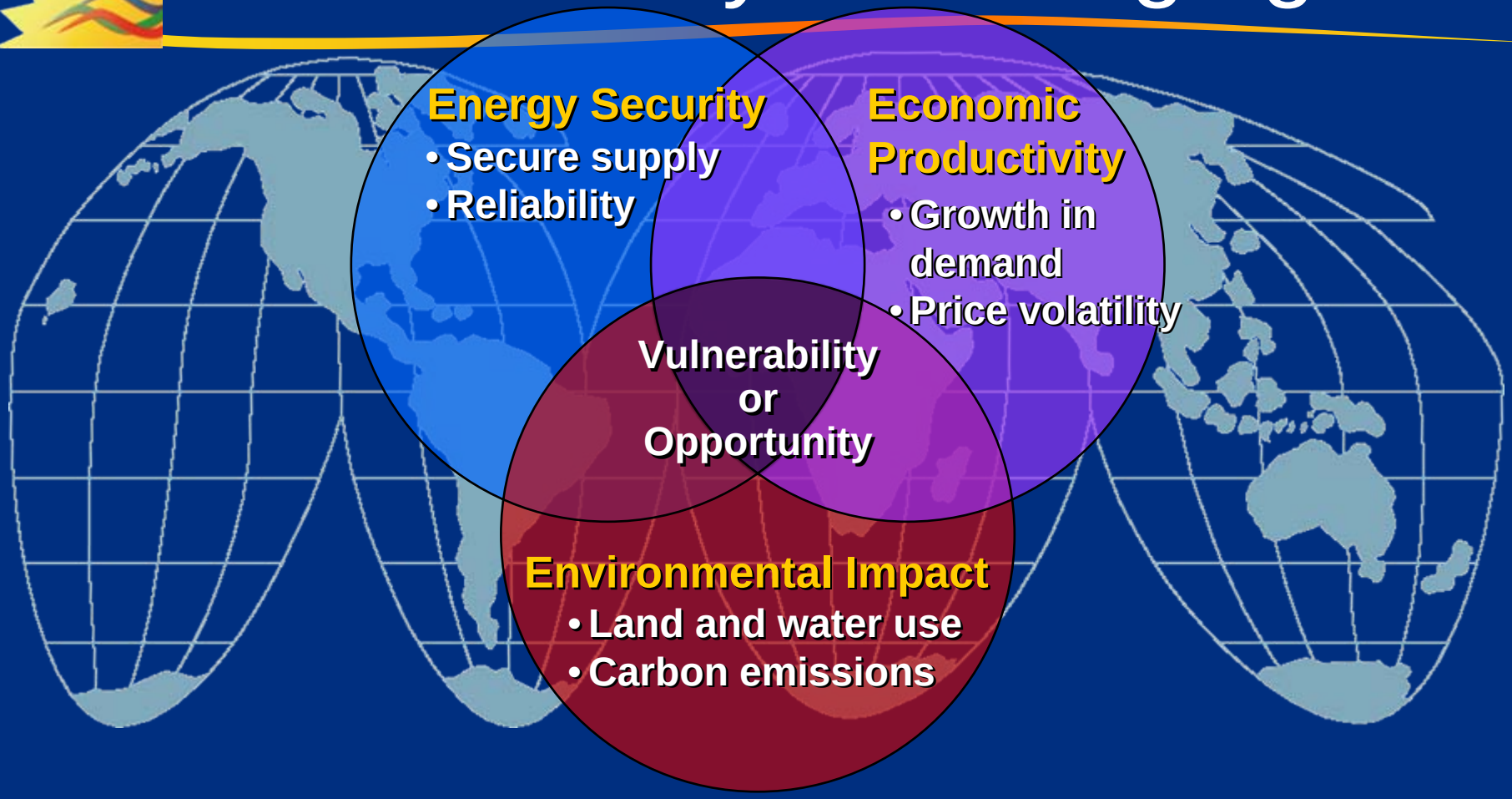
What will power your future?...

Renewable Energy Optimization (REO) and Frontiers of Research

Andy Walker PhD PE
National Renewable Energy Laboratory
US DOE Federal Energy Management Program

Energy Solutions Are Enormously Challenging



Must address all three imperatives

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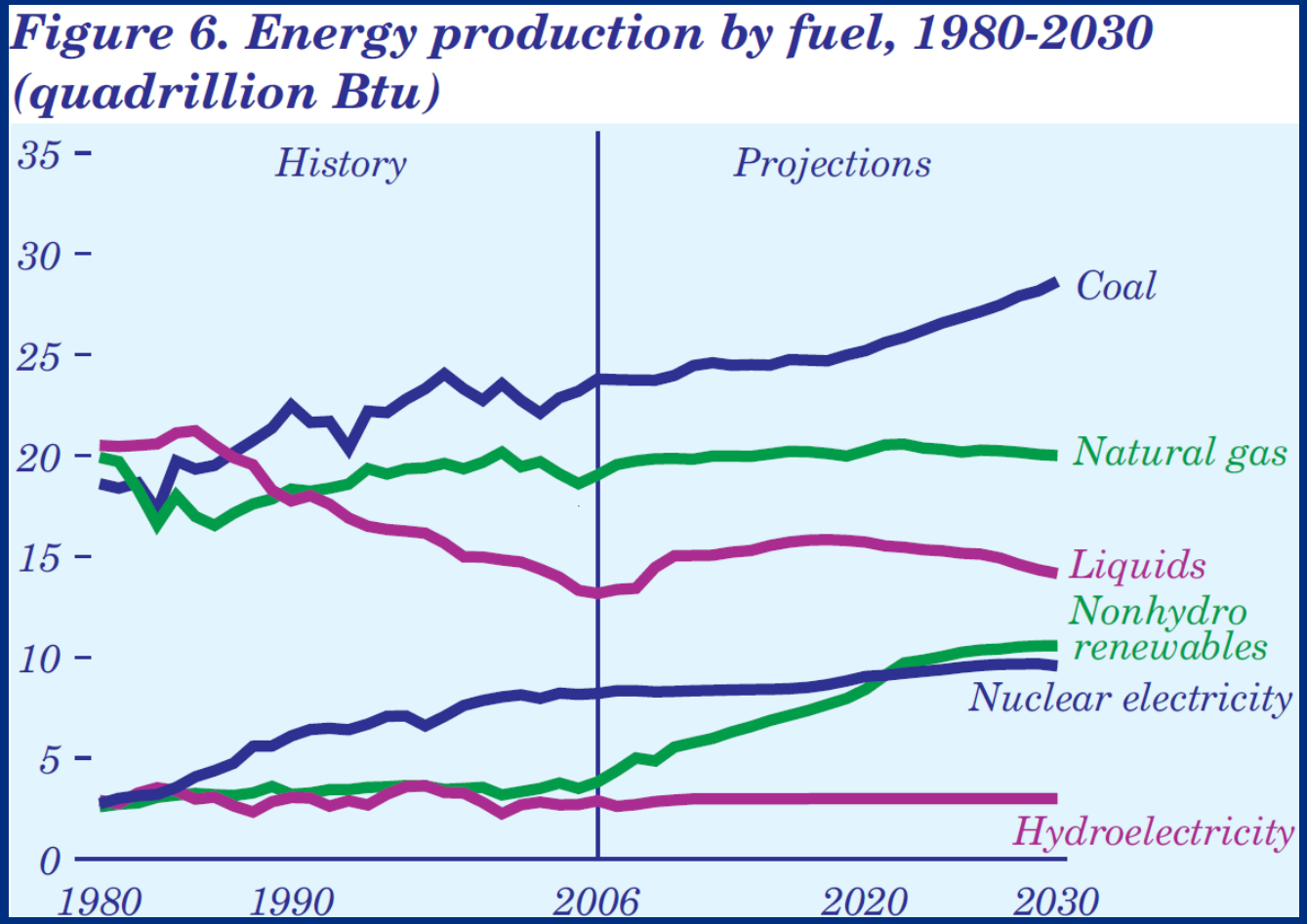
August 3-6, 2008

What will power your future?



Energy Information Administration / Annual Energy Outlook 2008

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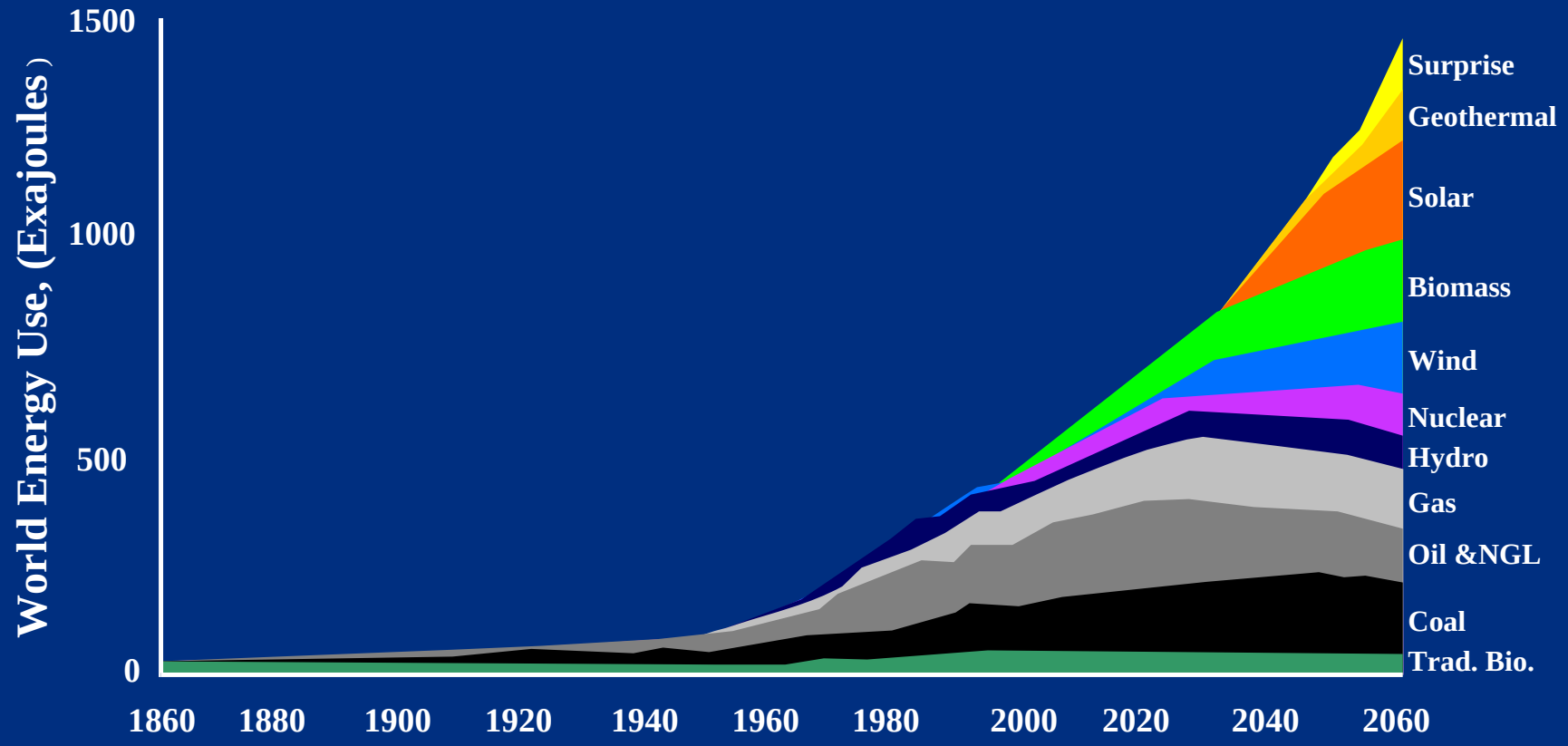
The Future of Energy



