Electric Energy Systems Curriculum

With Emphasis on
- Renewables
- Smart Delivery
- Efficient End-Use

ONR-NSF Workshop
Minneapolis, MN June 7-12, 2010

Electric Energy

- Electric Power Sector – The Big Picture
  - Crisis
  - Opportunities
- Curricular Reform

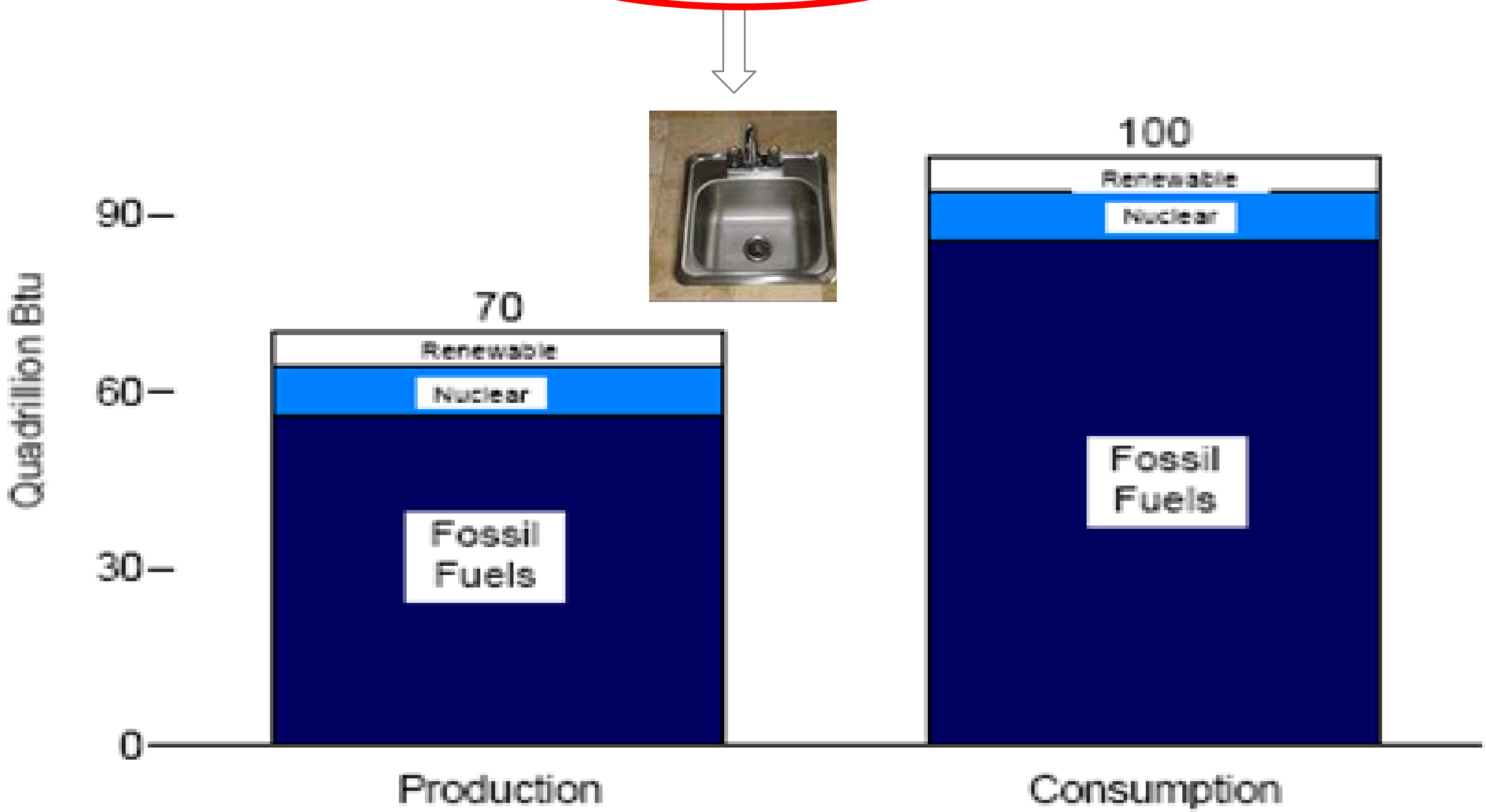
‘We Need Energy Miracles’

(Bill Gates: TED Speech 2010)

