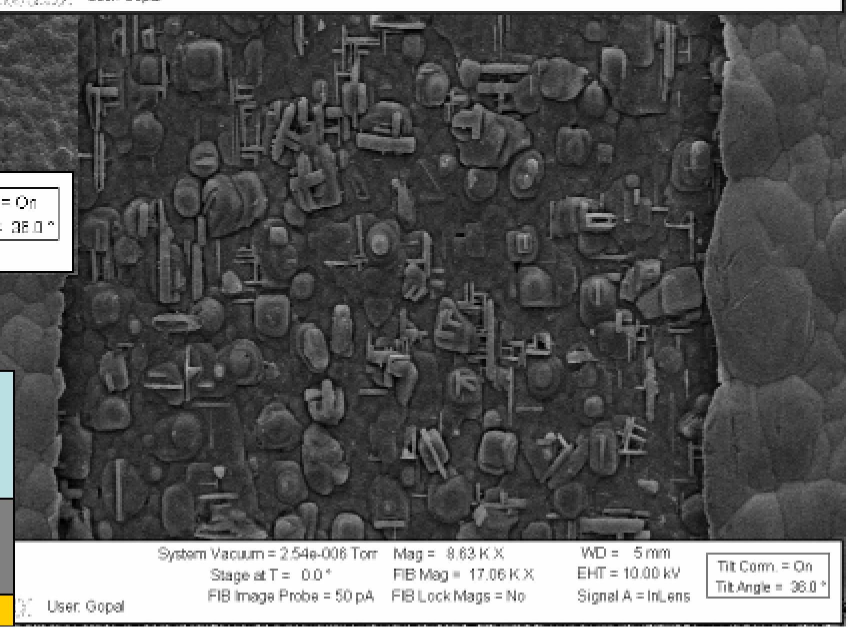


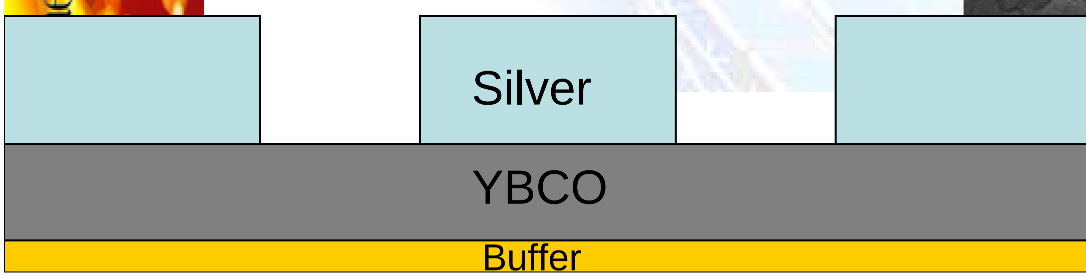
Courtesy of G. Pethuraja

100/25 Patterned Sample – Silver Etched