Source: *Shell, The Evolution of the World's Energy Systems*, 1995

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Renewable Energy Technologies

- Photovoltaics (solar electricity)
- Wind Power
- Ocean Energy (Current, Tide, Wave, OTEC)
- Solar Ventilation Air Preheating
- Solar Water Heating
- Solar Thermal
  - Heat
  - Electricity
- Biomass
  - Heat
  - Electricity
- Geothermal
- Daylighting

Best Mix of Renewable Energy Technologies Depends on:

- Renewable Energy Resources
- Technology Characterization
  - Cost ($/kW installed, O&M Cost)
  - Performance (efficiency)
- State, Utility and Federal Incentives
- Economic Parameters (discount rate, escalation rates)

Datasets used in the analysis

- NREL Geographical Information System (GIS) Datasets:
  - solar radiation 40x40 km grid
    - Horizontal, South-facing vertical, tilt=latitude
  - Wind Energy 200mx1000m grid
  - Biomass Resources
  - Illuminance for Daylighting
  - Temperature and Heating Degree Days
- Purchased Datasets
  - utility rates (wholesale/retail) for each service territory and customer class (residential, industrial, commercial) (Platts)
  - State and utility incentives and utility policy (from DSIRE)
  - Temperature and Heating Degree Day (NREL)
  - City Cost Adjustments (RS Means & Co)
- Location Independent
  - Installed Hardware Costs from NREL technology databook
  - Economic Parameters from NIST (discount rate, inflation rate)

Photovoltaics

4 kW; WAPA, Loveland CO; amorphous thin fim

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PV Manufacturing

Single Crystal

- 14-19 % efficiency
- 1108 MW in 2006
- $3.75/W

Multi-Crystal

- 13 to 17 % efficiency
- 1174 MW in 2006
- $3.55/W

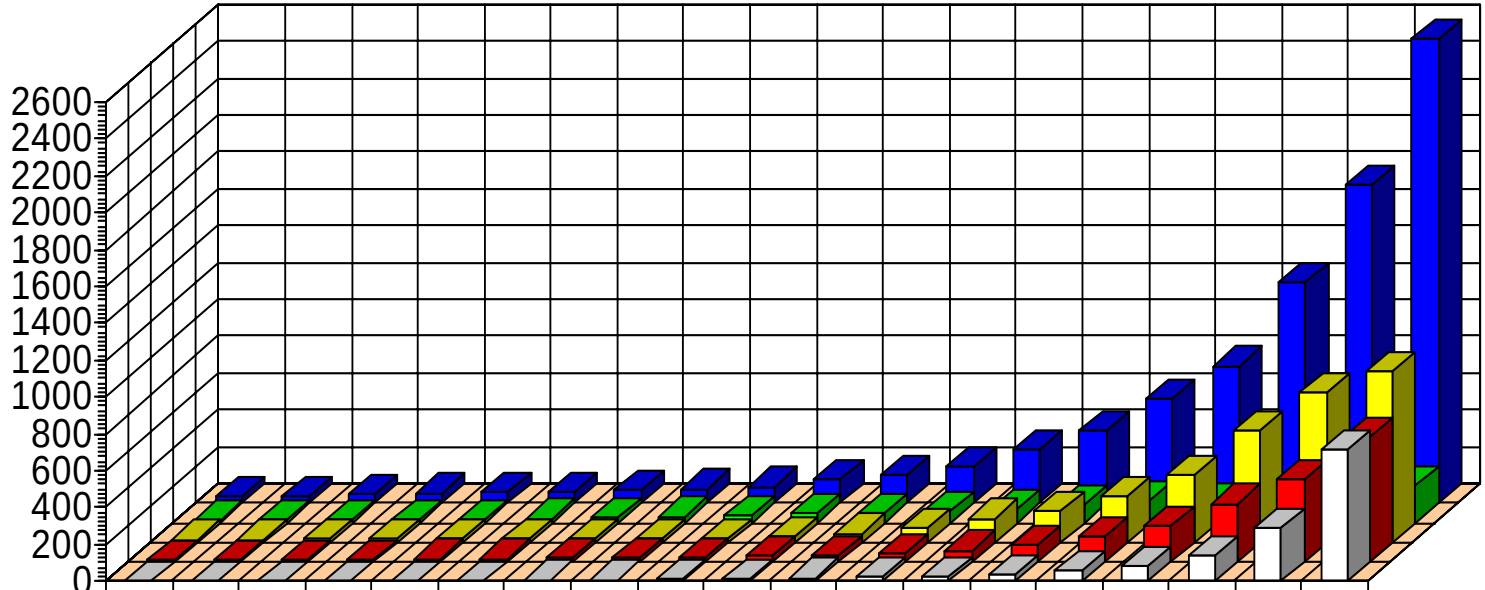
Thin Film

- 6 to 11 % efficiency
- 181 MW in 2006
- $2.50/W

Source: NREL, EIA Data, 2006

World PV Production

MW of PV produced per year

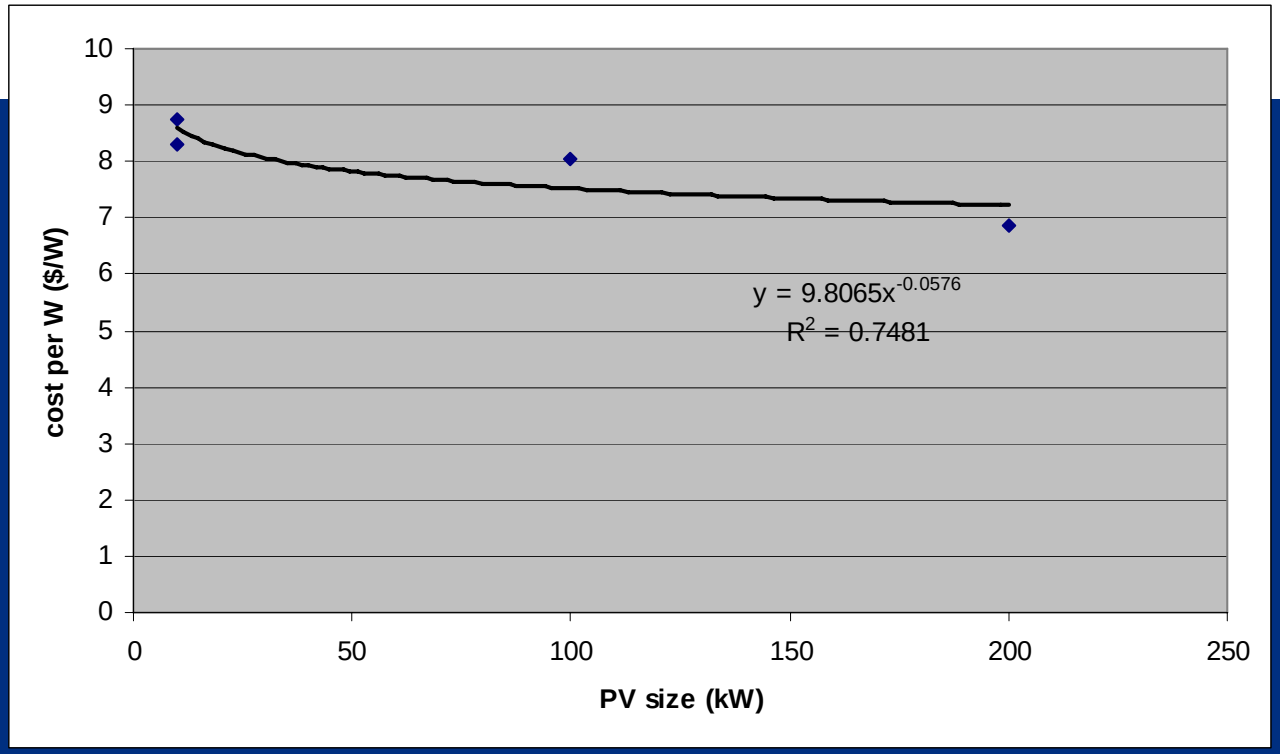


	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
Rest of World	3	4	4.7	5	4.6	4.4	5.6	6.35	9.75	9.4	18.7	20.5	23.42	32.6	55	83.8	140	290	714
Europe	6.7	7.9	10.2	13.4	16.4	16.55	21.7	20.1	18.8	30.4	33.5	40	60.66	86.38	135	193.3	314.4	450	678
Japan	12.8	14.2	16.8	19.9	18.8	16.7	16.5	16.4	21.2	35	49	80	128.6	171.2	251	363.9	602	810	927
United States	11.1	14.1	14.8	17.1	18.1	22.44	25.64	34.75	38.85	51	53.7	60.8	74.97	100.3	120.6	103	139	180	202
Total	33.6	40.2	46.5	55.4	57.9	60.09	69.44	77.6	88.6	125.8	154.9	201.3	287.7	390.5	561.8	744.1	1195	1727	2521