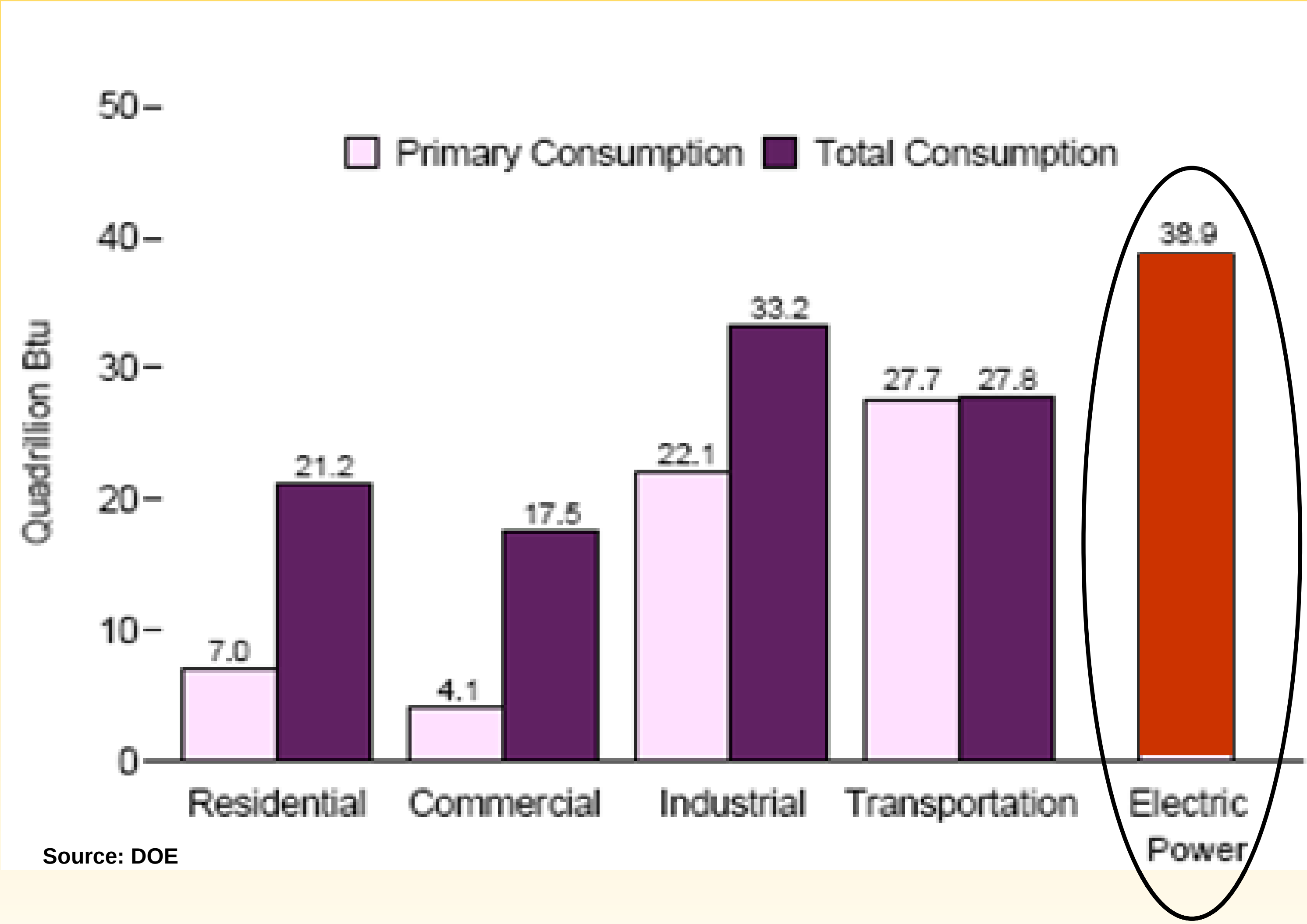
Source: www.huffingtonpost.com

Financial Cost

Production and Consumption 700 B$/yr

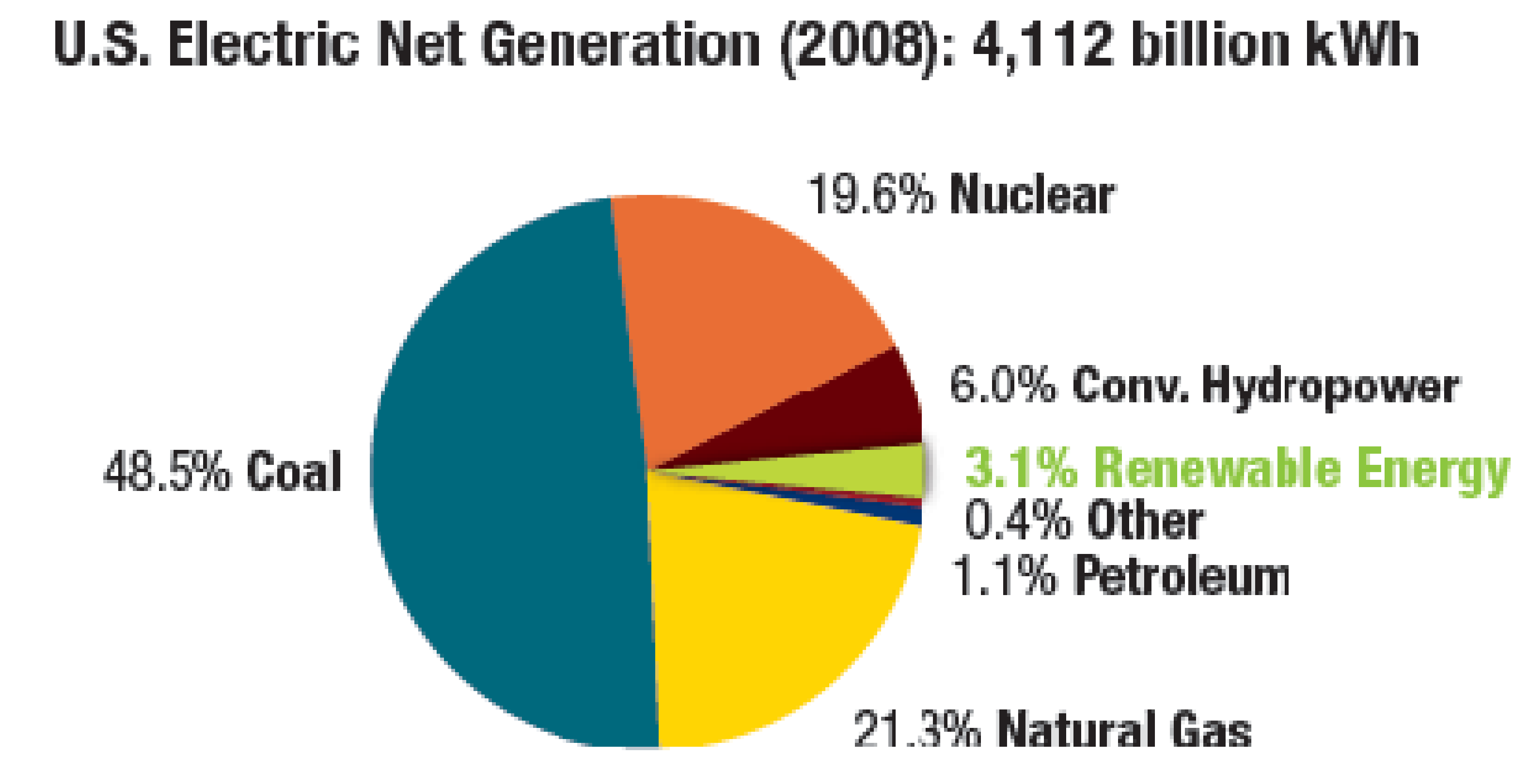


Electric Power



Source: DOE

Electric Power Generation by Fuel Type:



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Electricity from Renewables

- Wind
  - On-land
  - Offshore
- Solar
  - Concentrated Solar Power (CSP)
  - Photovoltaic (PV)
- Wave

WIND

Three most Important Criteria

- **Location**
- **Location**
- **Location**

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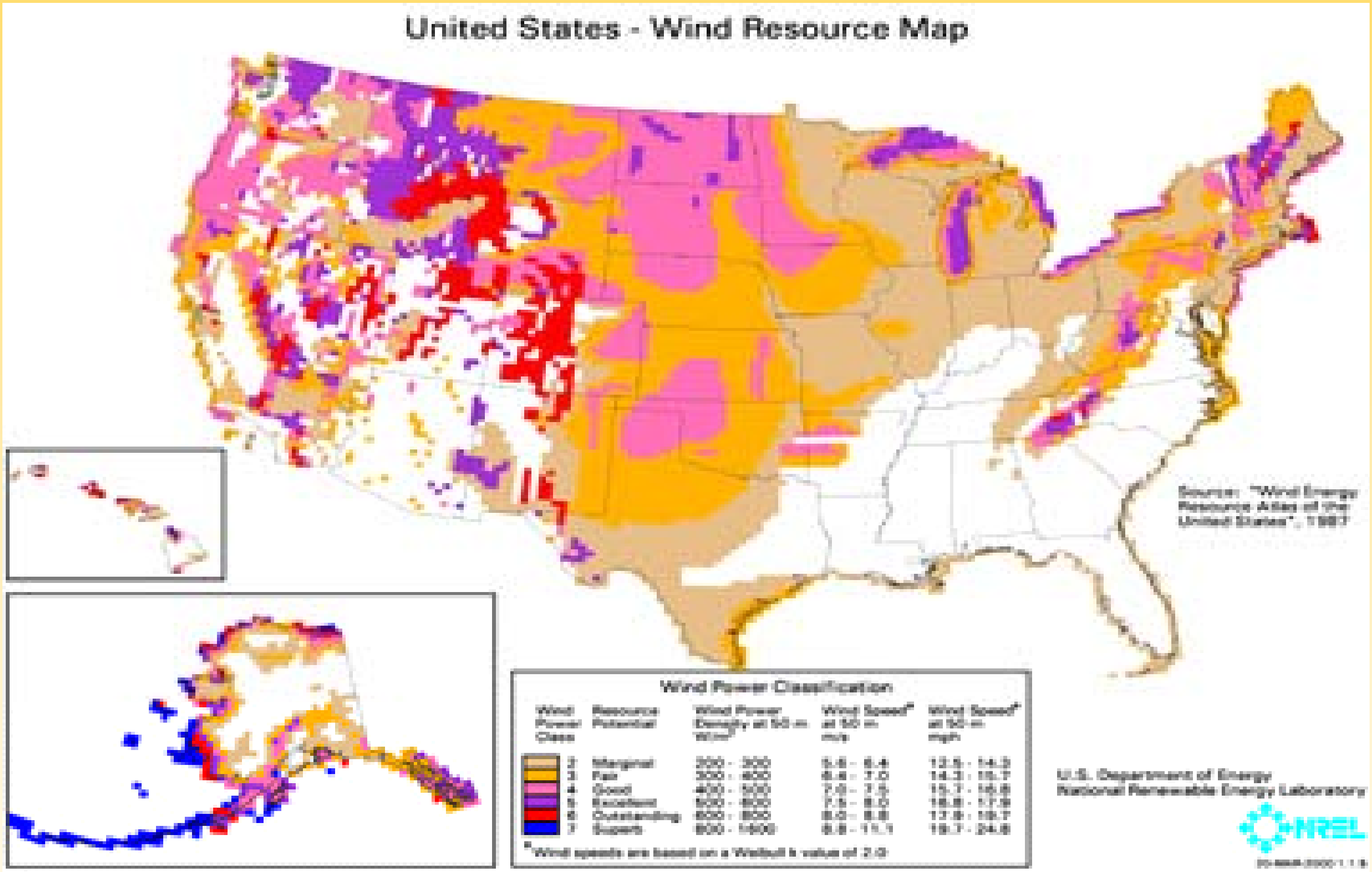
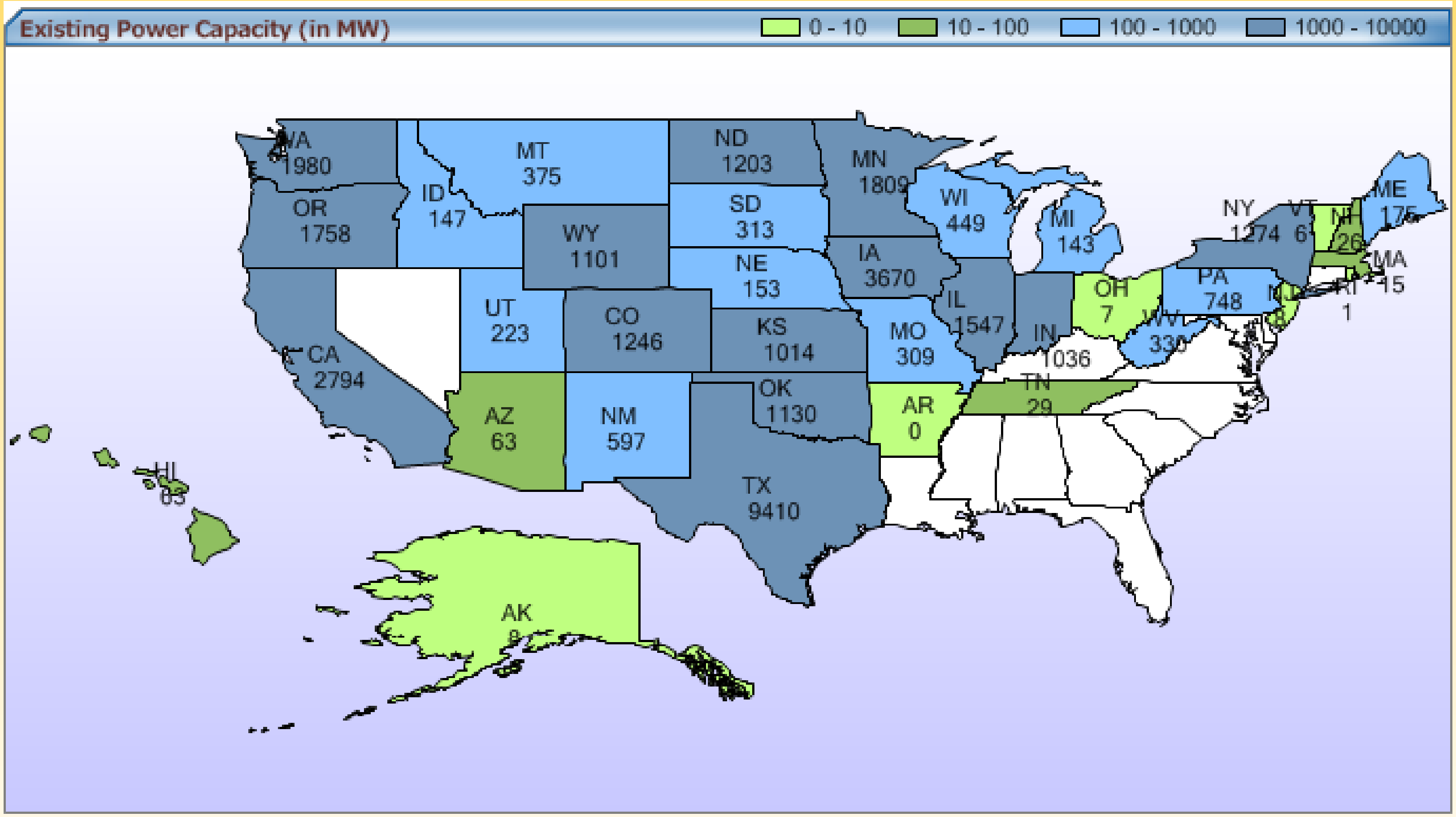
Wind in the U.S.