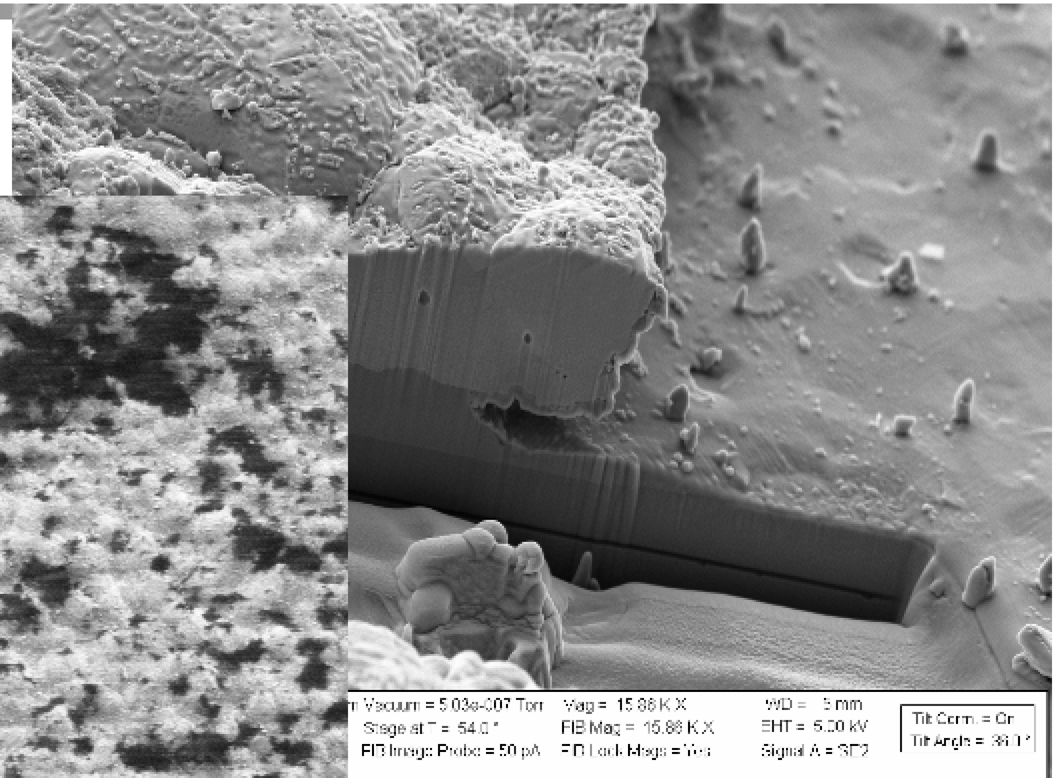


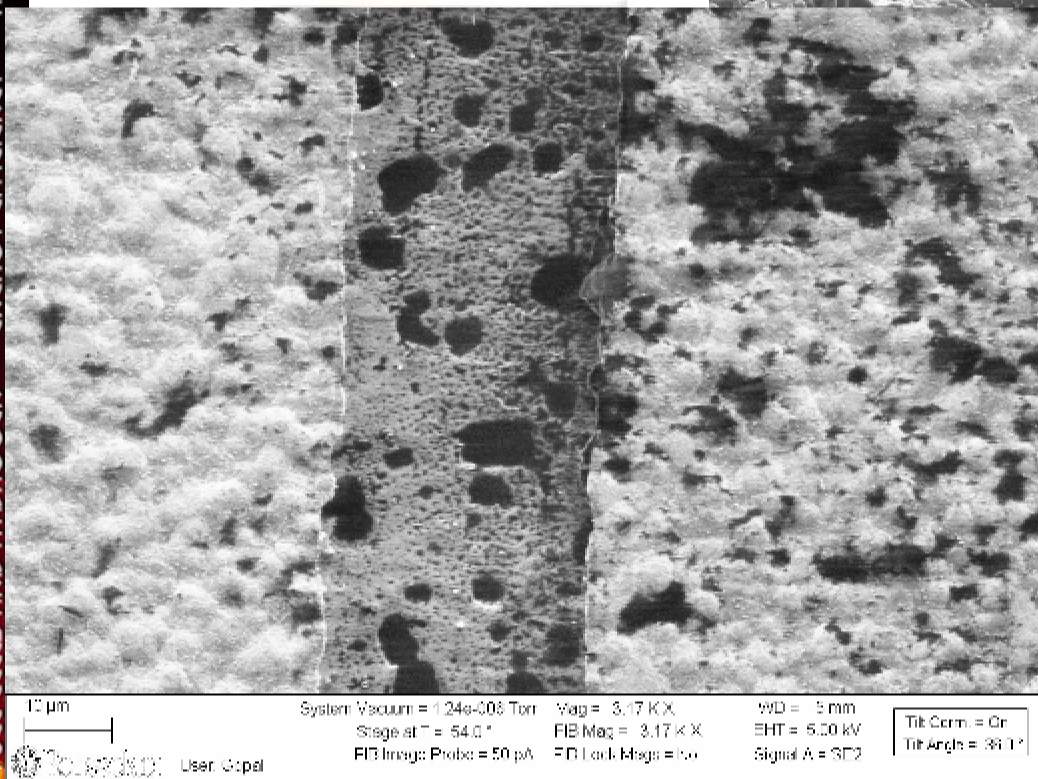


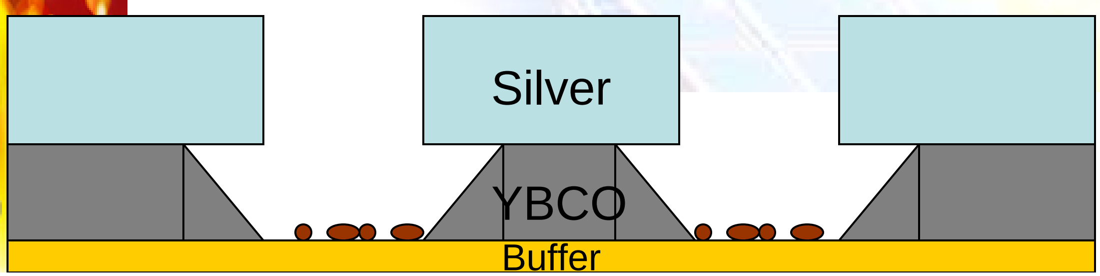