Sources: *2004 , 2006World PV Cell/Module Production* from Paul Maycock, PV News, March and April issues, 2005; Energy Information Administration; NREL National Center for

Characteristics of Photovoltaic Technology

Initial Cost	$8,730.00	$/kW	RS Means Green Building Project Planning and Cost Estimating, 2006
O$M	0.006	$/kWh	Renewable Energy Technology Characterizations, EPRI TR-109496, 1997.C185
BOS Efficiency	0.77		Balance of system efficiency



Jesse Dean, NREL, 2007

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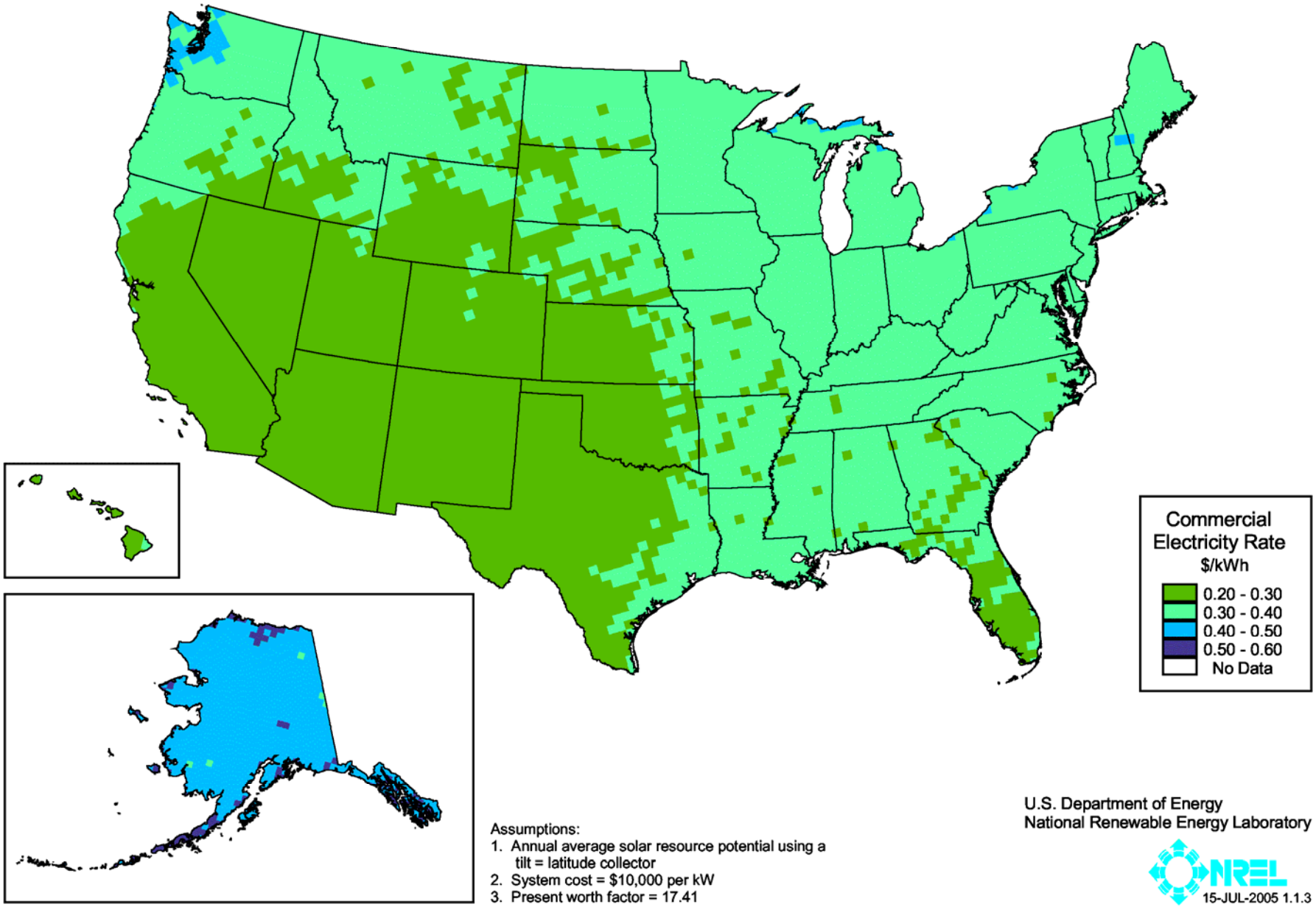
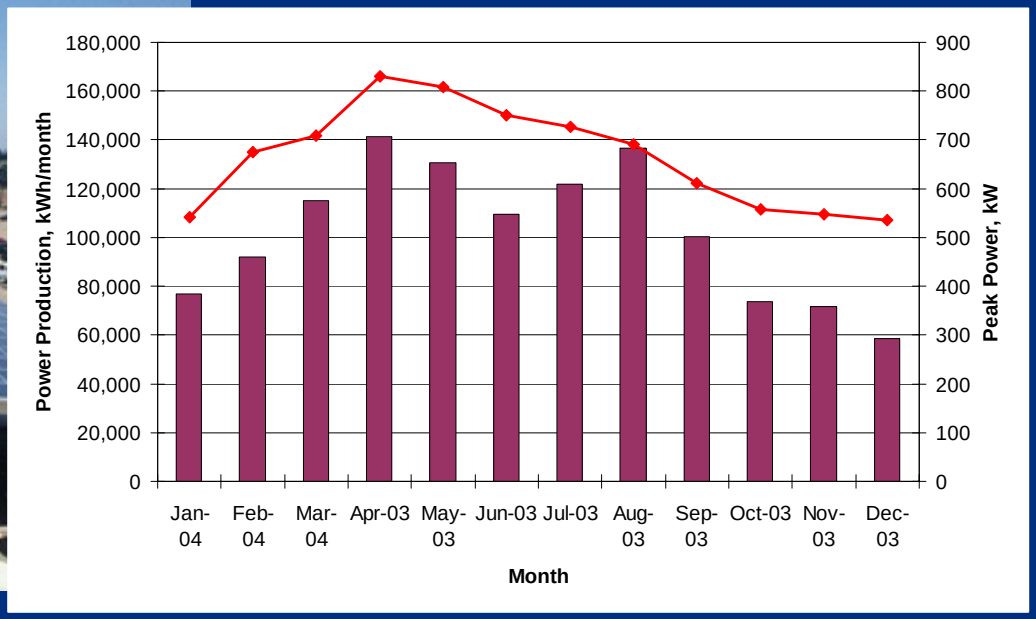
Photovoltaics: Electricity Rate Corresponding to Savings to Investment Ratio = 1



Case Study: Naval Air Station N. Island



924 kW DC rated, 829 kW AC maximum output

$7.7M cost ($8.28/W)
$228k/year savings
1,228,658 kWh/year delivery

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Photovoltaic Technology

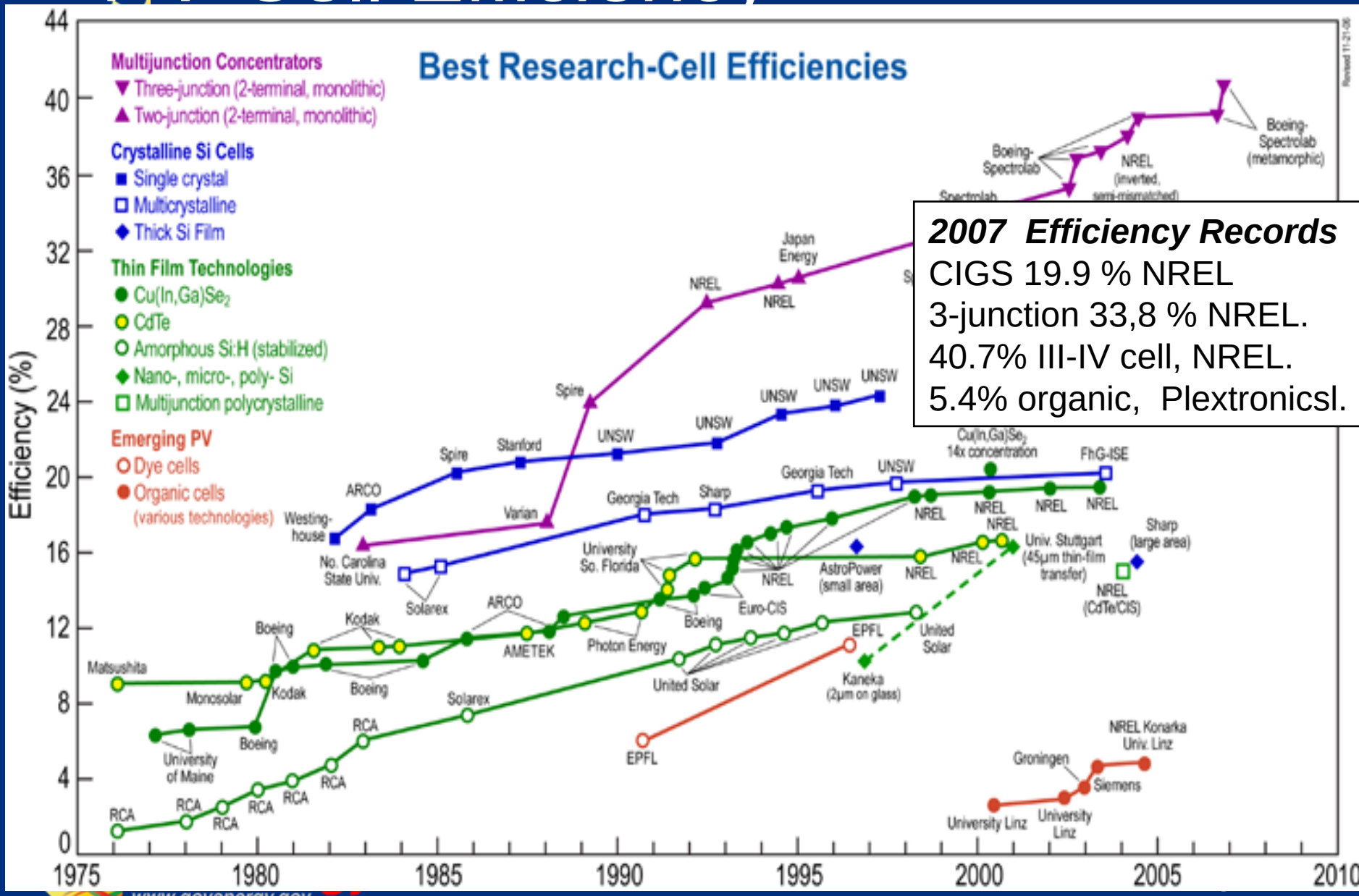
Silicon Technologies

- Sliced monocrystalline silicon (Siemens);
- Multicrystalline silicon cast ingot slices (Kyorcera);
- Multicrystalline silicon ribbon or sheet grown directly from the melt (Schott);
- Amorphous silicon (Unisolar);
- Amorphous silicon on monocrystalline silicon slice (SANYO's HIT cell); and
- Concentrators using silicon cells (Amonix's, produced at pilot levels).

