

# Renewable Energy Technologies

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August 2009

# National Renewable Energy Laboratory

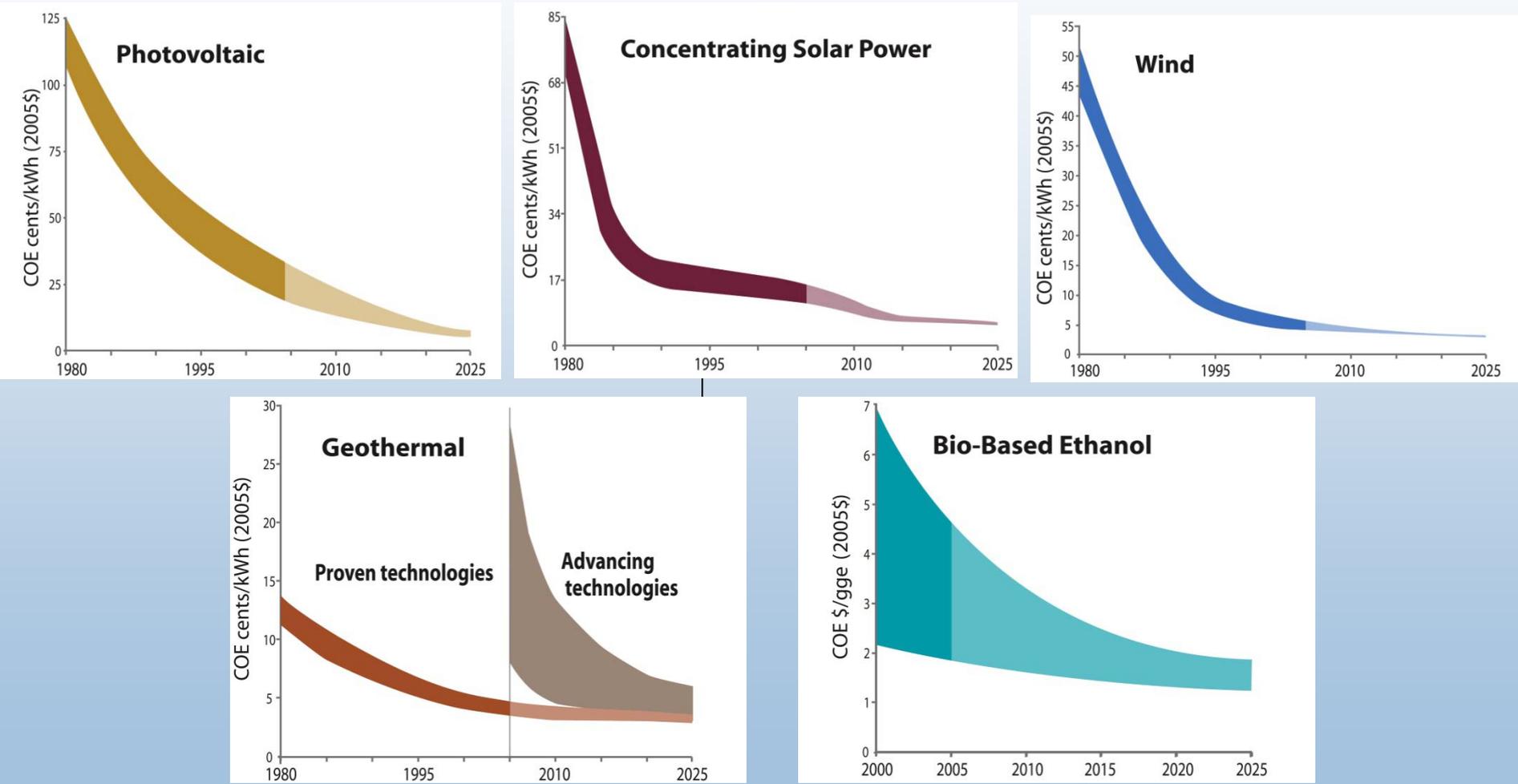
## What Makes Us Unique?

- Only national laboratory dedicated to renewable energy and energy efficiency R&D
- Research spans fundamental science to technology solutions
- Collaboration with industry and university partners is a hallmark
- Research is market relevant because of a systems focus
- New Mgmt & Operations Contract effective October 1, 2008
  - Key areas:
    - Campus Build out
    - Science and Technology
    - World Class Analysis---Virtual Joint Institute for Strategic Energy Analysis
    - Commercialization and Deployment