U.S. Wind Energy Projects

(as of 12/31/2009)



Source: www.awea.org

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Trip to a Wind Farm – 11:30 June 10th

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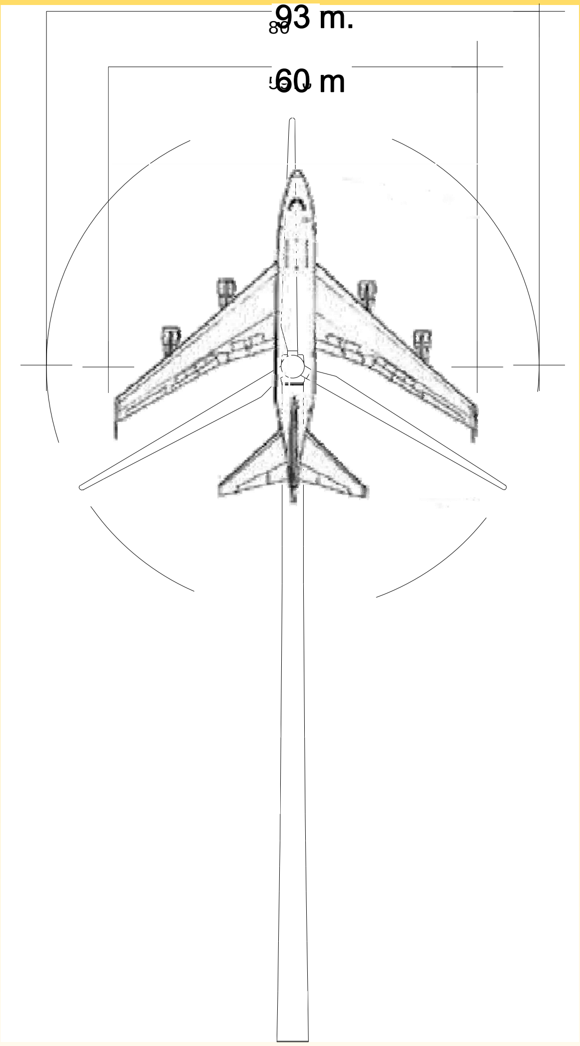
Turbines Are Getting Bigger . .

	1981	1985	1990	1996	1999	2000	2005	2008
rotor diameter (in meters)	10	17	27	40	50	71	104	120
rated capacity (in kilowatts)	25	100	225	550	750	1,650	3,600	5,000

How big is a 2.3 MW Wind Turbine?



- Boeing 747
  - 60 m diameter
- Siemens 2.3 MW turbine
  - 93 m diameter

Siemens blades, Port of Duluth, 2006 August

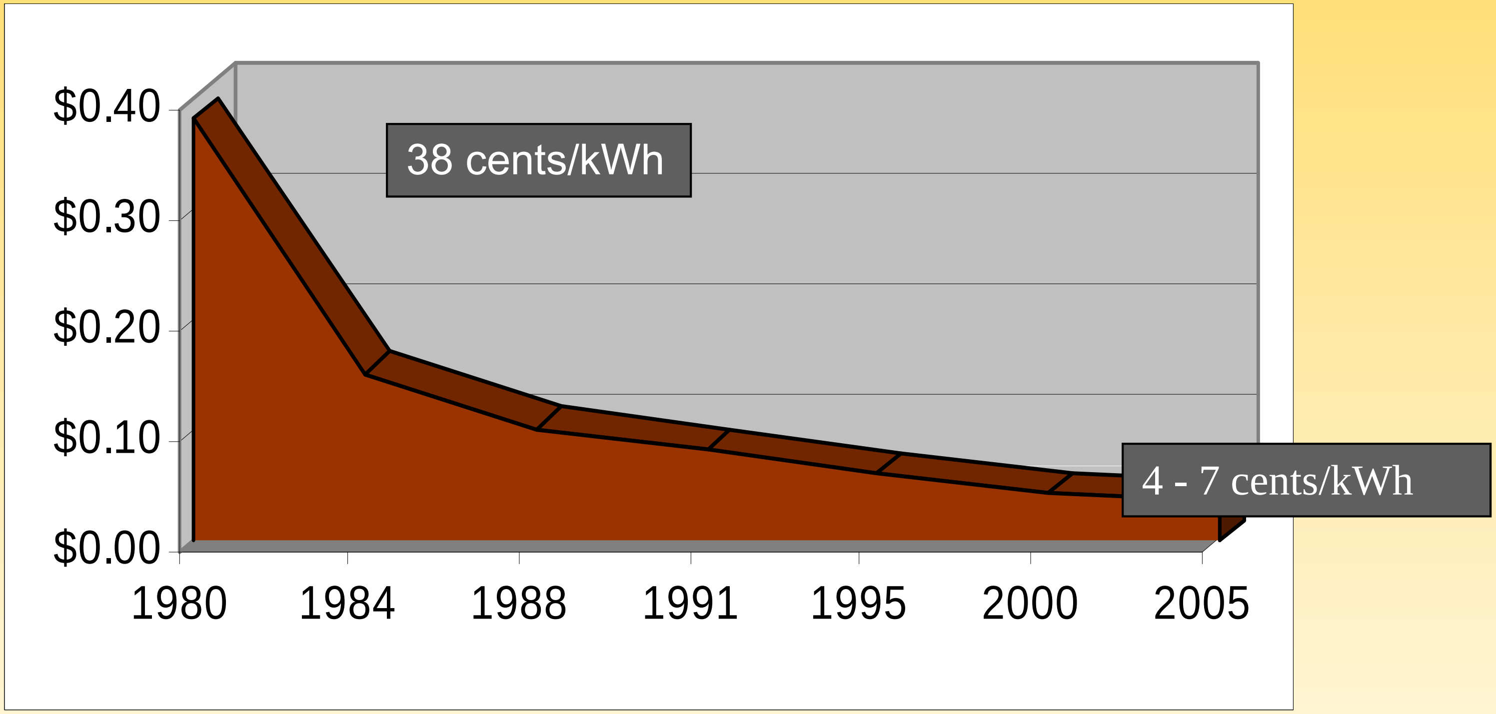
GE Wind Technology

GE WIND - 3.6 Offshore

Main Data:

- **Tower options:**	100 - 140m (328 to 459 ft)
- **Rotor diameter:**	104 m (341 ft)
- **Generator capacity:**	3600 kW
- **Control:**	Pitch
- **Rotor speed:**	8.5 – 15.5 Rpm
- **Swept area:**	7854 m^2

Reduced Cost Driving Wind's Success



Levelized cost at good wind sites in nominal dollars, *including tax credit*

20% Wind by 2030

- 350 GW of wind power must be installed
- 35 GW of total wind power installed today
- Investment required -- **$1 Trillion**

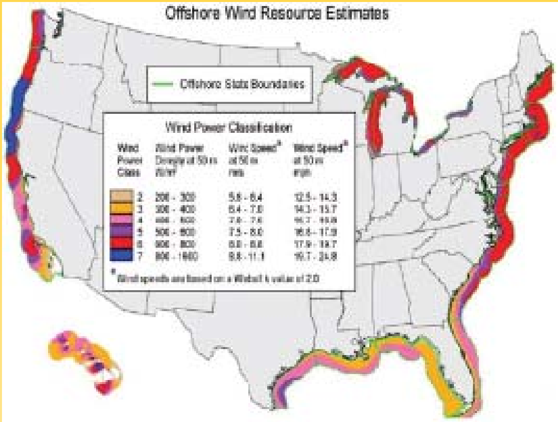
U of M-led consortium wins major DOE wind energy award

MINNEAPOLIS / ST. PAUL (10/15/2009) -- U.S. Energy Secretary Steven Chu announced today that the University of Minnesota is among three university-led consortiums that will receive significant funding for wind energy research facilities. The funding is from the American Recovery and Reinvestment Act, and the research will focus on improving both land-based and offshore wind generation.

The U of M and its collaborators will receive up to $8 million to support research and development programs to improve wind turbine performance and reliability, as well as provide educational opportunities for undergraduate and graduate students in wind energy technologies. Fotis Sotiropoulos, professor in the Institute of Technology and director of the Saint Anthony Falls Laboratory, along with researchers from the Institute of Technology and the University of Minnesota, Morris, are leading the U of M consortium.

Wind Energy Essentials
College of Science & Engineering, University of Minnesota
(EE 5940 - Fall 2010)

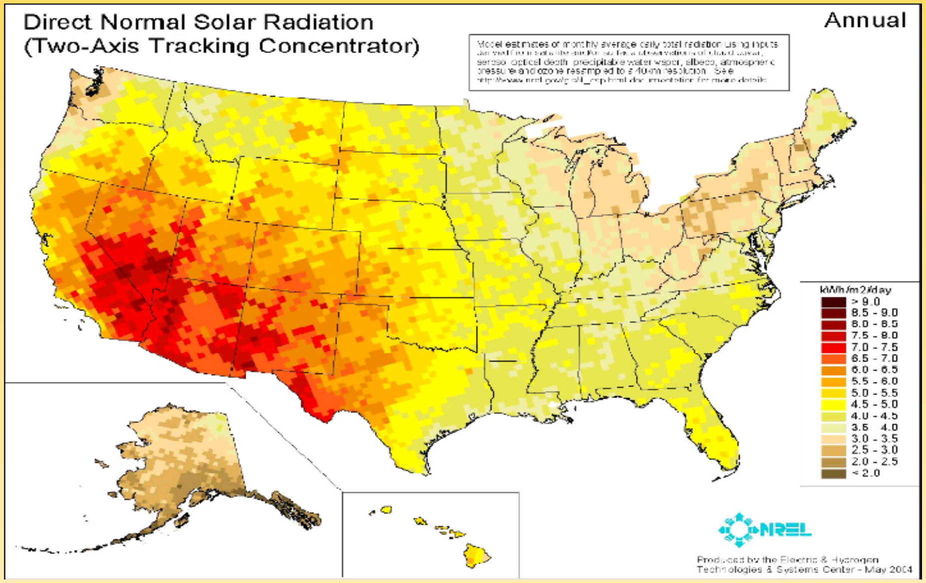
1. Introduction (Fotis Sotiropoulos - CE, Ned Mohan - ECE)
2. New Challenges in a High Penetration of Wind Power (Ed Muljadi, Senior Engineer, National Wind Technology Center, NREL)
3. Gears/Transmission (Kim Stelson - ME)
4. Blade Aerodynamics and Acoustics (Fotis Sotiropoulos, Roger Arndt - CE)
5. Foundation Design (Chris Kopchynski, Jennifer Entwistle, Barr Engineering)
6. Controls (Mihailo Jovanovic - ECE, Gary Balas - AEM)
7. Electric Generation and Power Electronics (Ned Mohan - ECE)
8. Materials and Structural Reliability (Sue Mantell - ME, Henryk Stolarski - CE)
9. Wind Assessment and Wind Forecasting (Mark Ahlstrom, CEO, WindLogics Inc.)
10. Grid Integration (Matt Schuerger, Energy Systems Consulting Services)
11. Wind Farm Development, Socio-economic Aspects (Jack Levi – Co-Founder and Co-Chairman, National Wind LCC.)
12. Environmental Considerations – Radar Interference (Mos Kaveh – ECE, others TBD)