Emerging non-silicon alternatives:

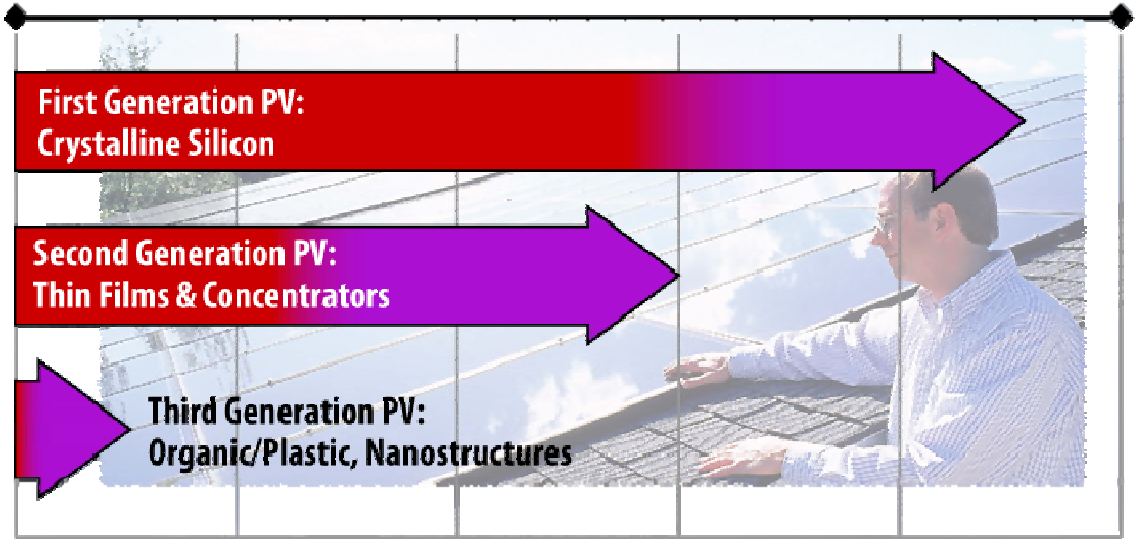
- CdTe modules (First Solar and Antec),
- CIS cells (Shell Solar and Würth Solar, and Global Photovoltaics)'
- SIGSS (Nanosolar)
- High efficiency III-V concentrators made from Gallium compounds (Spectrolab, Boeing).

PV Cell Efficiency



Photovoltaics R&D

Technology Maturity



Key Drivers	Attributes
Technology based on abundant, well-known semiconductor material also used by electronics industry	Proven manufacturing, solar conversion efficiencies, and long-term durability in the field
Need for lower semiconductor materials usage and lower manufacturing costs	Building integration of thin-film products (flexible or semitransparent); large-scale central power systems (concentrators)
Need for a very high solar conversion efficiencies and/or very low costs	Potential for discovery of new materials and new physical processes for sunlight to electricity conversion

Organizations Leading the R&D

- Lab/Academia
- Industry

- **U.S. National goal to be market competitive by 2015**
- **New materials,**
- **Lower cost manufacturing processes,**
- **Concentration**
- **Nanostructures**

Source: NREL 2007

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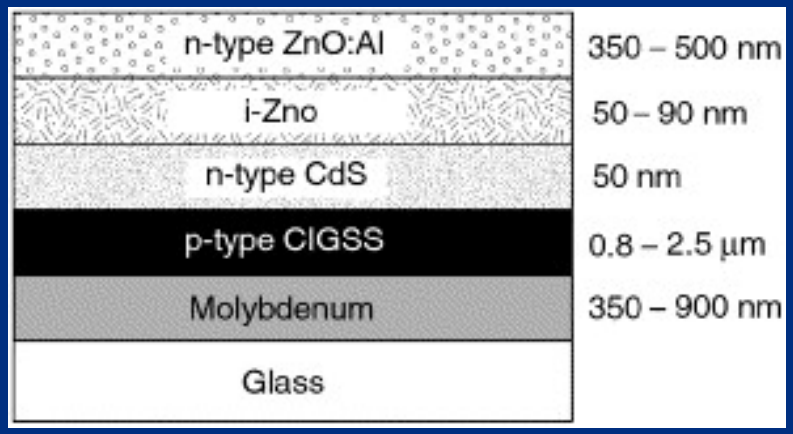
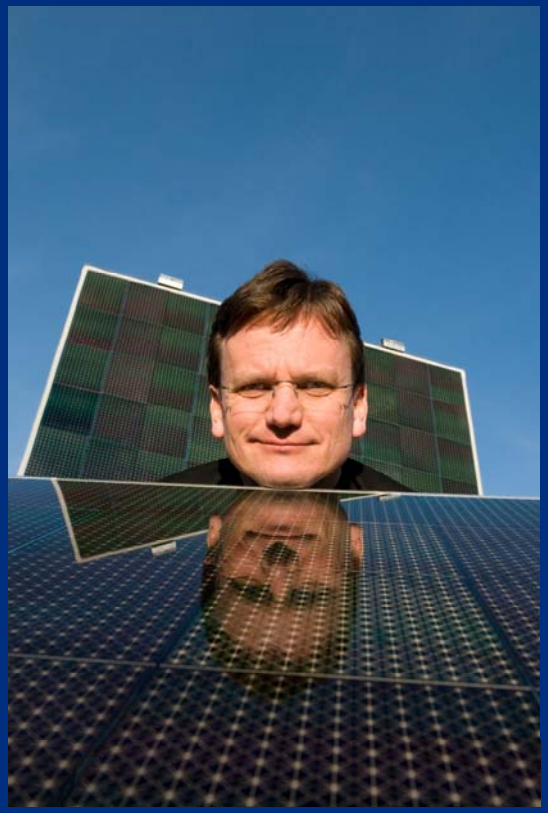
Nanosolar “Powersheet”





Building 430 MW Plant in San Jose CA

Efficiency ~14% ???

Cost $0.30/Watt ???

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Wind Power

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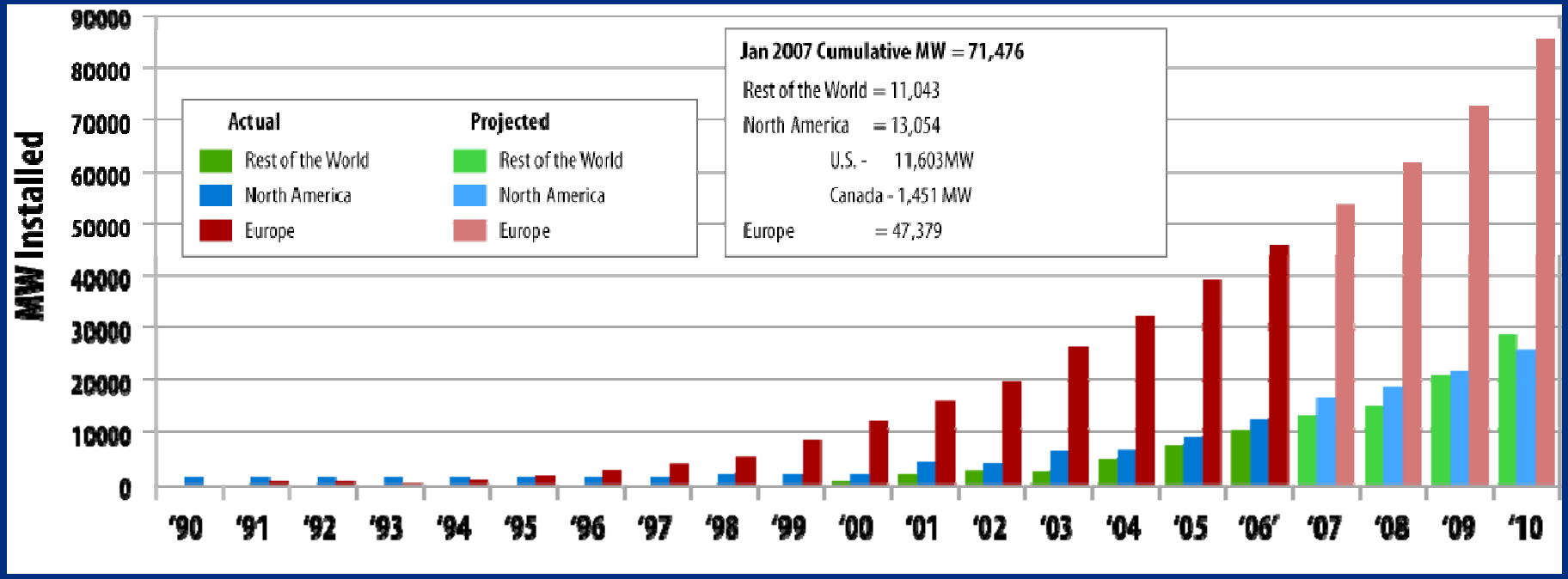
Global Growth of Wind Energy Capacity