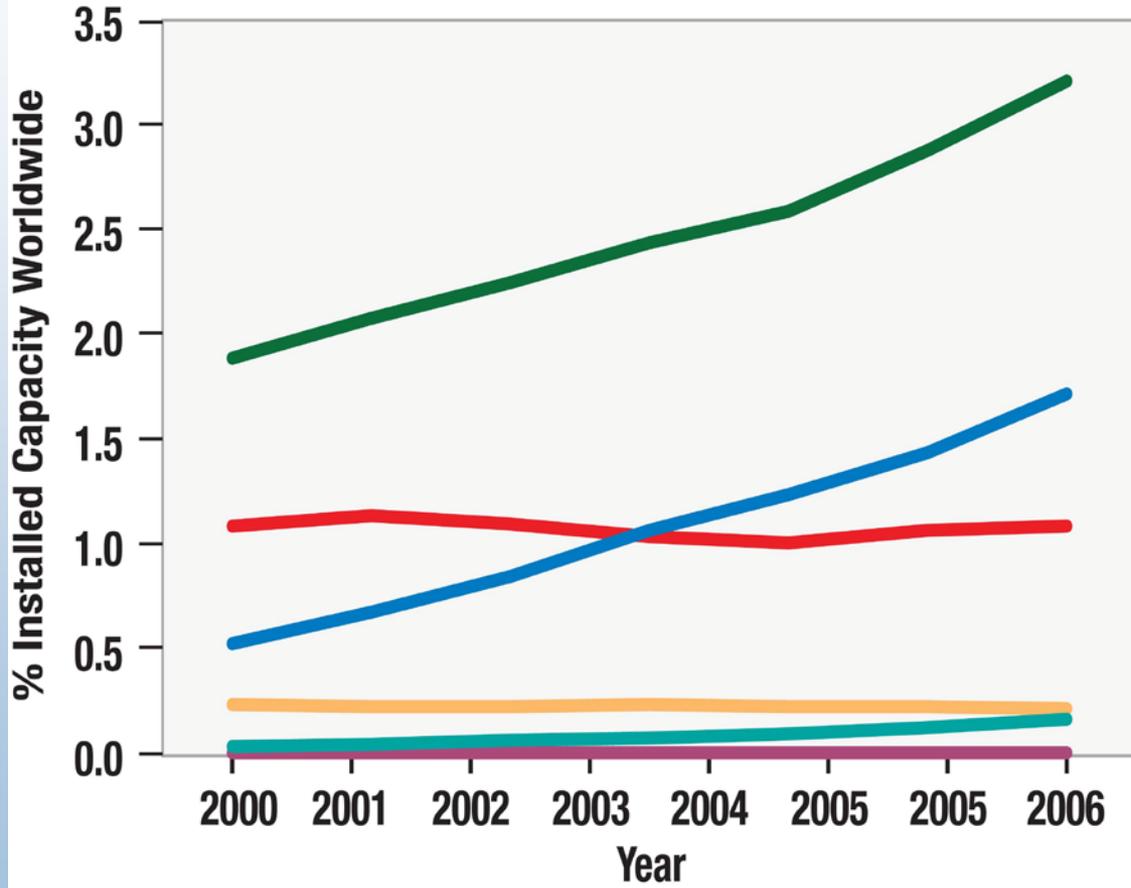


# Renewable Energy Cost Trends

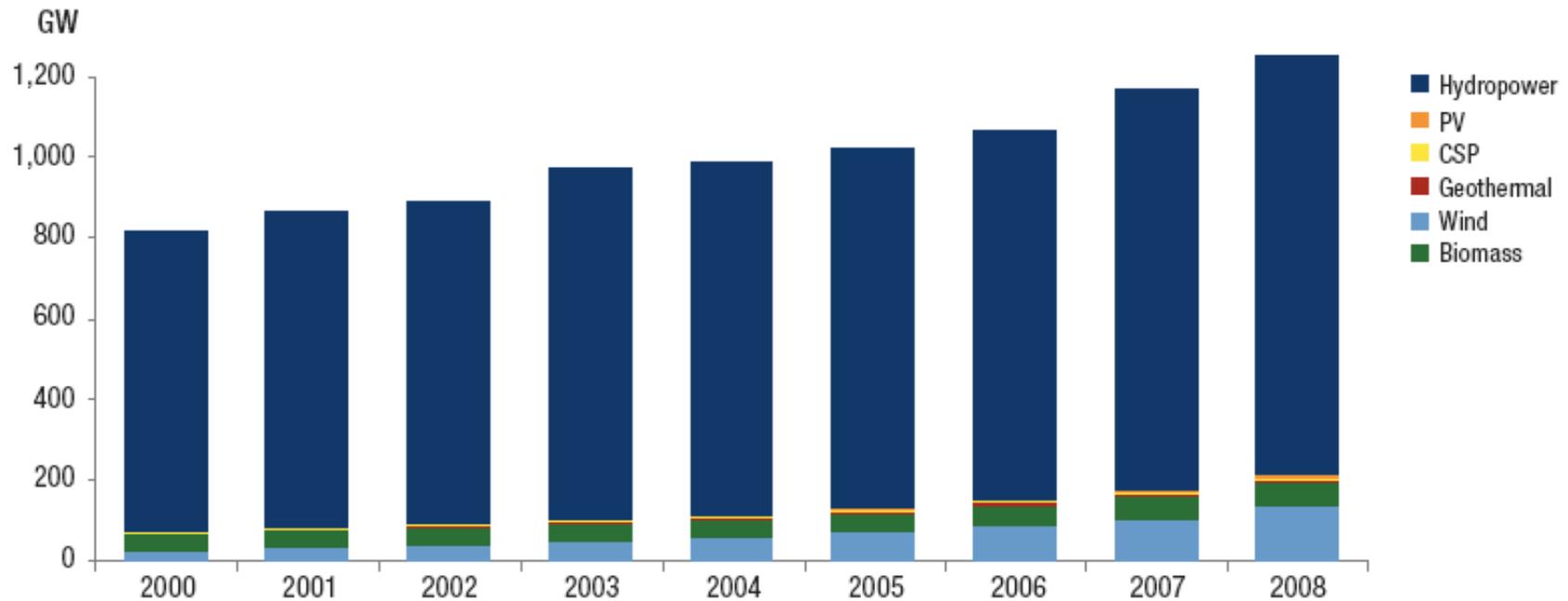
Levelized cost of energy in constant 2005\$<sup>1</sup>