100/25 Patterned Sample – HTS Etch



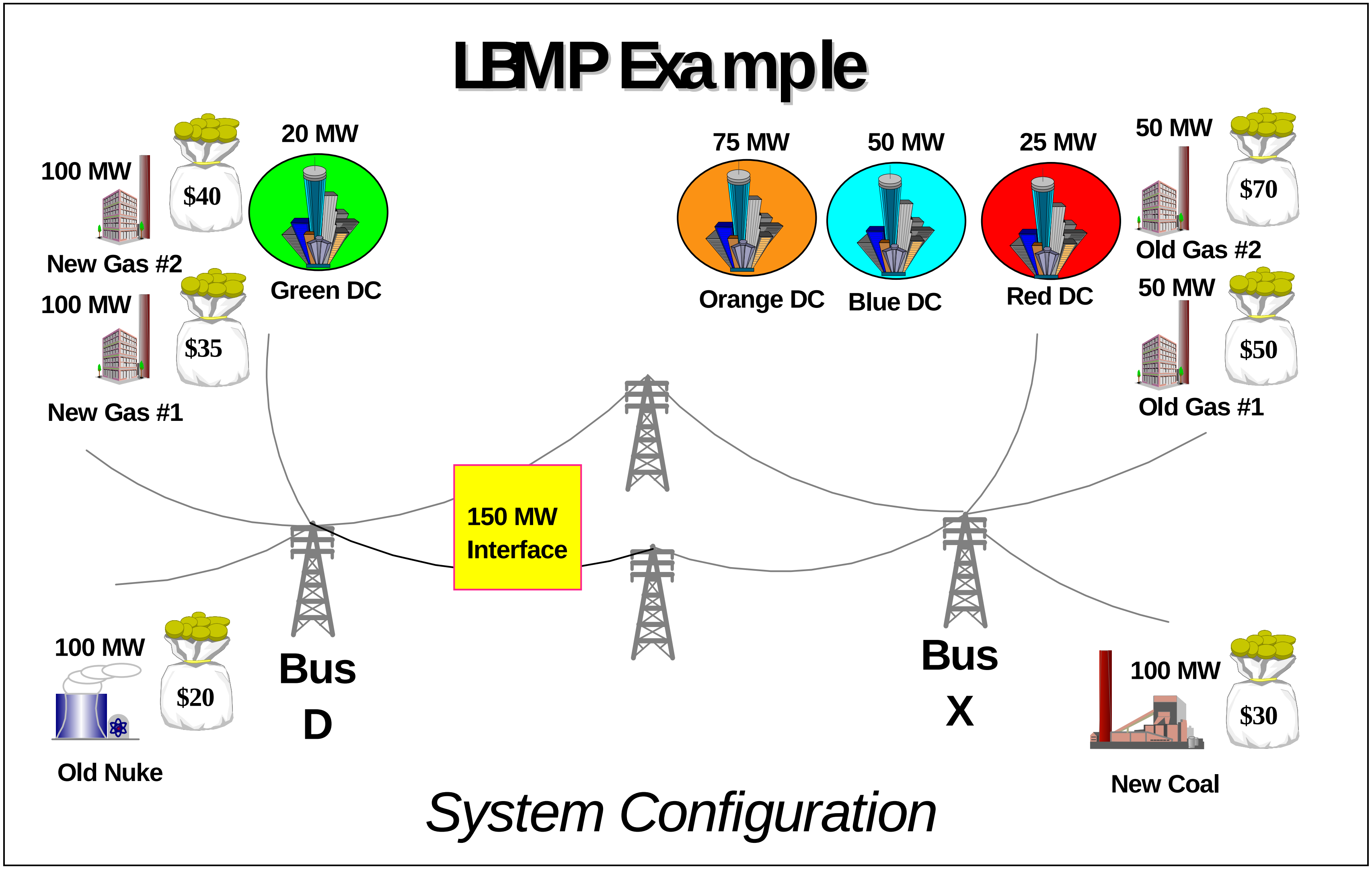




Summary & Conclusions