- **U.S. National goals:**
  - **20% of total provided energy by Wind by 2030**
  - **Improve energy capture by 30%**
  - **Decrease costs by 25%**

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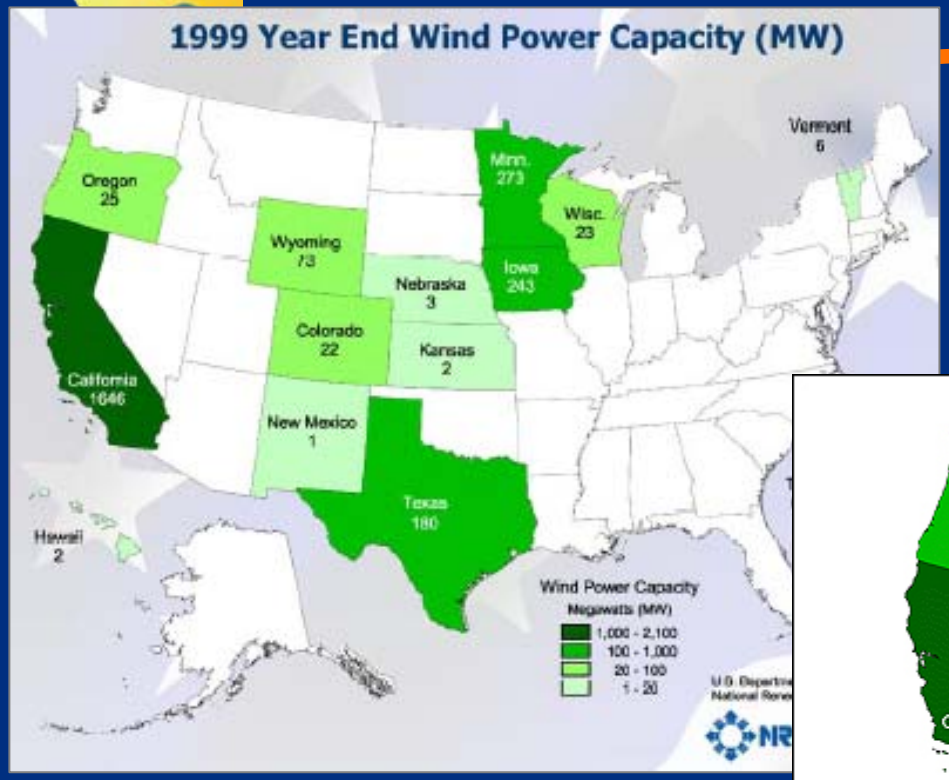
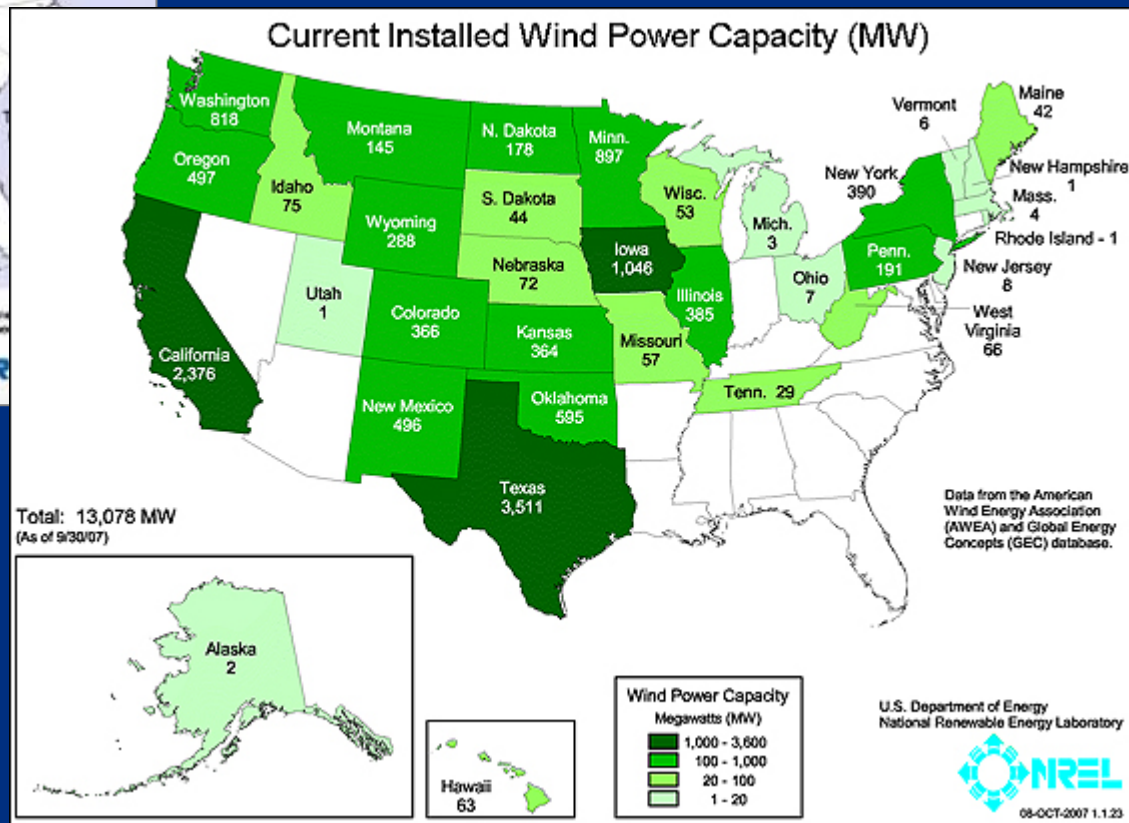
Installed Wind Capacities (99-07)



4th quarter of 2007 alone (2,930 MW) surpassed the amount installed in all of 2006 (2,454 MW)



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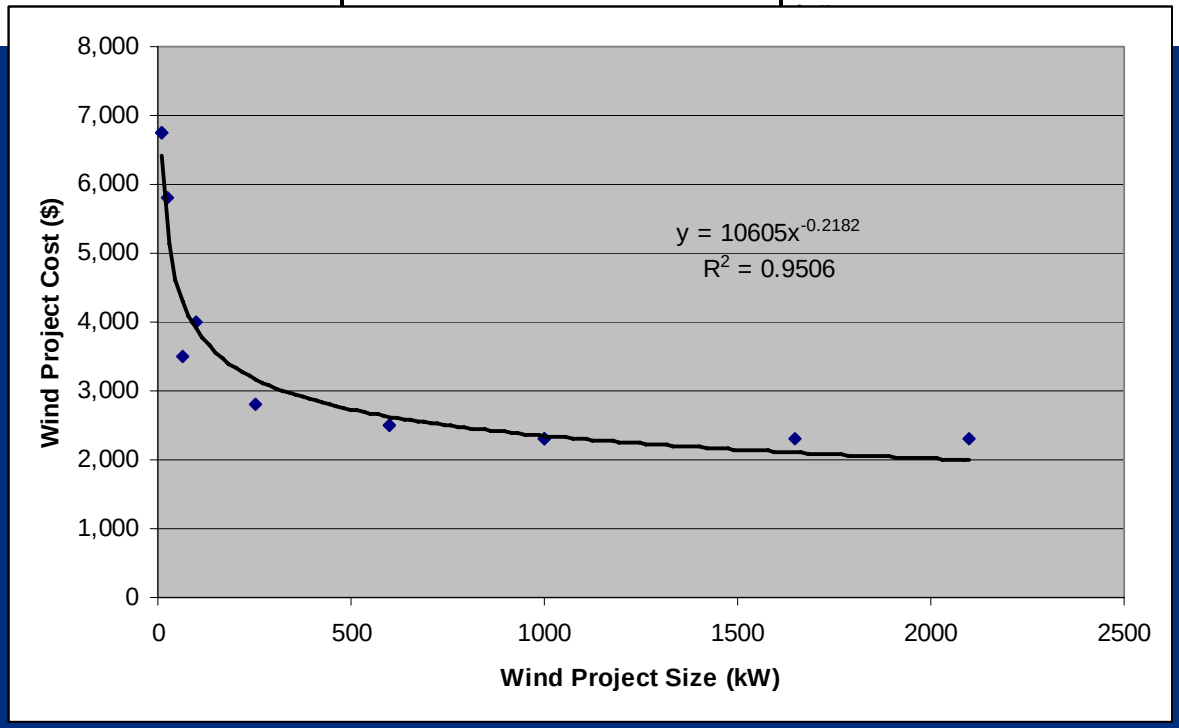
Characteristics of Wind Power Technology