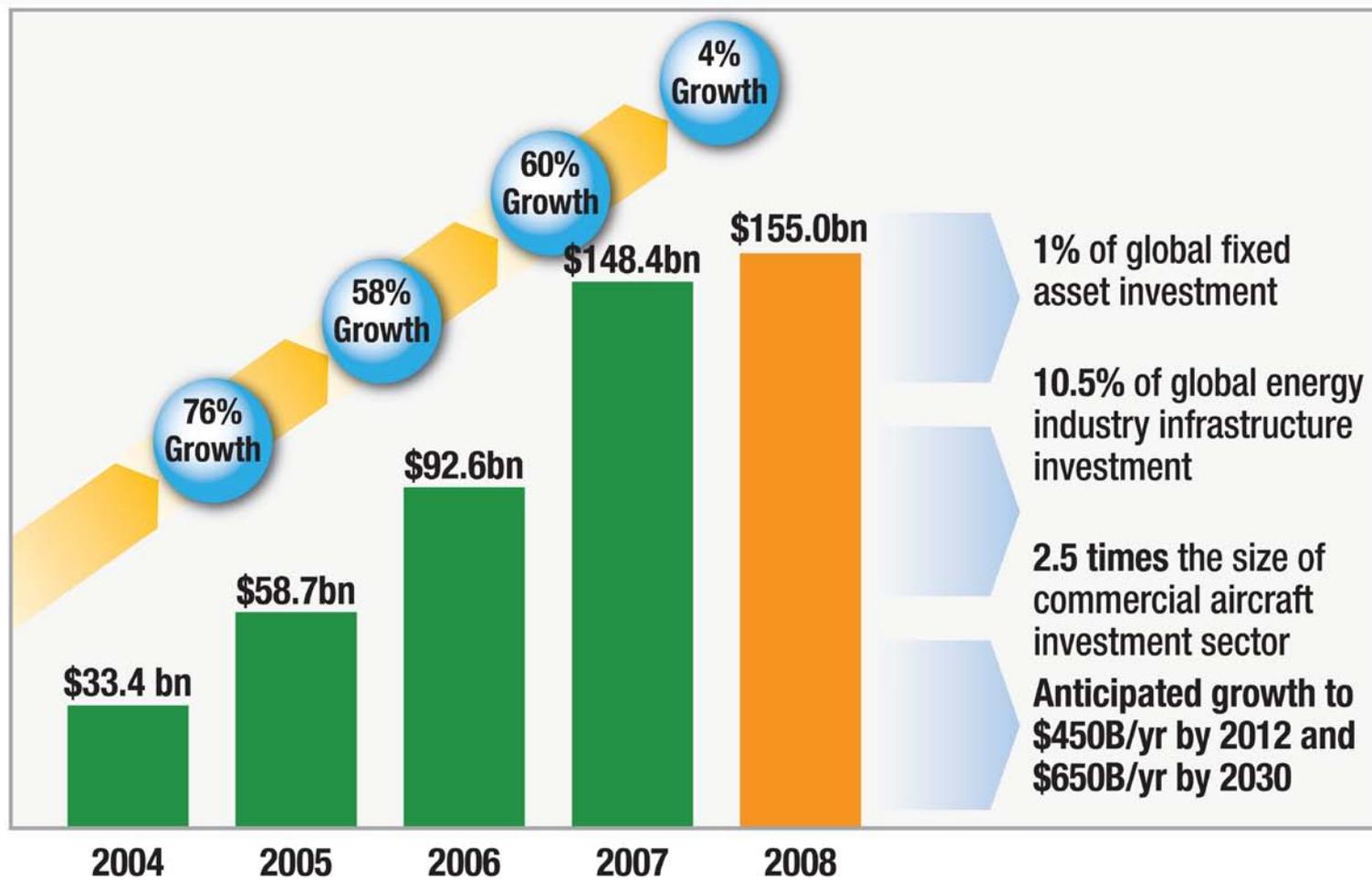
# ...but yet RETs are small contributors



# Global Renewable Electricity Capacity



# Total Global New Investment in Clean Energy 2004 – 2008



Adjusted for reinvestment. Geared re-investment assumes a 1 year lag between VC/PE/Public Markets funds raised and re-investment in projects.

Source: New Energy Finance, IMF WEO Database, IEA WEO 2007, Boeing 2006 Annual Report

# Wind

## Today's Status

- 121 GW installed at end of 2008
- Cost 4-9¢/kWh at good wind sites\*

## DOE Cost Goals

- 3.6¢/kWh, onshore at low wind sites by 2012
- 7¢/kWh, offshore in shallow water by 2014

## US "Vision"

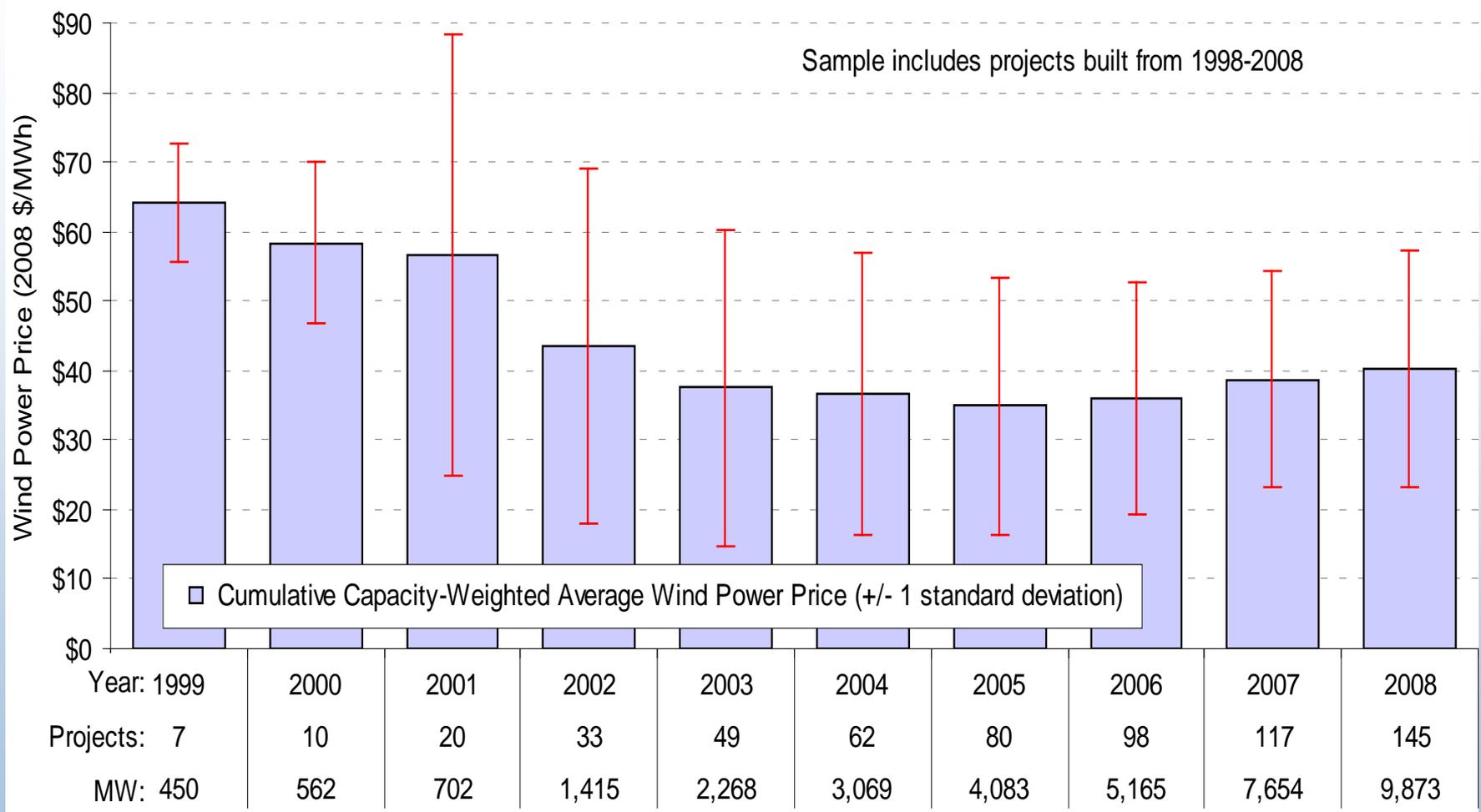
- 20% of the nation's electricity supply