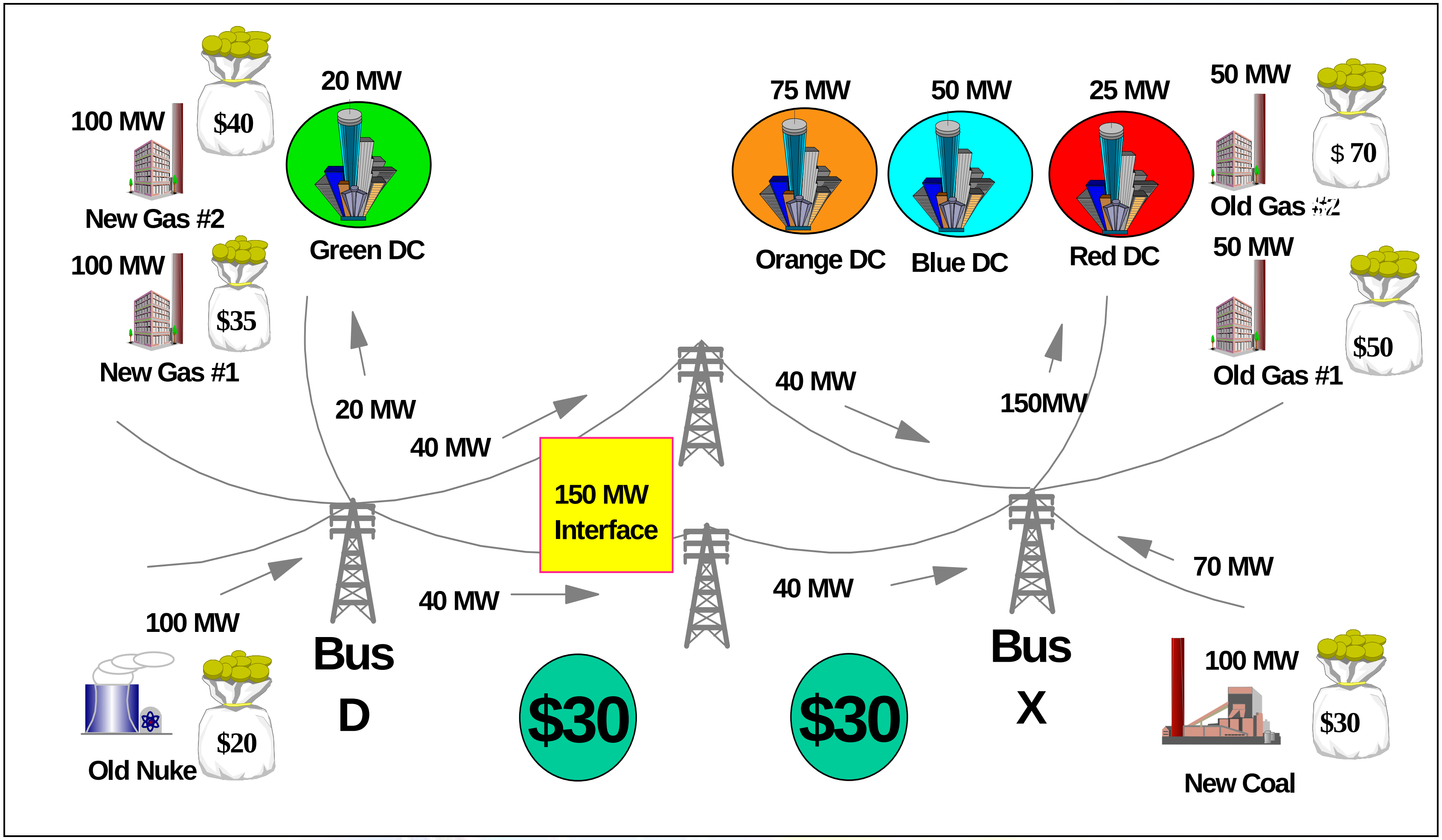
Critical energy issues facing our nation need a viable and sustainable long-term strategy with contributions from