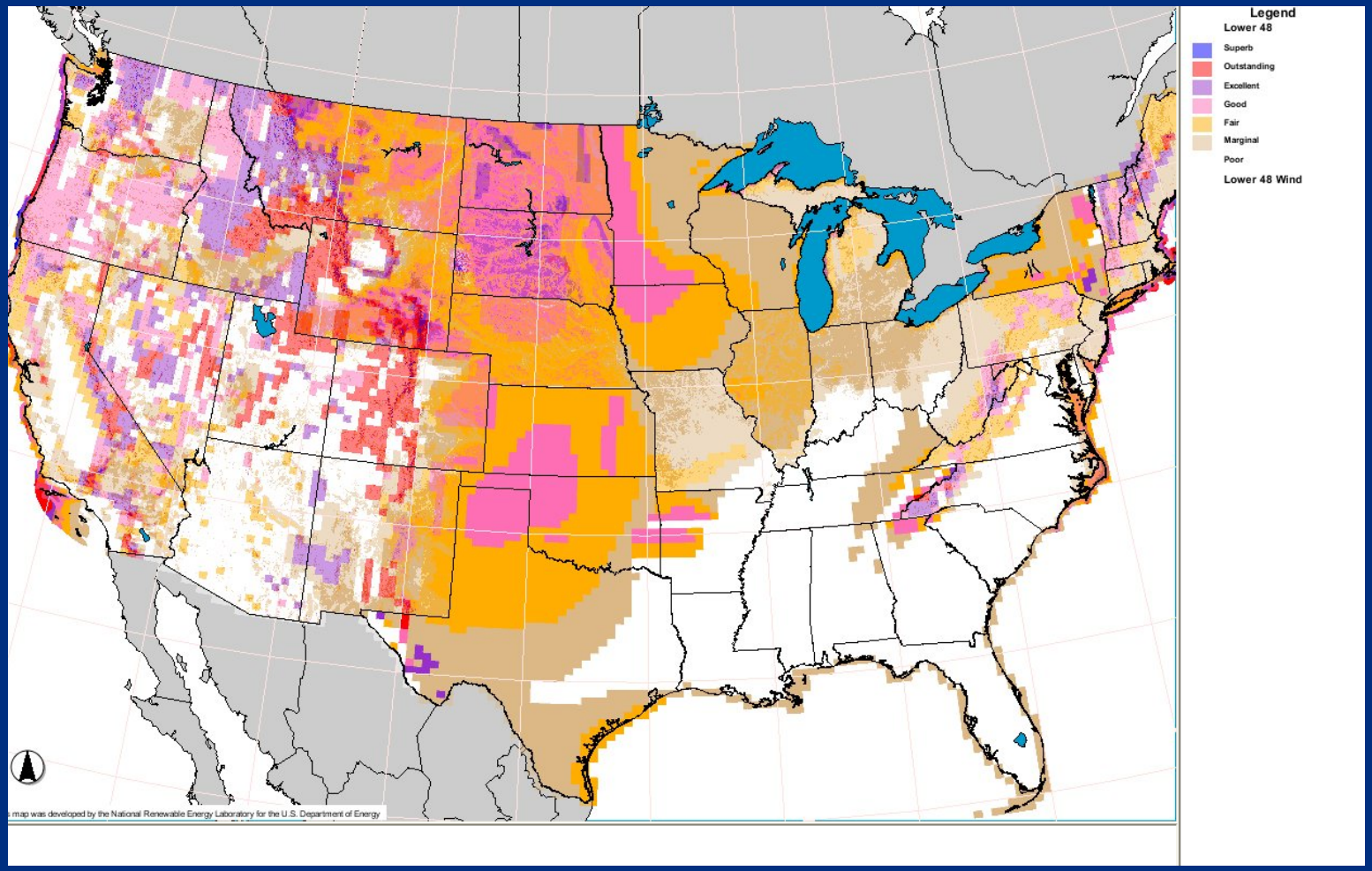
Wind Turbine Efficiency	35%	
Capital Cost	$1,528	$/m2 swept area
O&M Cost	7.9	$/year/kW
Power/Area	0.46	kW/m2
Capital Cost		

- Wind Technology has matured over 25 Years
- Availability now reported at 98-99%
- Certification to international standards
- Current designs produce electricity for 5-8 cents/kWh at Class 5-6 wind sites (15 mph or higher average wind)



PG&E Available Funding and Program Statistics (updated 06/05/07)
http://www.pge.com/suppliers_purchasing/new_generator/incentive/available_funding_and_program_statistics.html

Wind Resource Data



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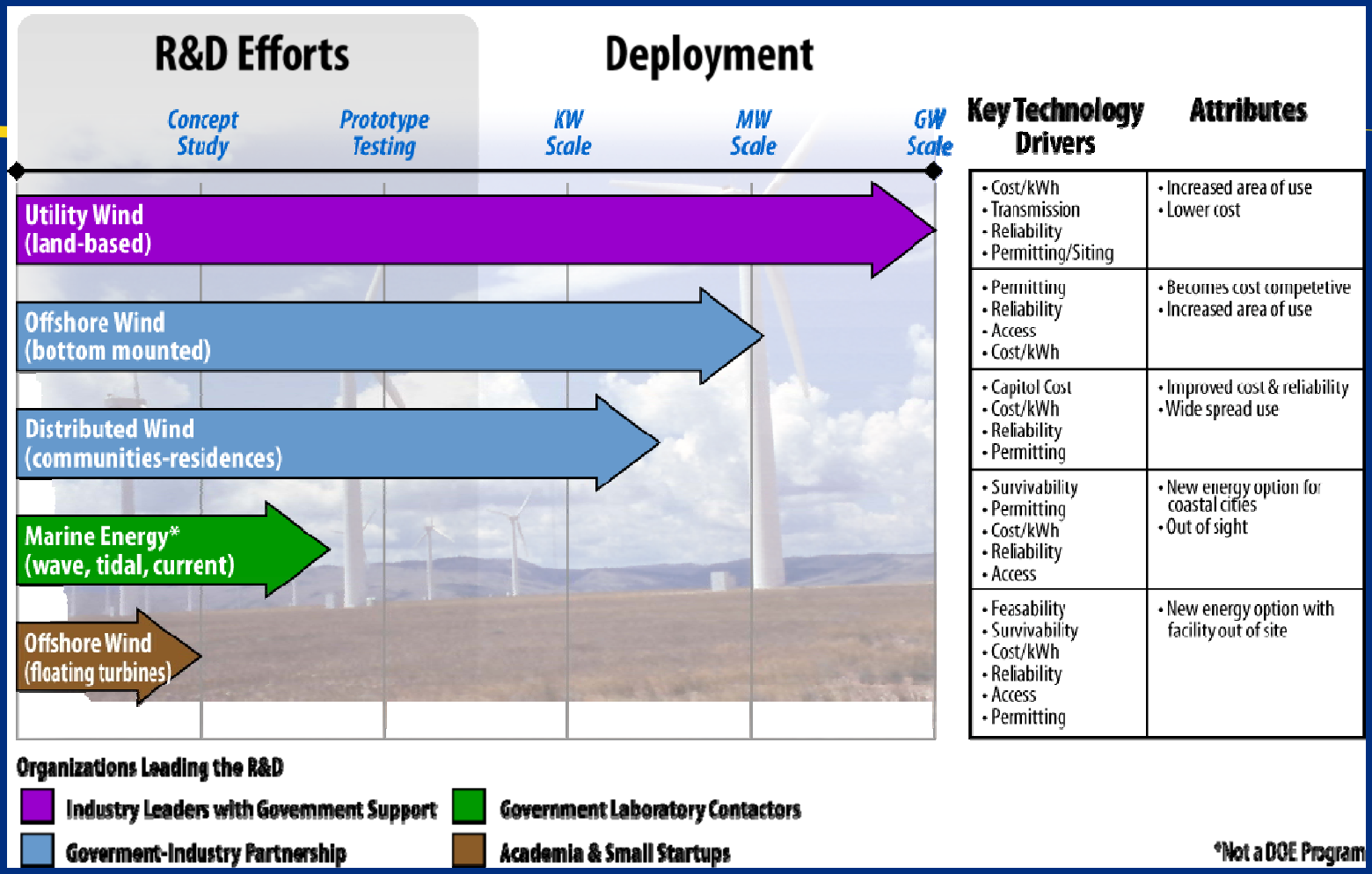
Wind and Marine Energy R&D



Frontiers: BIGGER 2 to 5 MW, rotors diameters to 120 meters
TALLER towers
LOWER WIND: Class 4 (13.4 mph wind site)
OFFSHORE

Source: NREL 2007

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Bigger Turbines

Enercon 4.5MW 112 meter rotor

440 metric tonnes

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Tall Tower Concepts:

Vestas V66 on 117 m tower

- Novel Steel tubes
- Truss towers
- Pre-stressed concrete
- Composite
- Hybrid towers
- Self-erecting/no cranes
- On-site manufacturing
- Tower load feedback control

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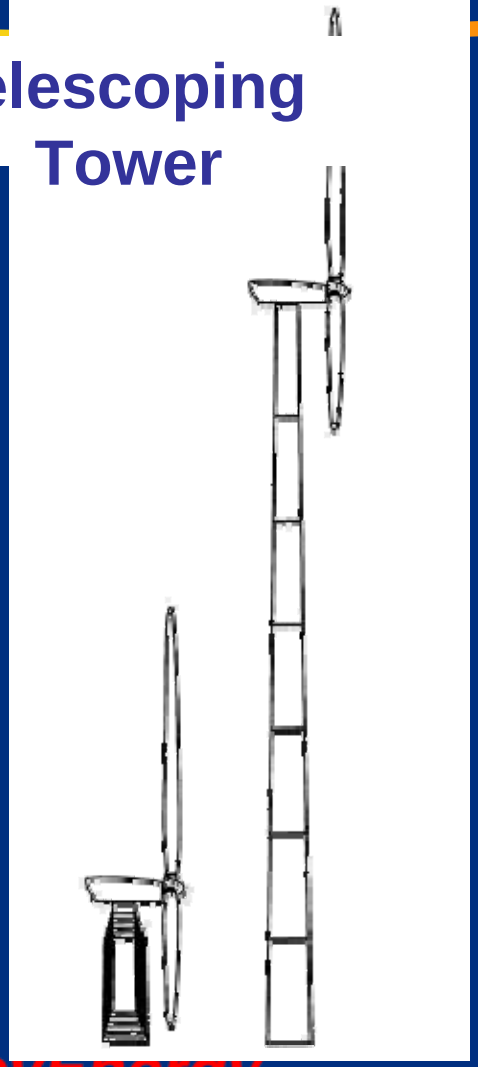
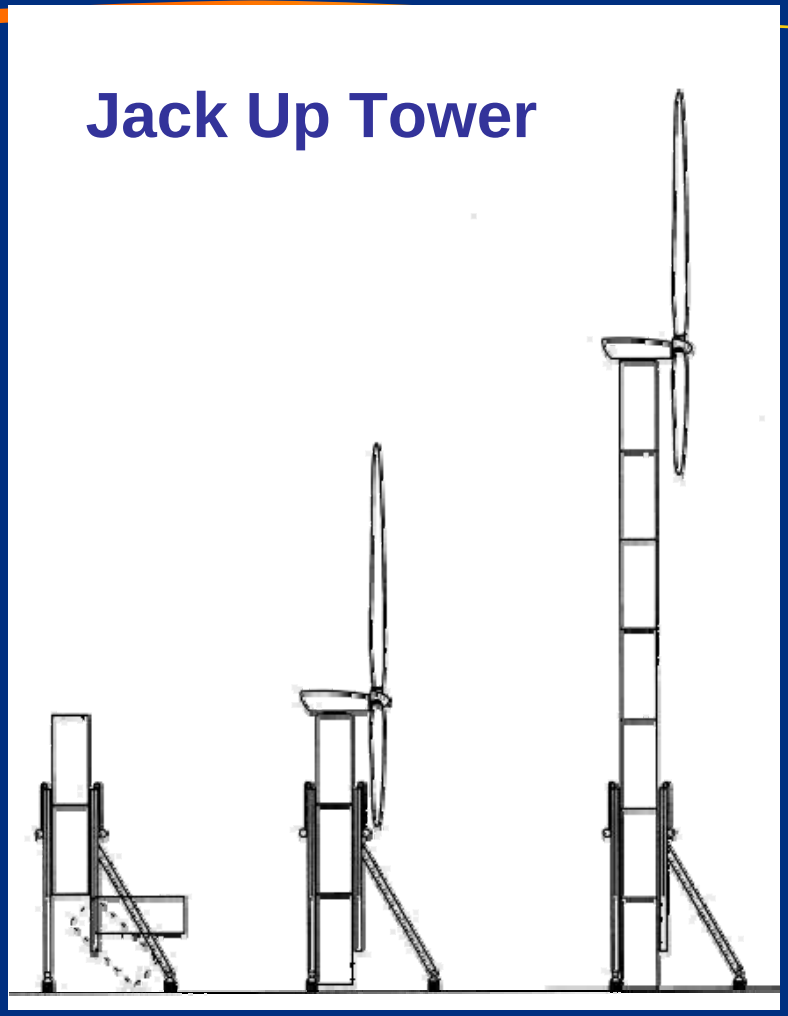
Self Erection Concepts