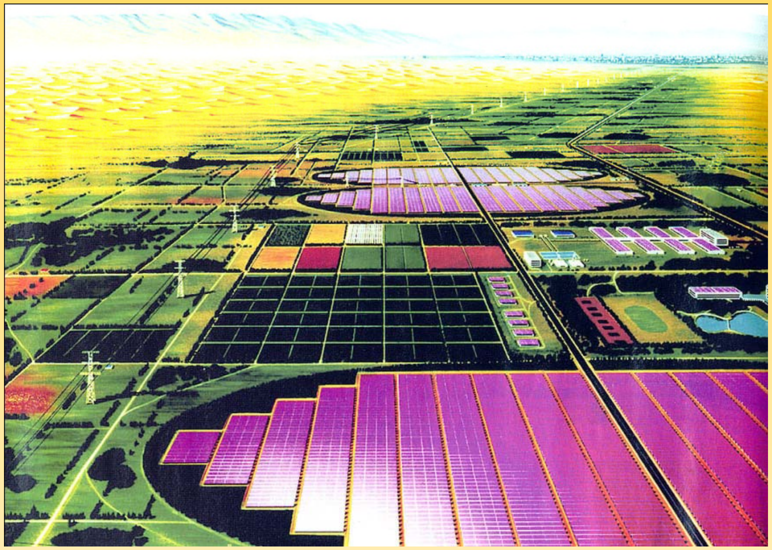


Offshore Wind

DOE estimates offshore resources to be 900,000 MW.

Solar





Source: www.esolar.com

Solar is today where wind was 5-8 years ago.

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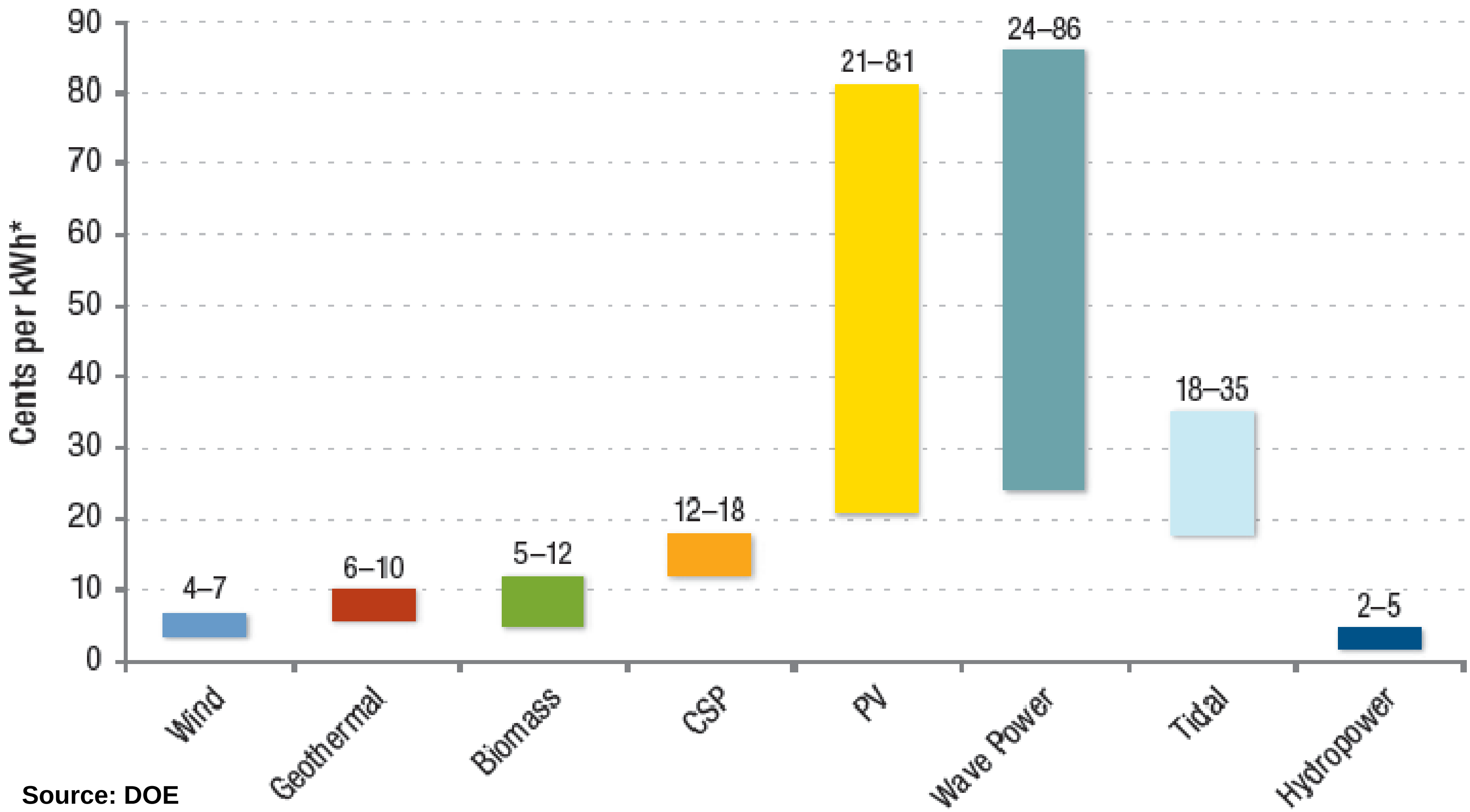
Wave Energy

- **It is estimated that if 0.2% of the ocean's untapped energy could be harnessed, it could provide power sufficient for the entire world.**
  - Tidal
  - Current
  - Temperature gradient (OTEC and SWAC)
  - Salinity
  - Wave
- Compared to other renewables, wave energy has advantages:
  - Higher availability
  - More predictable and forecastable: up to 10 hours forecast time
  - Low viewshed impact
- At present, wave energy is estimated at 20-30 cents per kwh. Coal and wind are 4 to 9 cents per kwh.
- Wave energy is about 20-30 years behind wind, but it is predicted that wave energy can catch up quickly.

Price Range of Renewable Electricity by Technology (2008)



Source: DOE

Nuclear

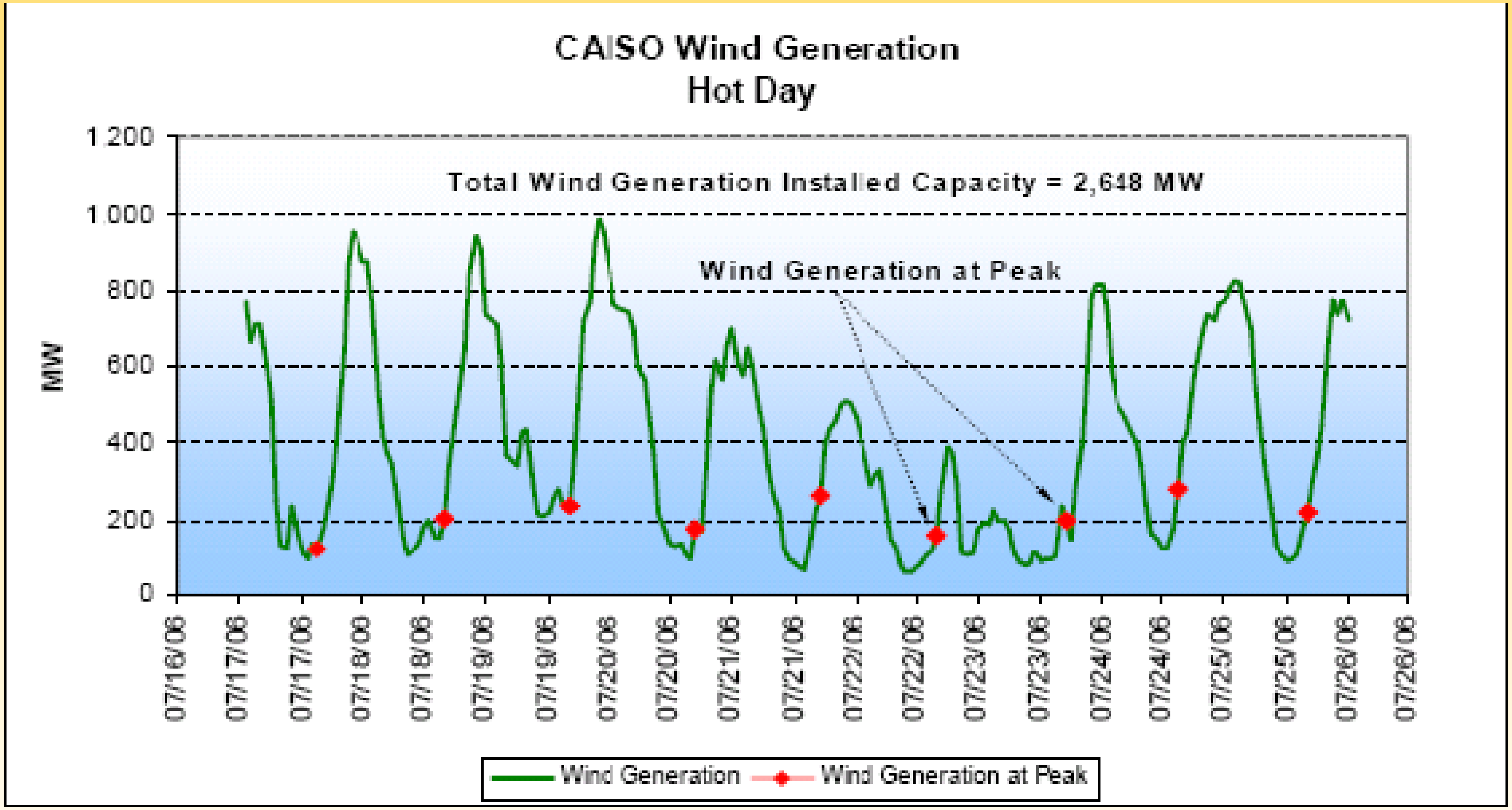
Jan 30, 2010

Obama moves quickly to promote nuclear power

Jan 29, 2010

Obama's call for nuclear power plants angers supporters

Storage



CAISO Wind Generation
Hot Day
Total Wind Generation Installed Capacity = 2,648 MW
Wind Generation at Peak
MW
1,200
1,000
800
600
400
200
0
07/16/06
07/17/06
07/17/06
07/18/06
07/18/06
07/19/06
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07/26/06
Wind Generation
Wind Generation at Peak