\* With no Production Tax Credit

Source: U.S. Department of Energy, American Wind Energy Association

# Wind



Source:DOE/R. Wiser 2009 Wind Annual update

## NREL Research Thrusts

- Improved performance and reliability
- Advanced rotor development
- Utility grid integration

# Solar

## Photovoltaics and Concentrating Solar Power

### Status in U.S.

#### PV

- 1106 MW
- Cost 18-32¢/kWh

#### CSP

- 419 MW
- Cost 12-14¢/kWh

### Potential:

#### PV

- 11-18¢/kWh by 2010
- 5-10 ¢/kWh by 2015

#### CSP

- 8-10 ¢/kWh by 2015
- 6-8 ¢/kWh by 2020



### NREL Research Thrusts:

#### PV

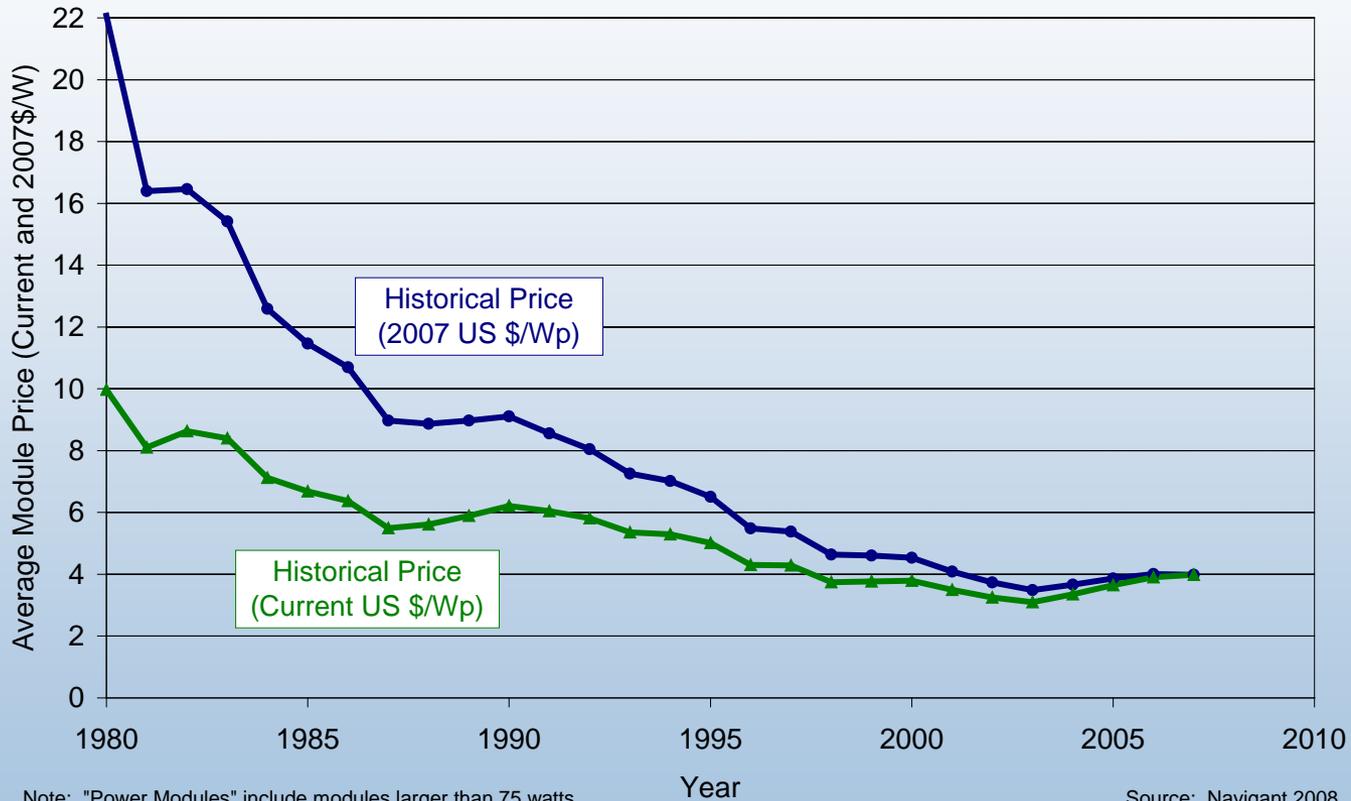
- Partnering with industry
- Higher efficiency devices
- New nanomaterials applications
- Advanced manufacturing techniques

#### CSP

- High performance, low cost storage for baseload markets
- Advanced absorbers, reflectors, and heat transfer fluids
- Next generation solar concentrators