Telescoping Tower



Jack Up Tower

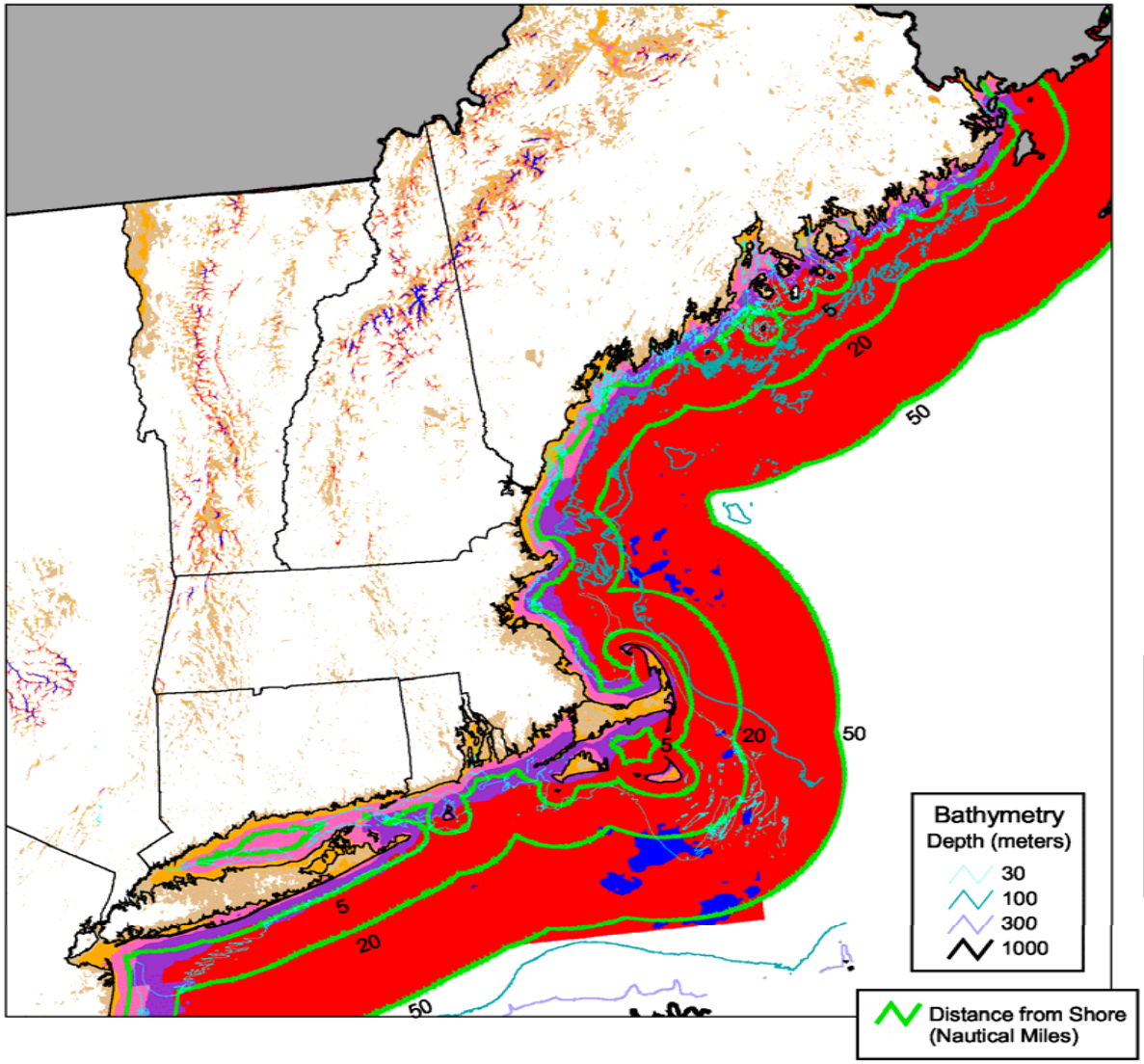


Low Wind Speed Technology

- Increases area available for wind development by factor of 20 or more
- Accelerates meeting National Energy Policy (NEP) and DOE Program Strategic Performance Goals

GE Wind Energy 3.6 MW turbine

Future Wind - Offshore



New England Offshore Wind Resource Potential

All areas > 5 nautical miles offshore likely to be class 4 resource or better.

Area 5-20 nautical miles from shore (67% excluded):
- 10,300 sq. km. (51,500 MW)
- 1,980 sq km (9,900 MW) <30m depth

Area 20-50 nautical miles from shore (33% excluded):
- 33,800 sq. km. (169,000 MW)
- 540 sq km (2,700 MW) <30m depth

The wind power resource data for this map was produced by TrueWind Solutions using the Mesomap system and historical weather data, and has been validated by NREL.

The bathymetry contour lines were derived from NOAA's coastal relief models (nominal resolution 1 km) from NOAA's National Geo-physical Data Center.

Wind Power Classification

Wind Power Class	Resource Potential	Wind Power Density at 50 m W/m^2	Wind Speed[a] at 50 m m/s	Wind Speed[a] at 50 m mph
2	Marginal	200 - 300	5.6 - 6.4	12.5 - 14.3
3	Fair	300 - 400	6.4 - 7.0	14.3 - 15.7
4	Good	400 - 500	7.0 - 7.5	15.7 - 16.8
5	Excellent	500 - 600	7.5 - 8.0	16.8 - 17.9
6	Outstanding	600 - 800	8.0 - 8.8	17.9 - 19.7
7	Superb	> 800	> 8.8	> 19.7

[a] Wind speeds are based on a Weibull k value of 2.0

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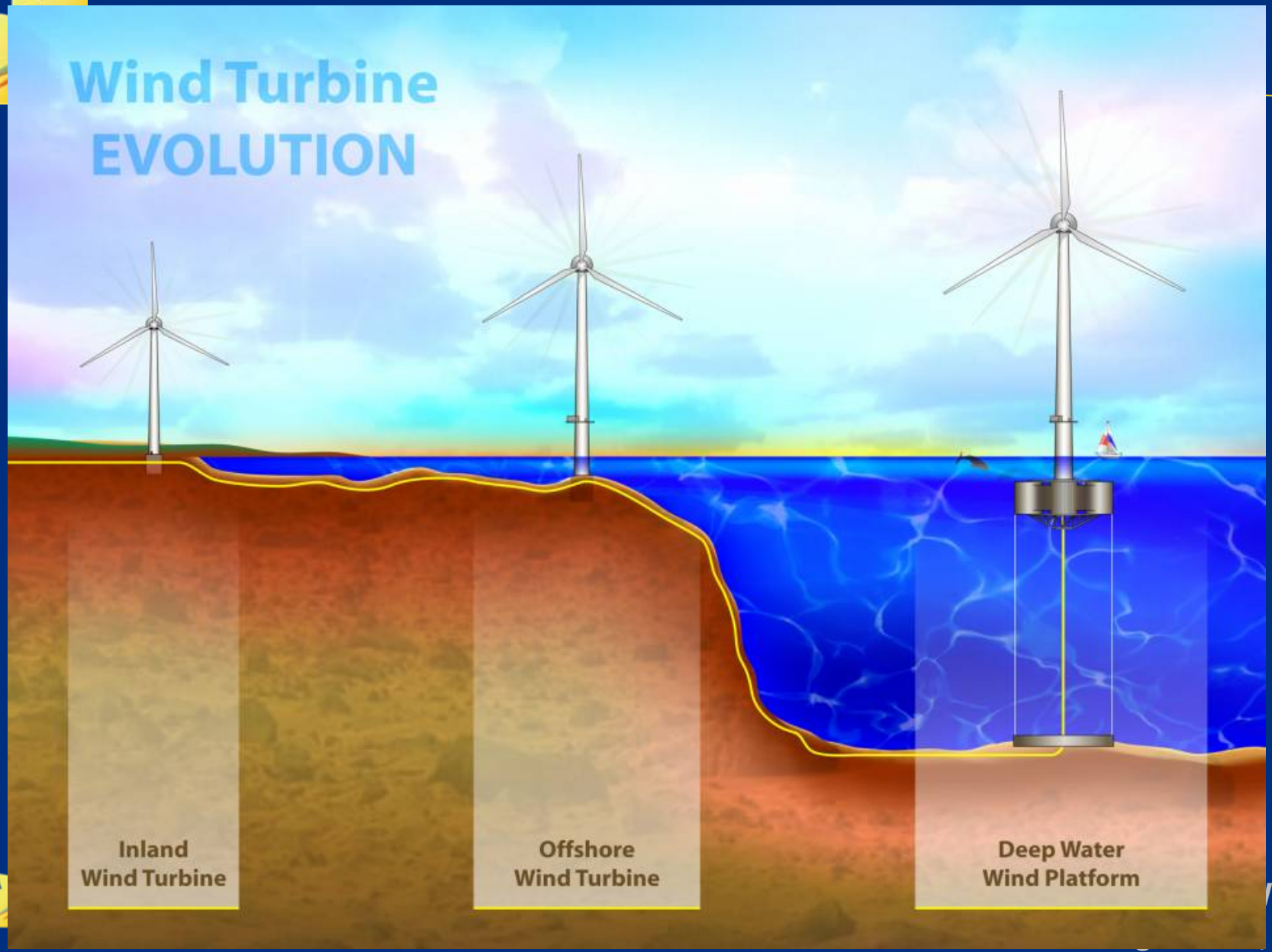
NREL