Storage Options

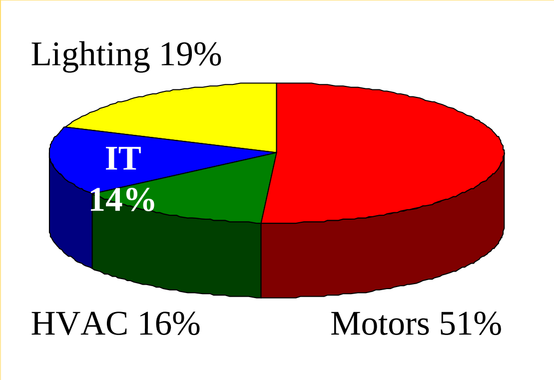
- Compressed Air
- Fuel Cells
- Flywheels
- Superconducting Magnetic
- Ultra-Capacitors
- Batteries
  - Lead Acid, Li-ion, NiMH, Flow, Sodium Sulfur

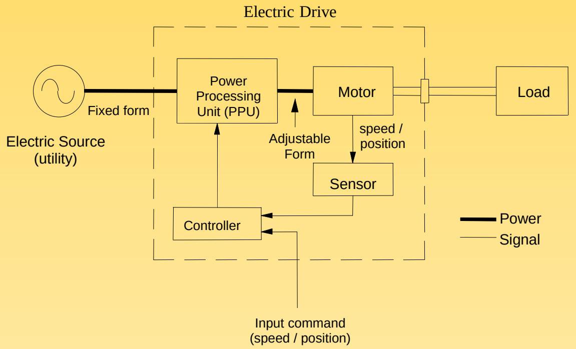
Sodium Sulfur Battery Energy Storage and its Potential to Enable Further Integration of Wind

Project Description

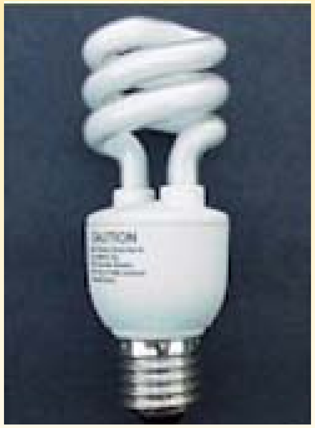
- **1 MW NaS Battery System**
- Can deliver 1 MW for 7 hrs
- Power Conditioning Equipment
- 175 kW backup power
- Wind farm/grid interconnection
- Local and remote data and communication equipment
- **Two Phases of Study**
- Understand how system could optimize wind farm economies
- Understand how system could optimize utility integration of wind resources