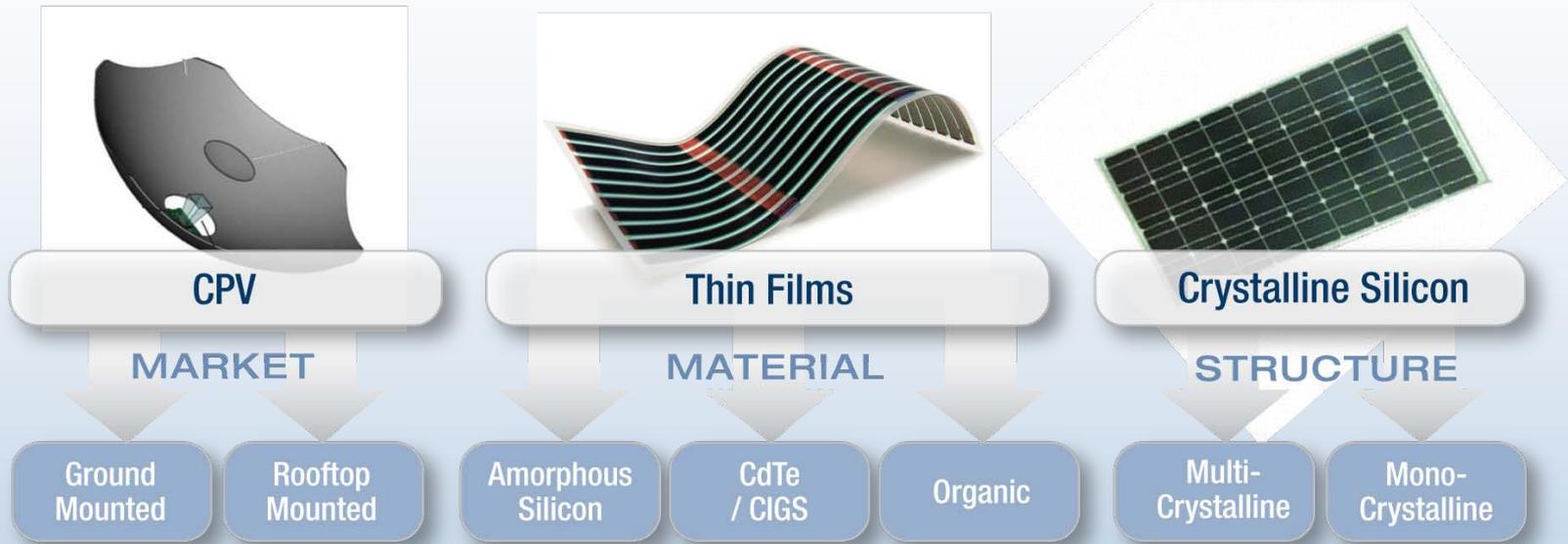
# PV Price Trends

## Historical PV Module Price (Power Modules)





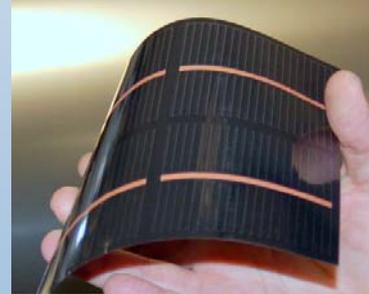
# Many promising PV technologies



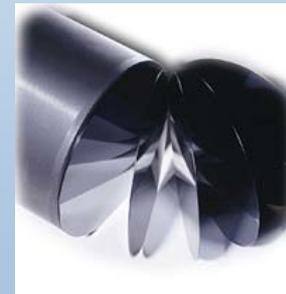
20x-100x



500x



$\text{Cu(In,Ga)Se}_2 \sim 1\text{-}2 \text{ }\mu\text{m}$



c-Si  $\sim 180 \text{ }\mu\text{m}$



# Also pursuing a range of promising Concentrating Solar Power (CSP) technologies



**Trough**



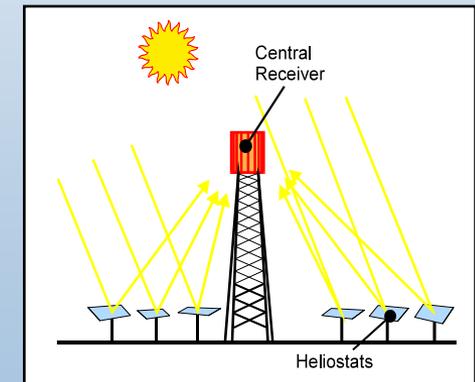
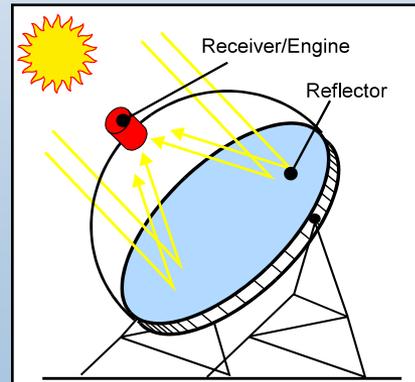
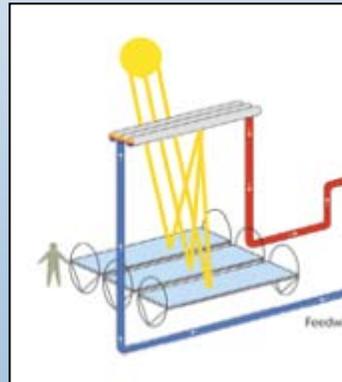
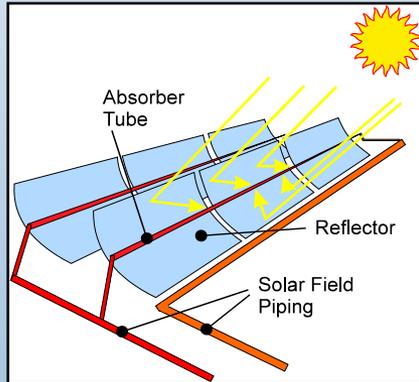
**Linear Fresnel**



**Dishes**

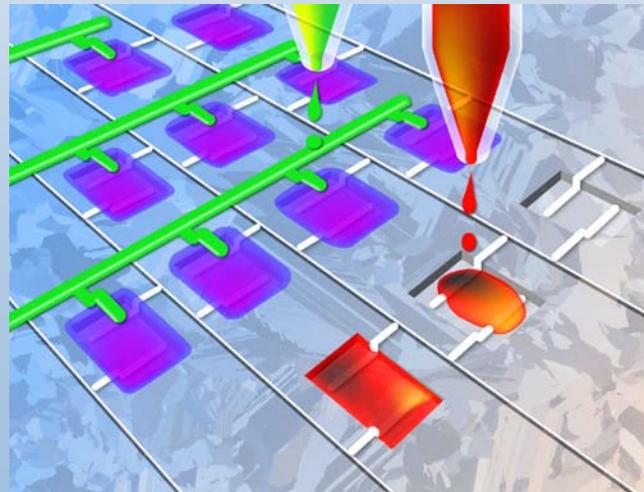
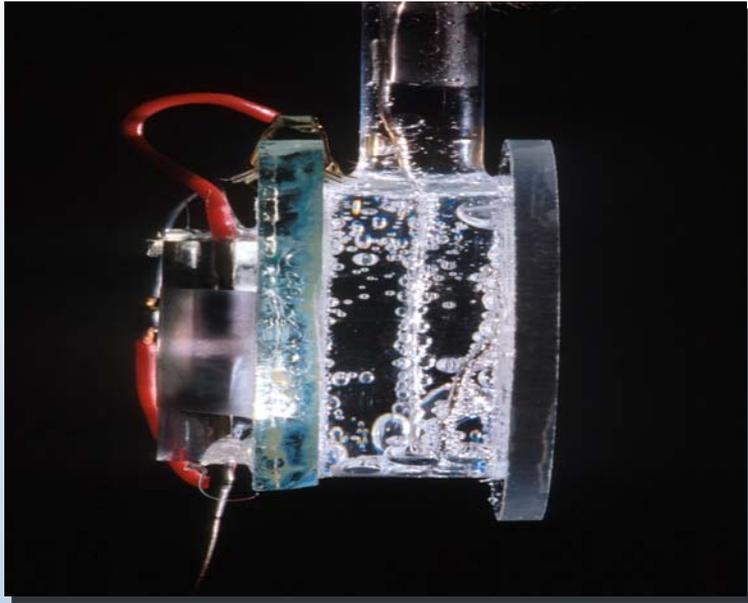