- Fundamental Technology Development
- Energy Efficiency
- Clean and/or Renewable Generation
- Public Policy and Financial Incentives
- Education & Outreach

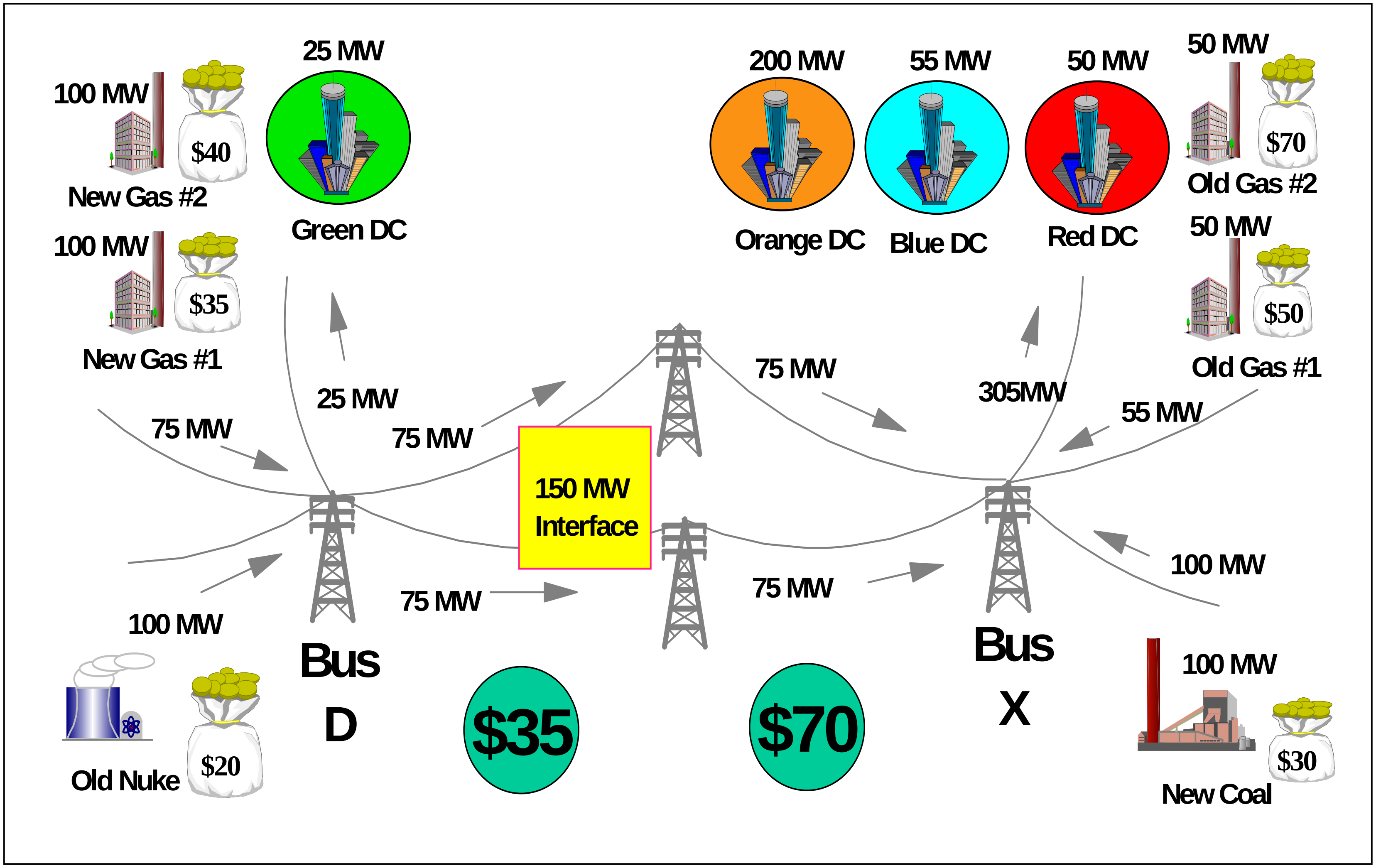


NYISO coordinates transmission and generation

NYISO – "Non-Congested" Market Transaction



NYISO – "Congested" Market Transaction



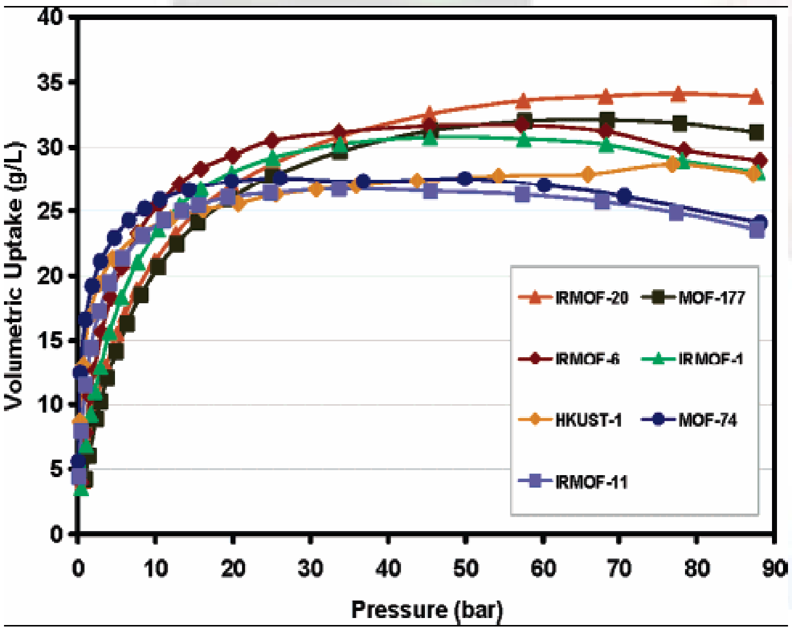
Hydrogen Storage Projects – In Development

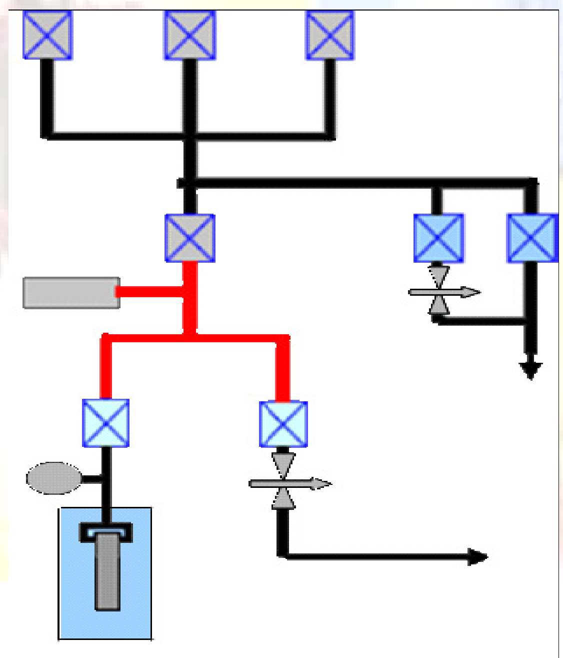
GM / DOE

- Identification of Suitable Materials for Hydrogen Storage

  ➢ Focus on Characterizing Hydrogen Sorption into various hydrates, zeolites,metal-organic frameworks ($Zn_4O(CO_2)_6$), carbon nanotubes, Palladium, etc.

  ➢ DOE target for on-board automobile storage systems (by 2010): 60 mg H2/g (gravimetric) and 45 g H2/L (volumetric)





Data Source: Wong-Foy, et.al

Rensselaer

CENTER FOR FUTURE ENERGY SYSTEMS

FUEL CELLS AND HYDROGEN • ENERGY EFFICIENCY • RENEWABLE ENERGY

Opportunities & Solutions

- **Efficiency and Conservation**
  - New Products (LED Lighting, OLED Displays) Manufacturing Automation, etc.

- **Innovation and Emerging Technology**
  - High Temperature Superconductivity, Nanotechnology

- **Renewable and/or Clean Distributed Generation**
  - Wind, PV, Fuel Cells and Efficient Onsite Generation (ex: CHP)

- **Fuel Diversity**
  - Biofuels, Biomass, Hydrogen