Efficient End-Use

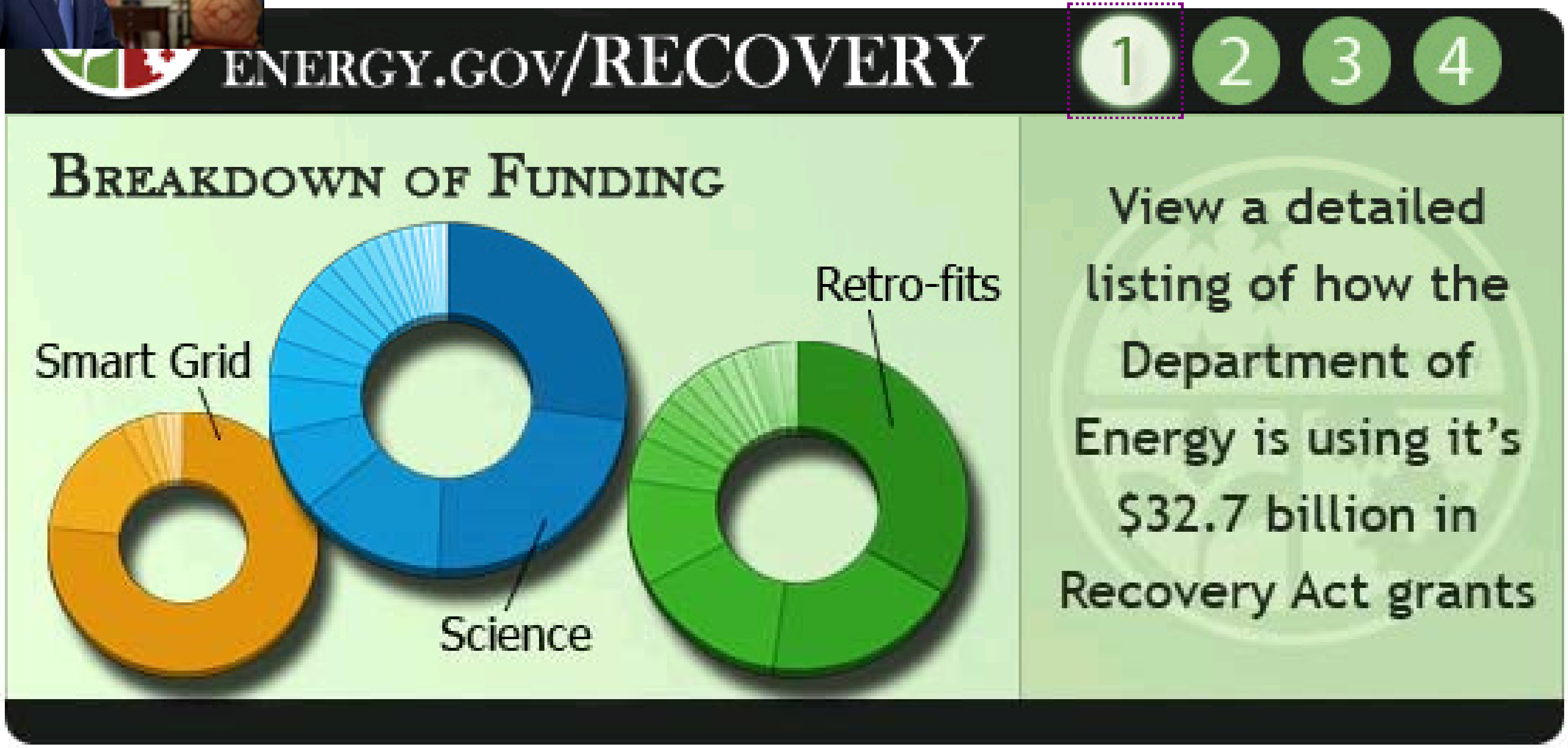




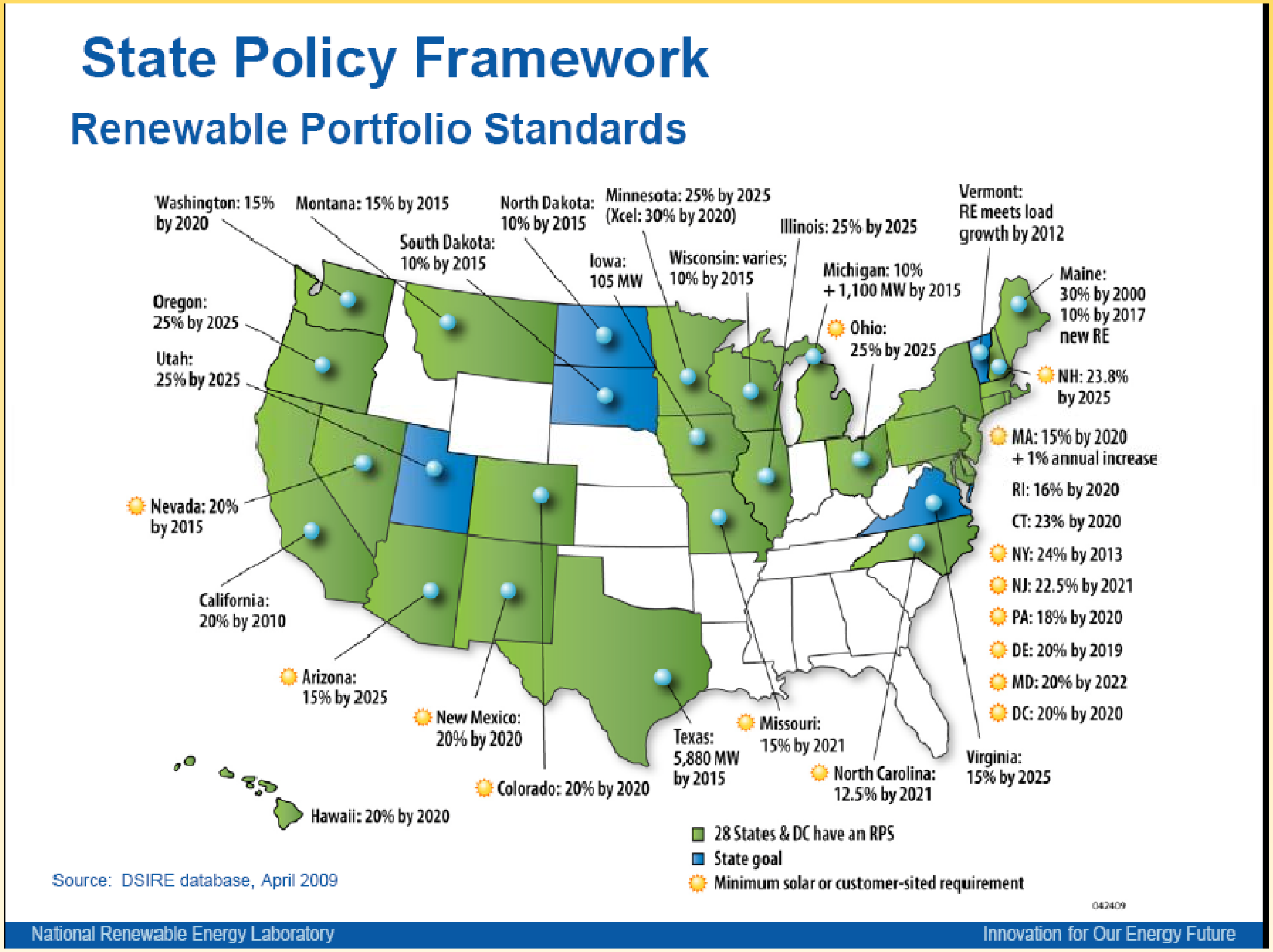
Adjustable Speed Drives



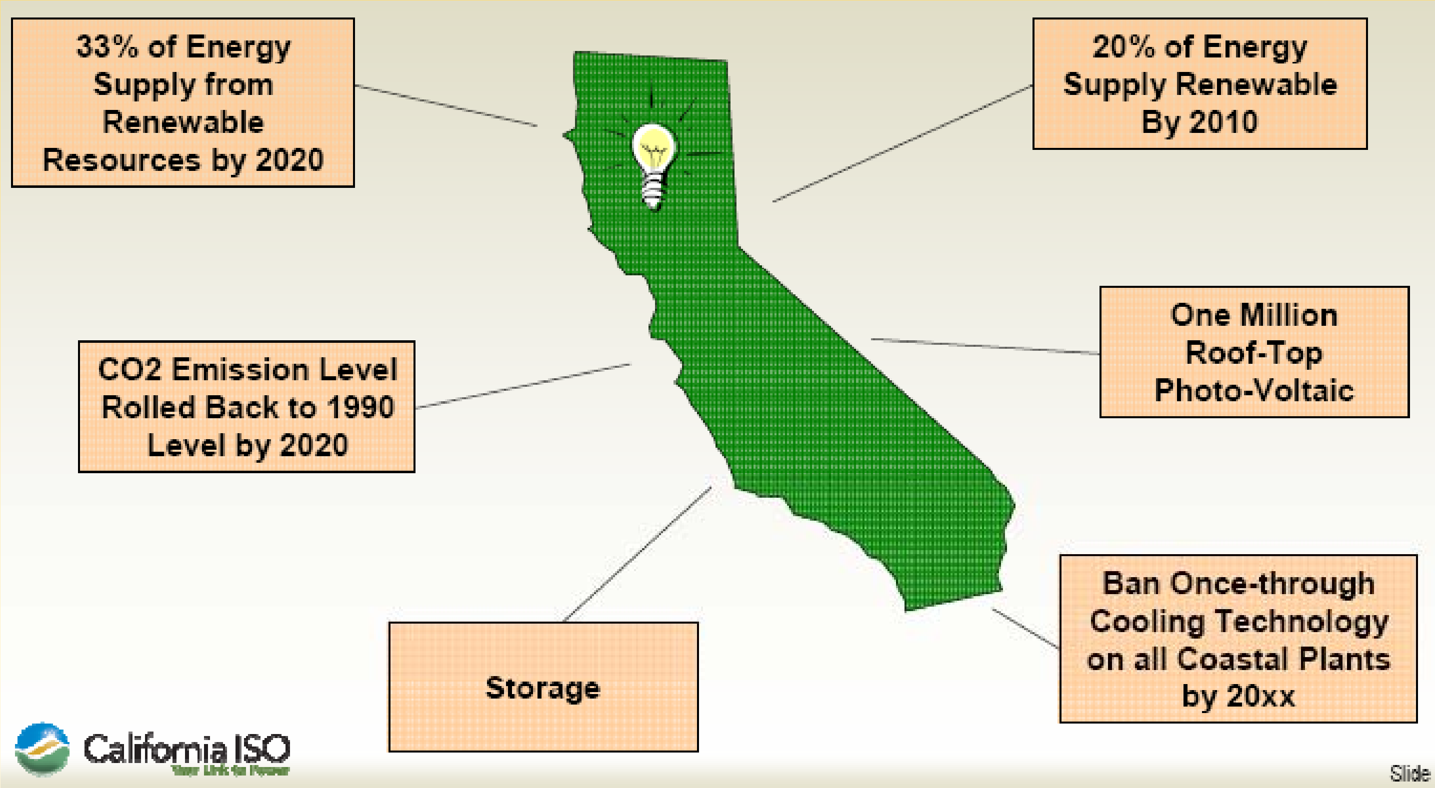
The American Recovery and Reinvestment Act of 2009



Renewable Portfolio Standards



California RPS



Curricular Reform

Group Effort:

- Ned Mohan
- Bill Robbins
- Bruce Wollenberg
- Paul Imbertson
- Tom Posbergh
- Dr. Narain G. Hingorani (Project Consultant)
- Students

www.ece.umn.edu/groups/power

Past Sponsors:

Lab Development Grants:

- NSF CCLI-EMD
- NASA
- ONR

Initial Dissemination Grant: NSF CCLI-ND

Present ONR Dissemination Grant:

Program Officer: Terry Ericsen

(1.23 Million Dollars over 5 years)

Supported by NSF

DARPA-RA-10-3

Introduction

The United States has entered into a significant national decline in the number of college graduates with STEM degrees. This downward trend is an issue of national importance as it affects our capacity to maintain a technological lead in critical skills and disciplines related to CS-STEM. Our ability to compete in the increasingly internationalized stage will be hindered without college graduates with the ability to understand and innovate cutting edge technologies in the decades to come.

- **Funding Profile** – DARPA anticipates 1-3 awards. The funding allotted for Cooperative Agreements under this RA is approximately $1-2 million for the first year (for each award), increasing at a rate of approximately $500k each year.

Outline:

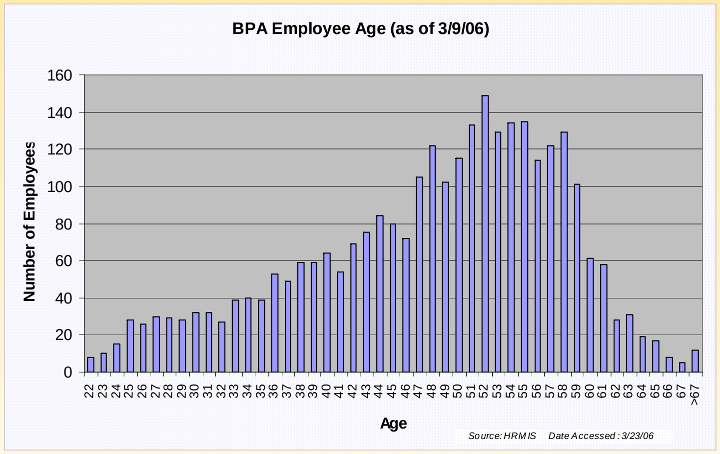
- Problem
- Approach and Results
- Available Resources
- Dissemination Goals
- Brief Description of the Courses

Workforce Crisis:

- Serious shortfalls predicted
  - ◆ NSF-Sponsored Workshop in Arlington, Virginia Nov, 2008

BPA Workforce:

- 2,944 employees
- Median age is 50
- 21% eligible to retire by 12/07
- 42% eligible to retire by 12/11



Data Source: HRMIS as of 2/9/06

Source: Clark Gellings, EPRI

Crisis in Undergraduate Education in Power Engineering

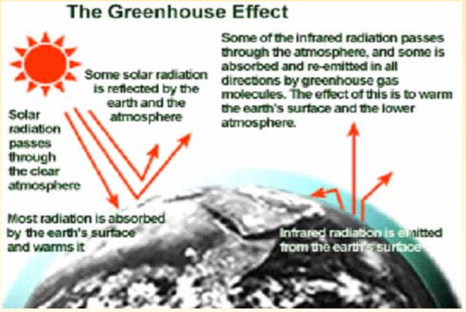
- Courses have not kept pace with Industrial Practices

We can all agree….

- **Goal: Increase Quality <u>and</u> Quantity**
- **Faculty Resources are Limited**

Young People are Concerned about the Environment -

We can tap into their enthusiasm to make a difference and provide them a career path.