**Tower**

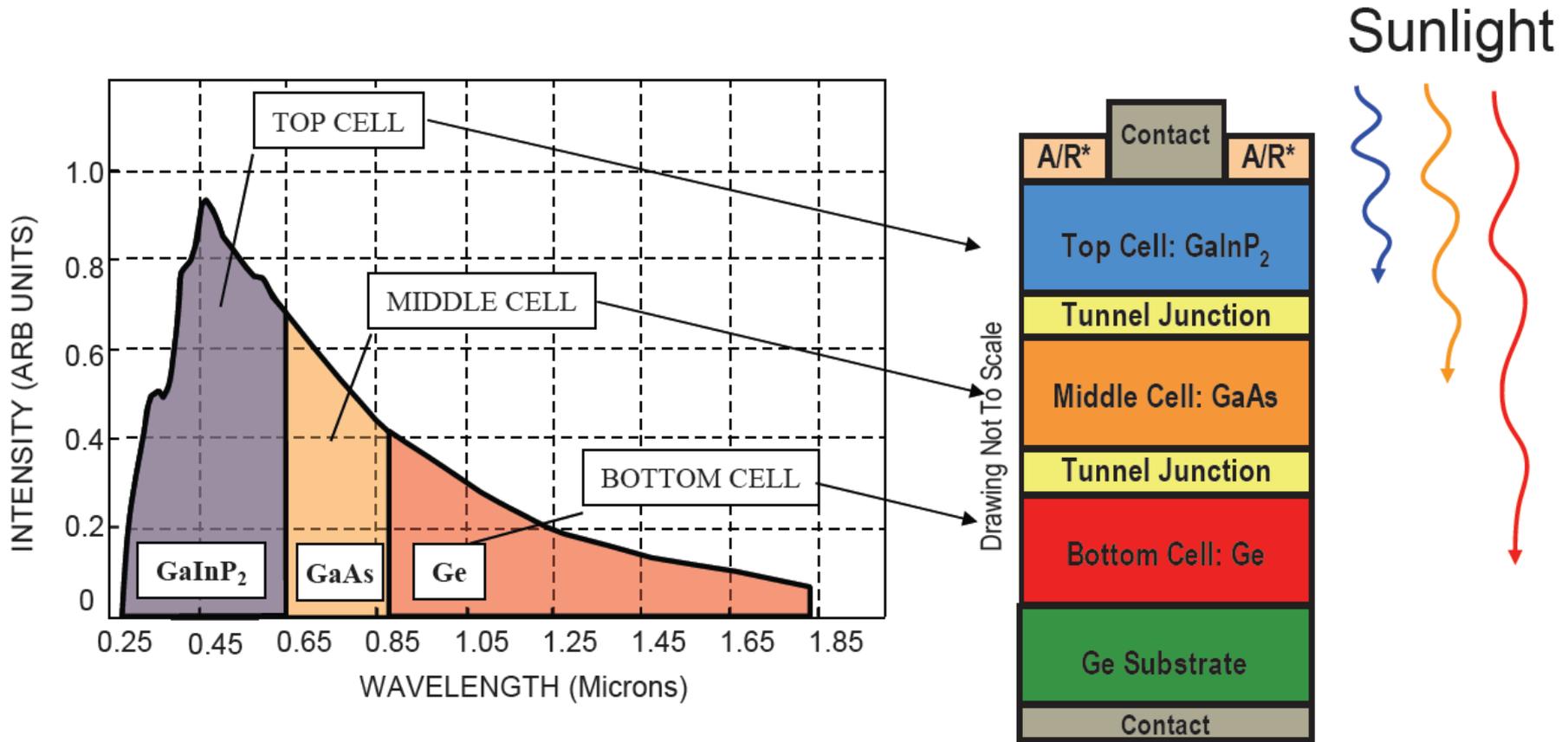


Utility scale power plants – intermediate and base load power

# Explorations leading to new discoveries



# ~41% Efficient Multiple Junction Concentrator Cell (~250X; Spectrolab/Boeing/NREL, 2007;)



**capital cost~(\$75,000/m<sup>2</sup>)**

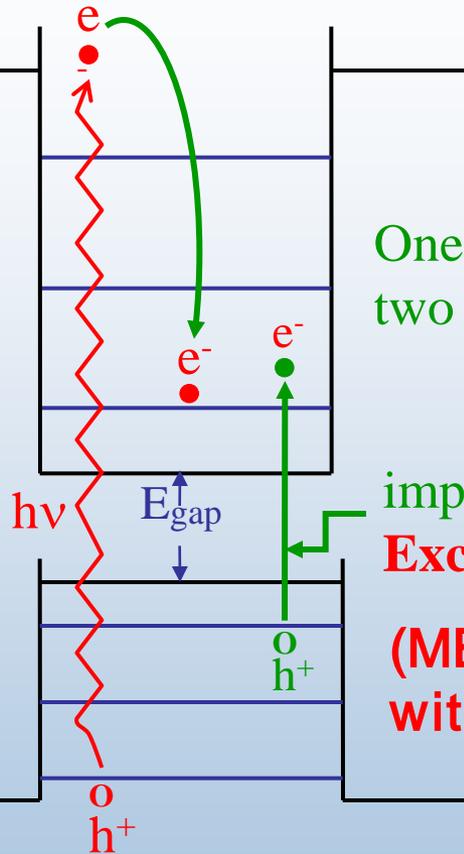
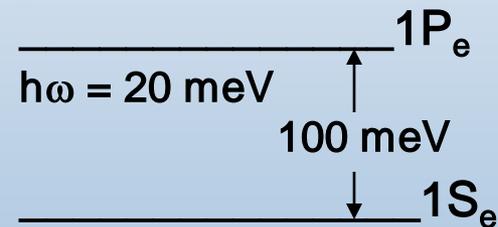
\*A/R: Anti-Reflective Coating

- Typical 3J cell contains 20 layers or more.
- Divides the solar spectrum ( $\lambda < 1.750 \mu\text{m}$ ) to maximize efficiency.

# Enhanced Photovoltaic Efficiency in Quantum Dot Solar Cells by Multiple Exciton Generation

MEG is an inverse Auger process; Auger processes are enhanced in QDs:  
 $\langle 2P_e | v(r_1, r_2) | 1S_e 1S_e 1S_h \rangle$   
 (crystal momentum need not be conserved (not a good quantum number))

Carrier thermalization is suppressed due to phonon bottleneck



One photon yields two  $e^-h^+$  pairs

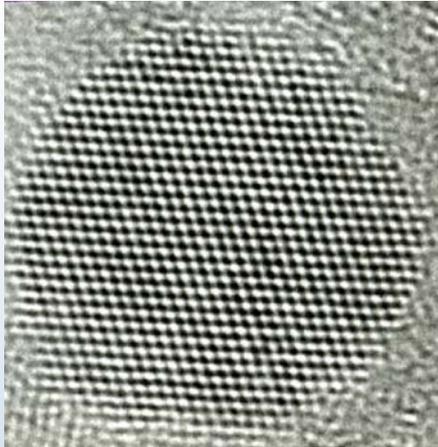
impact ionization (now called **Multiple Exciton Generation (MEG)**)

**(MEG can compete successfully with phonon emission)**

Quantum Dot

A.J. Nozik, *Physica E* 14, 115, 2002; *Ann. Rev. Phys. Chem.* 52, 193, 2001; in “*Next Generation Photovoltaics*”, Marti & Luque, Eds, AIP, 2003;

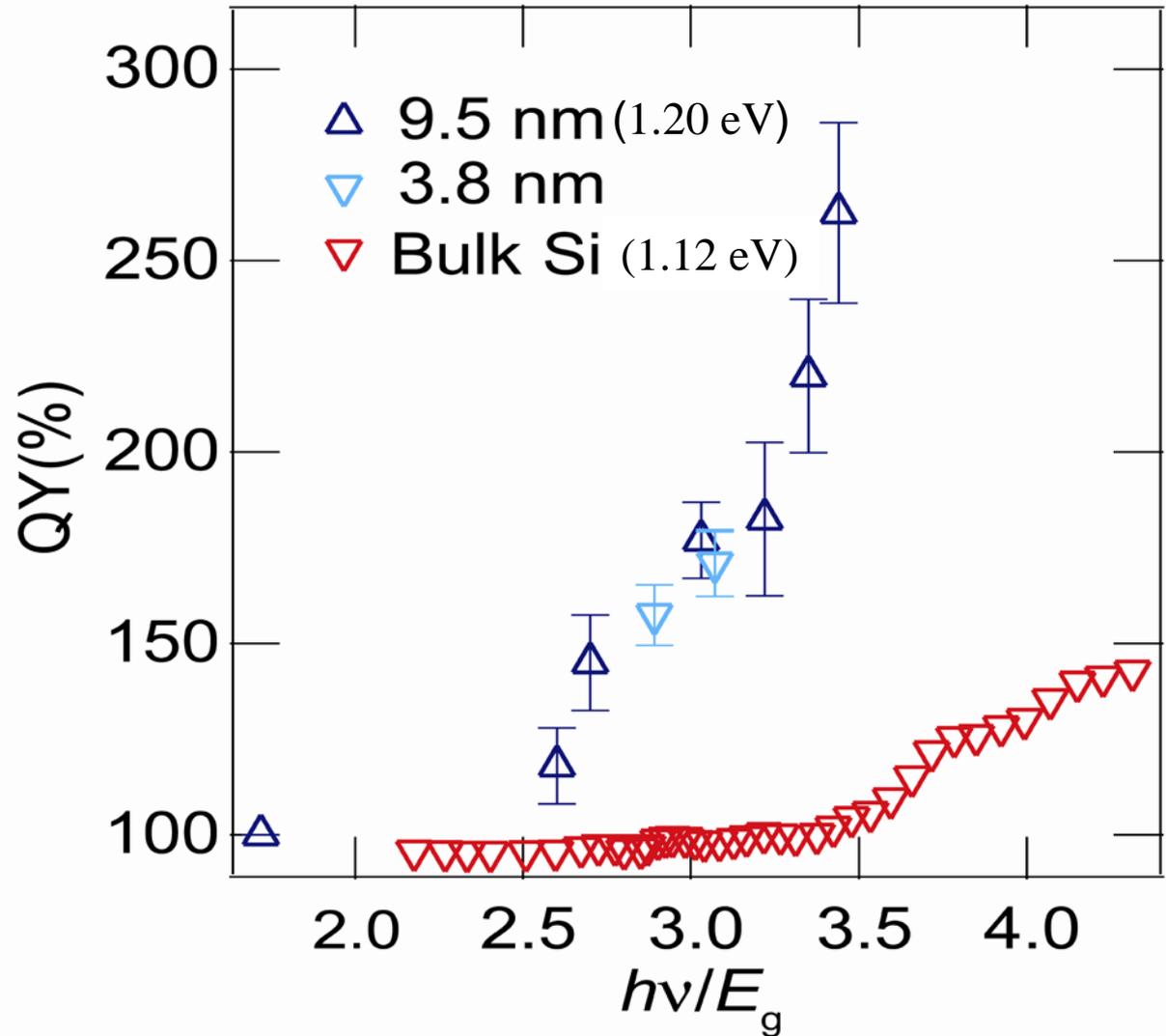
# MEG in Si Nanocrystals vs Impact Ionization in Bulk Si



Si Nanocrystal  
(7 nm dia)