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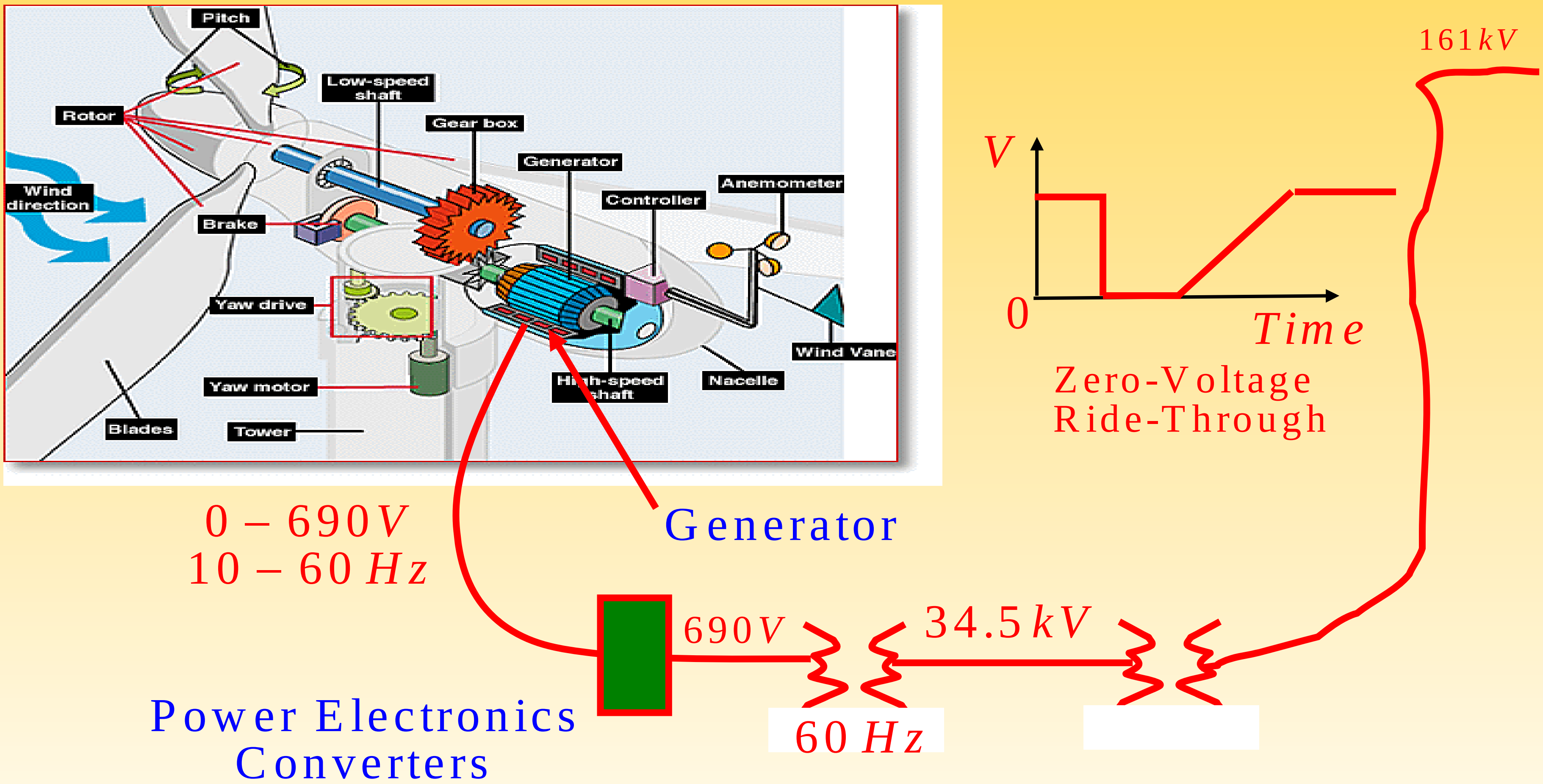
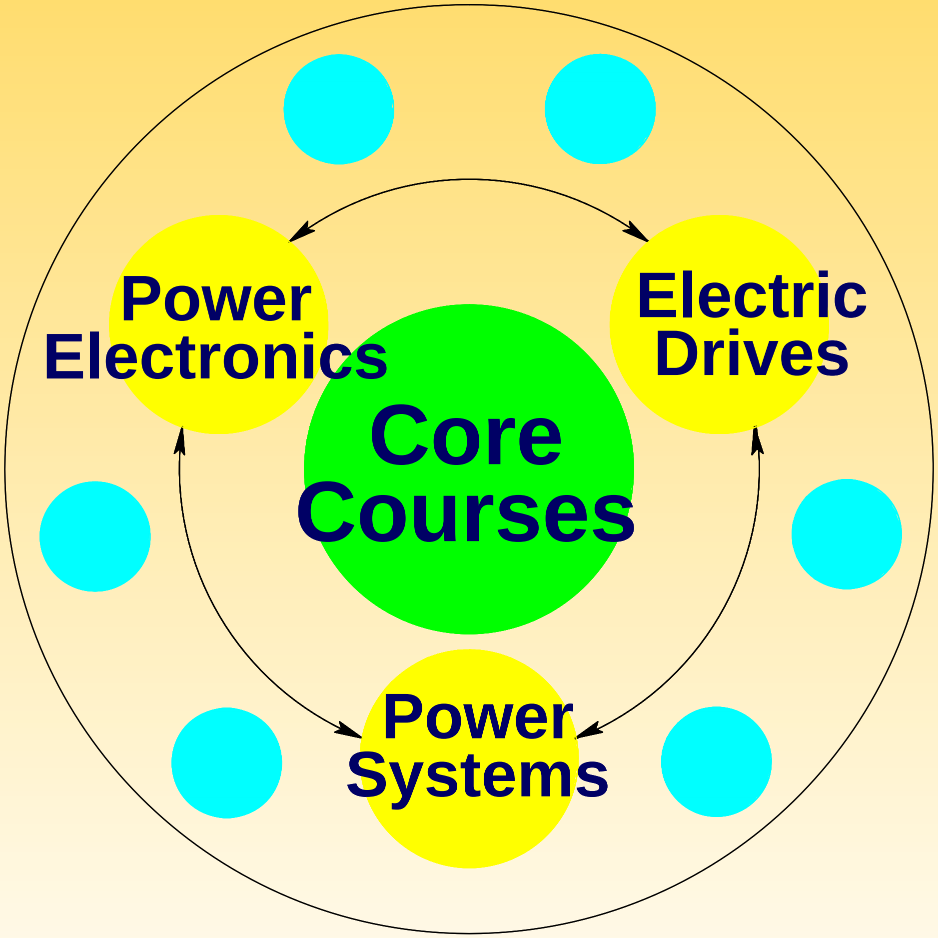
Wind Generation: Example of an Integrated System



Our Integrated Curriculum – Only 3 Courses



Complementary Courses:

- Analog/Digital Control
- DSPs, FPGAs
- Programming Languages
- Heat Transfer
- Thermo

Students are Broadly Trained; They can work in any field of EE.

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Increasing Student Enrollments –

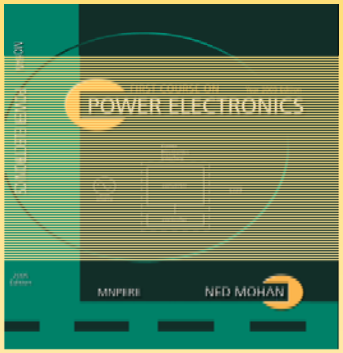
2008-2009 Enrollment:

Power Systems: 90
Power Electronics: 118
Electric Drives: 124

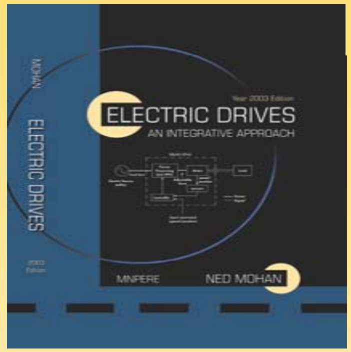
Fundamentals-based Education Leads to Graduate Education and PhD Research

Resources:

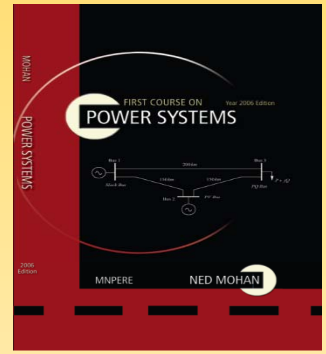
Power Electronics:



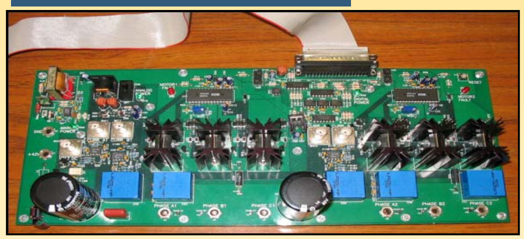
Electric Drives:



Power Systems:



PSpice Lab:



Software Lab:

MATLAB/Simulink
PowerWorld
PSCAD-EMTDC

ONR/NSF-Sponsored Faculty Workshops

2011 Annual Workshop
Napa, CA Feb 4-5, 2011

Weeklong Summer Training Workshops: (sponsored by ONR-NSF-EPRI-AEP)

Oregon State University

July 4-6, 2010

In collaboration with Prof. Ted Brekken of OSU

Goal of ONR/NSF Grants

Supported by EPRI & AEP:

Affect Curricular Change in at least 175 Schools Nationwide

– Adapted so far in various combinations at > 100 schools

Parallel International Effort

Online Courses

- Power Electronics
- Electric Machines/Drives
- Power Systems

◆ Modular
◆ Tightly-Coupled to our Textbooks
◆ CEUs/PDH
◆ Low Cost: $70/Module

Use of Online Courses:

- Certificates for Practicing Engineers
- at other Universities (ABET: 432)

Center for Innovation – Electric Energy Systems (CI-EESE)

Midwest ISO
New York ISO
ISO - New England
Air Force Research Lab
Hamilton Sundstrand
Ulteig Engineers
UMCEE Members