(Nano Lett, 7, 2506,  
2007)

Note very small blue  
blue shift of QD  $E_g$   
compared to bulk Si  
(only 80 meV)



# Biofuels

## Current Biofuels Status

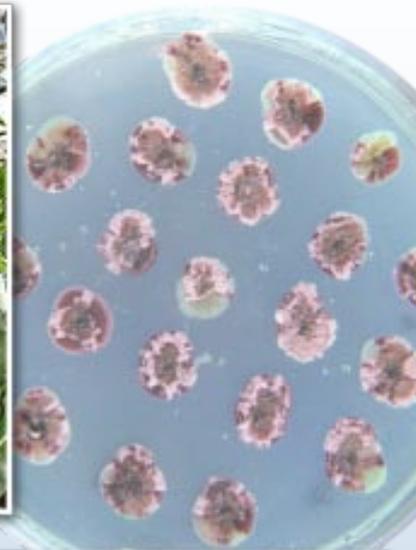
- Biodiesel – 165 companies; 1.85 billion gallons/yr capacity<sup>1</sup>
- Corn ethanol
  - 134 commercial plants<sup>2</sup>
  - 7.2 billion gal/yr. capacity<sup>2</sup>
  - Additional 6.2 billion gal/yr planned or under construction
- Cellulosic ethanol (current technology)
  - Projected commercial cost ~\$3.50/gge

## Key DOE Goals

- 2012 goal: cellulosic ethanol \$1.31/ETOH gallon or ~\$1.96/gge
- 2022 goal: 36B gal Renewable Fuel; 21B gal “Advanced Renewable Fuel”– 2007 Energy Independence and Security Act
- 2030 goal: 60 billion gal ethanol (30% of 2004 gasoline)

## NREL Research Thrusts

- The biorefinery and cellulosic ethanol
- Solutions to under-utilized waste residues
- Energy crops
- Other Pathways and fuels

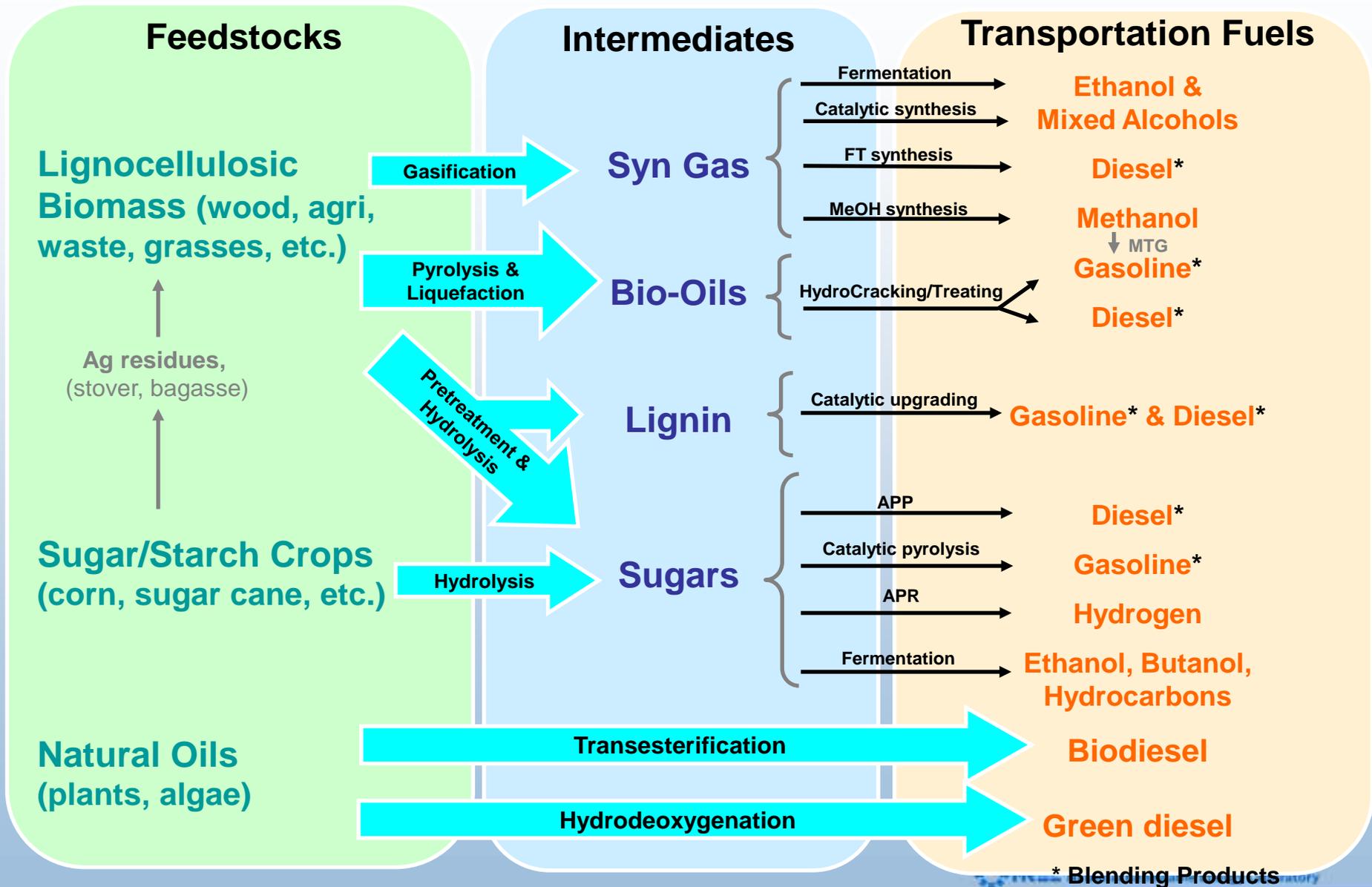


Updated February 2008

Sources: 1- National Biodiesel Board

2 - Renewable Fuels Association, all other information based on DOE and USDA sources

# Pathways to Biofuels



# Implications for Mitigating Climate Change

- RETs are:
  - Maturing
  - Growing in contribution, albeit from a small base
  - no/low emissions vs fossil fuels
  - Offer local, domestic resource diversification
  - Likely have much greater techno-economic potential than previously considered
  - Are supported by a variety of policies (some which need revisiting)



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