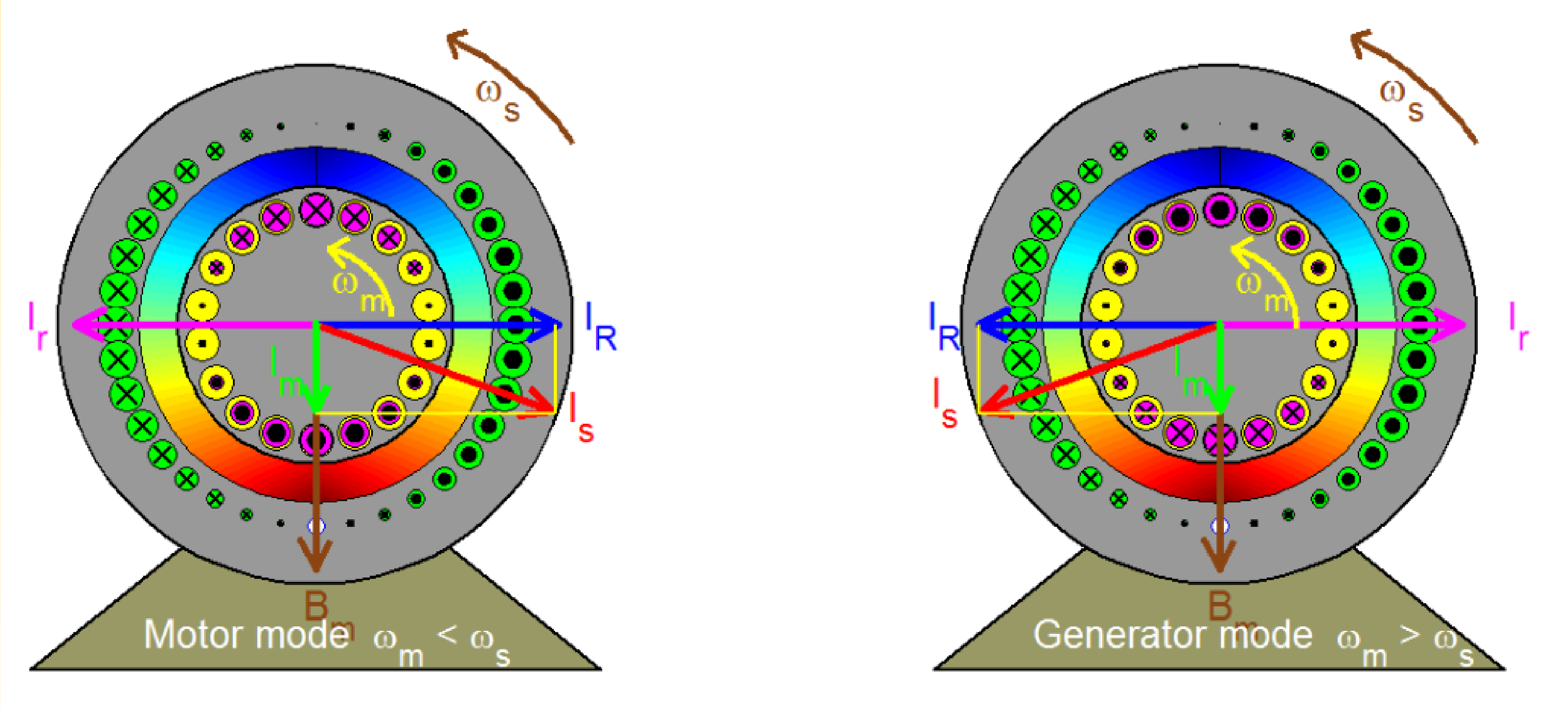
Benefit to Members: Courses are free to all their employees

Membership Fee: 10,000 $/year

Pedagogy-

- Motivation:
  – Students are actively engaged
- Procedure:
  – Pre-class: watch a 20-minute module and answer a brief online quiz
  – During-class: discuss and solve real-world, design-oriented, somewhat open-ended problems in small groups
  – Post-class: homework problems on individual basis; based on Moodle

Animations by Prof. Riaz:

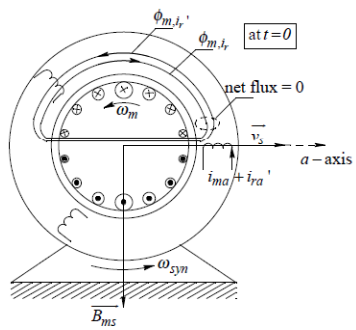


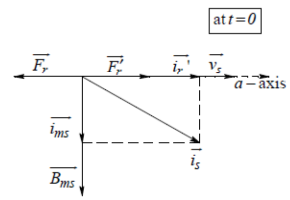
http://www.ece.umn.edu/users/riaz/animations/sqmoviemotgen.html

Instructor's CD

Rotor MMF – Reflected Rotor MMF – Reflected Rotor Current

11-11





$$\vec{F}_s(t) = \vec{F}_{ms}(t) + \vec{F}_r'(t)$$

$$\vec{i}_s(t) = \vec{i}_{ms}(t) + \vec{i}_r'(t)$$

$$\hat{I}_r' = k_i \hat{B}_{ms} \omega_{slip}$$

- ❑ $\vec{F}_r$ produced by rotor currents
- ❑ $\vec{F}_r'$ produced by additional stator currents to keep total flux unchanged (transformer analogy)
- ❑ These currents are viewed as a current space vector $\vec{i}_r'$
- ❑ Total stator current is magnetizing current plus this reflected rotor current

Exit

Audio TOC ⇦ ⇨

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Power Systems Lab:

Lab Manual - Experiments

1. Visit to a Local Substation/Generating Plant
2. Familiarization with PSCAD/EMTDC
3. Obtaining Parameters of a 345 kV Transmission Line and Modeling it in PSCAD/EMTDC
4. Power Flow using MATLAB and PowerWorld
5. Including Transformers in Power Flow using PowerWorld and Confirmation by MATLAB
6. Including an HVDC Transmission Line for Power Flow Calculations in PowerWorld and Modeling of Thyristor Converters in PSCAD/EMTDC
7. Power Quality
8. Synchronous Generators
9. Voltage Regulation
10. Transient Stability using MATLAB
11. AGC using *Simulink* and Economic Dispatch using *PowerWorld*
12. *Transmission Line Short Circuit Faults using MATLAB and PowerWorld, and Overloading of Transmission Lines using PowerWorld*
13. Switching Over-Voltages and Modeling of Surge Arresters using PSCAD/EMTDC

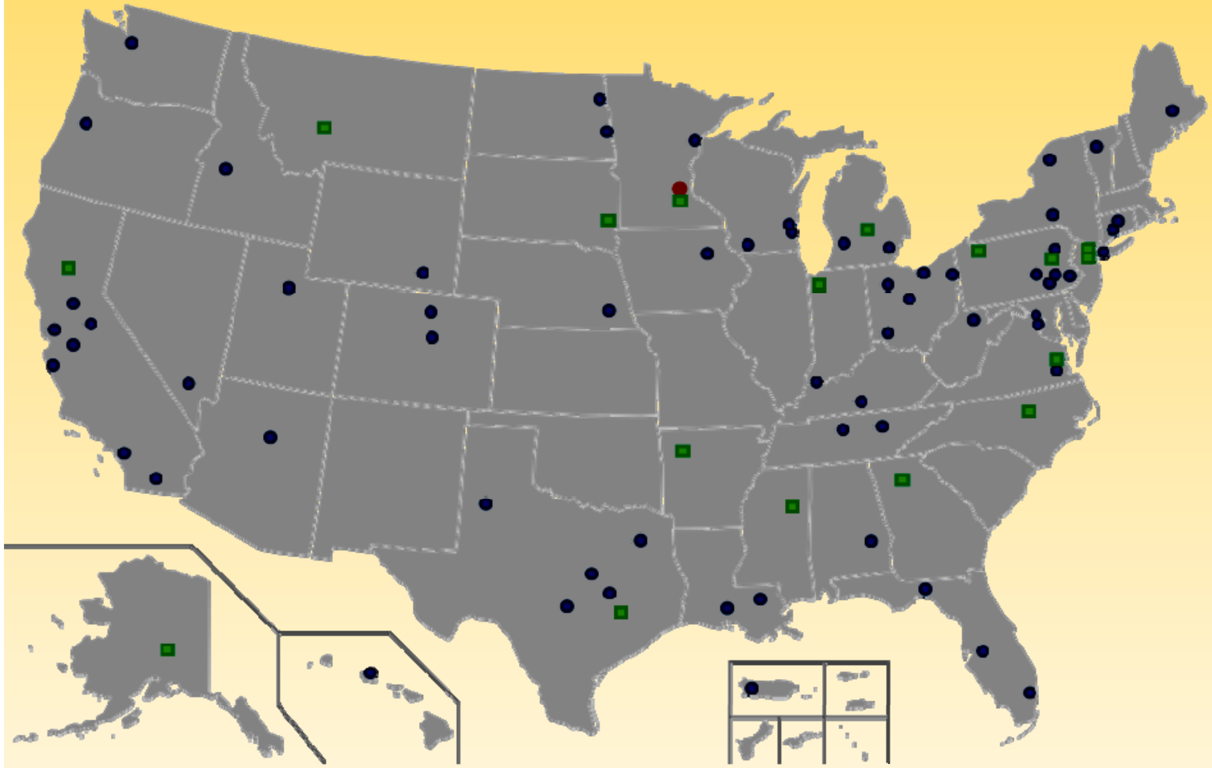
CD with 18 Video Clips

http://www.ece.umn.edu/groups/power/labs/ps/video_instructions.html

1.	**Installation of PowerWorld and PSCAD-EMTDC**
2.	**Familiarization with using PSCAD-EMTDC**
3.	**Obtaining Parameters of Transmission Line using PSCAD/EMTDC**
4.	**Simulating a Transmission Line in a Power System using PSCAD/EMTDC**
5.	**Power Flow using PowerWorld**
6.	**Power Flow using MATLAB**
7.	**Including Off-Nominal Turns-Ratio and Phase-Shifting Transformers in Power Flow using PowerWorld**
8.	**Including an HVDC Transmission Line for Power Flow in PowerWorld**
9.	**Modeling of Thyristor Converters in PSCAD-EMTDC**
10.	**Power Quality Calculations using PSCAD-EMTDC**
11.	**Modeling of Synchronous Generators using PSCAD-EMTDC**
12.	**Voltage Regulation by Thyristor Controlled Reactors (TCR) using EMTDC**
13.	**Thyristor Controlled Series Capacitors (TCSC) using PSCAD-EMTDC**
14.	**Transient Stability using MATLAB**
15.	**AGC using *Simulink***
16.	**Transmission Line Short Circuit Faults using PowerWorld**
17.	**Tripping of Transmission Lines due to Overloads using *PowerWorld***
18.	**Switching Over-Voltages and Modeling of Surge Arresters using EMTDC**

Software:
MATLAB/Simulink
PowerWorld
PSCAD-EMTDC

DOE Proposal Accepted:
"A Nationwide Consortium of Universities to Revitalize Electric Power Engineering"



82 Universities

"These 82 schools represented about 25% of all the graduates in electrical engineering in 2008." – William P. Robbins

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