30-JUL-2003 2.1.2

Future Wind Turbines



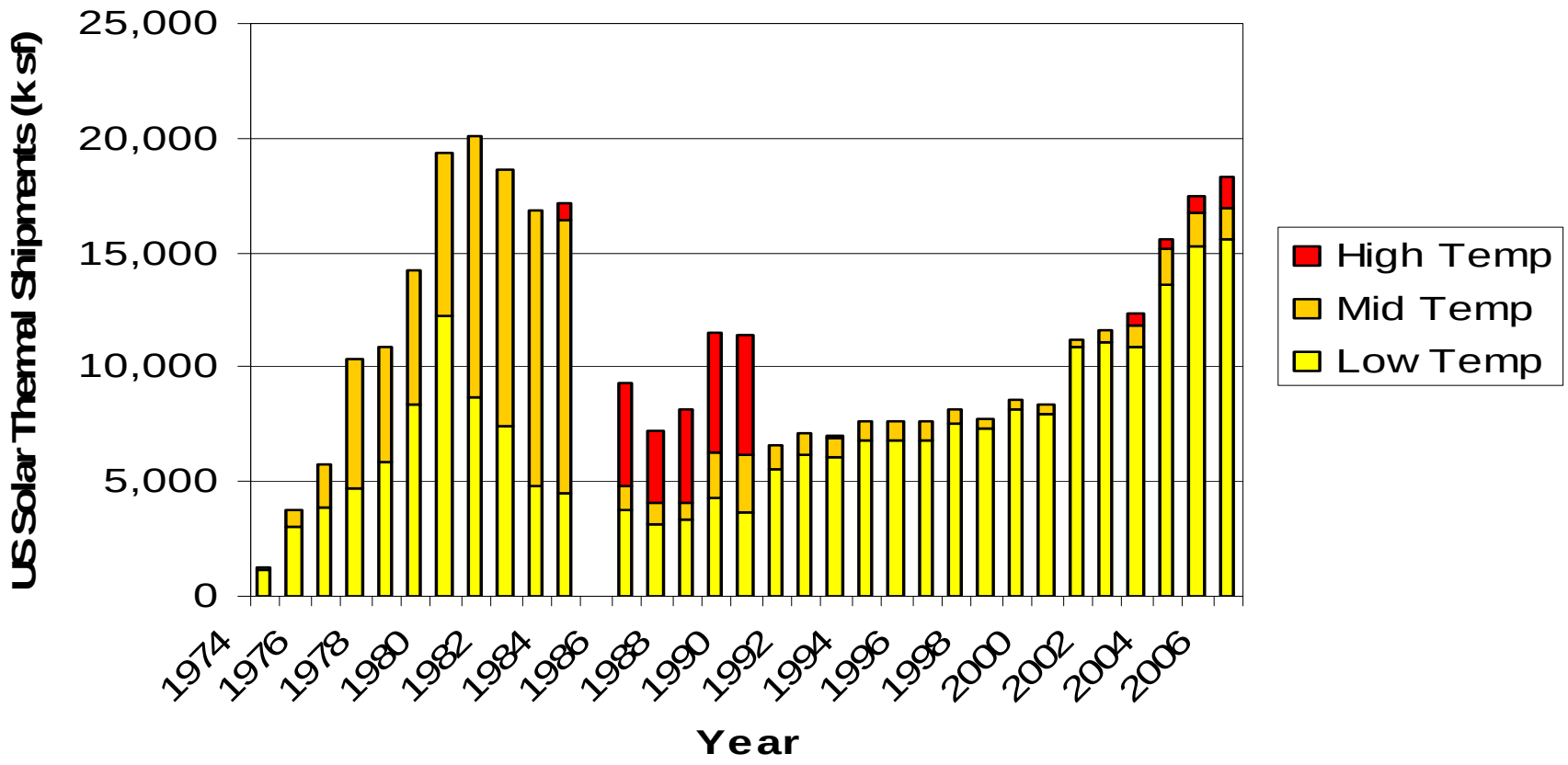
alker
2008

Solar Water Heating

- Existing Technology
  - Swimming pool heating
  - Flat Plate Collectors
  - Evacuated Tube Collectors

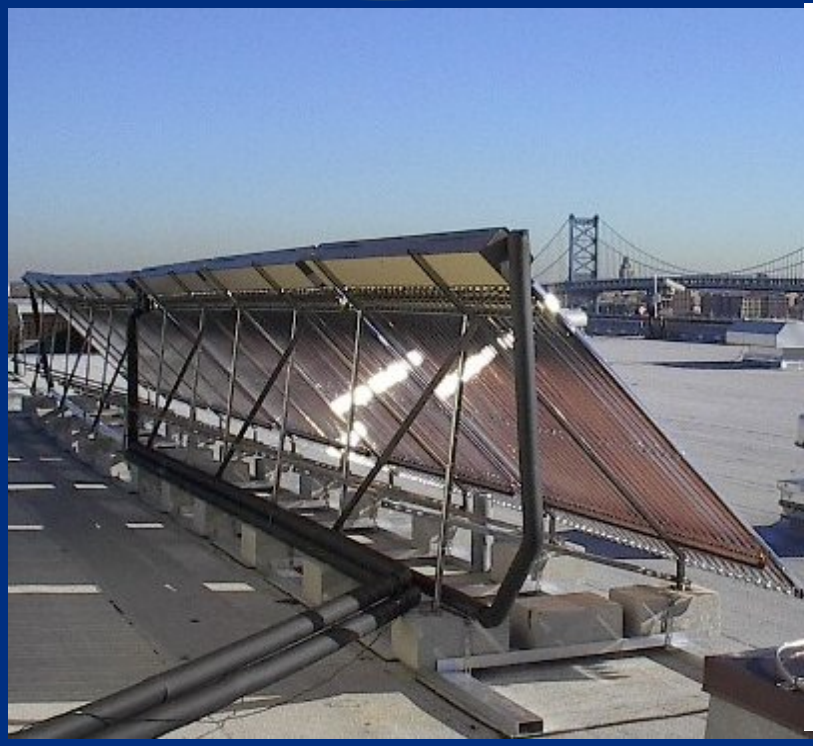
- New Developments
  - Low-cost Polymer Collectors
  - Freeze-proof piping

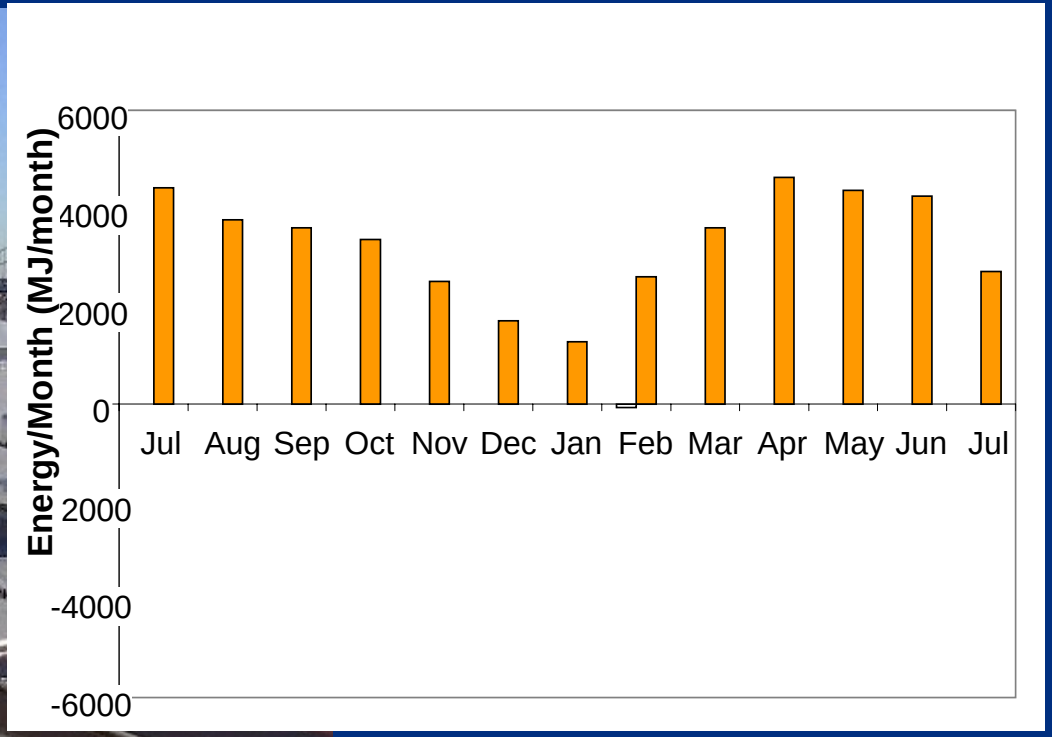
US Solar Thermal Shipments



Source: http://www.eia.doe.gov/cneaf/solar.renewables/

Solar Water Heating Case Study: SSA Philadelphia PA





Reheats Recirculation Loop
180 Evacuated Heat-Pipe Collector tubes, 27 m2 gross area
Cost $37,500
Delivery of 38 GJ (36 million Btu)/year measured
Installed 2004.

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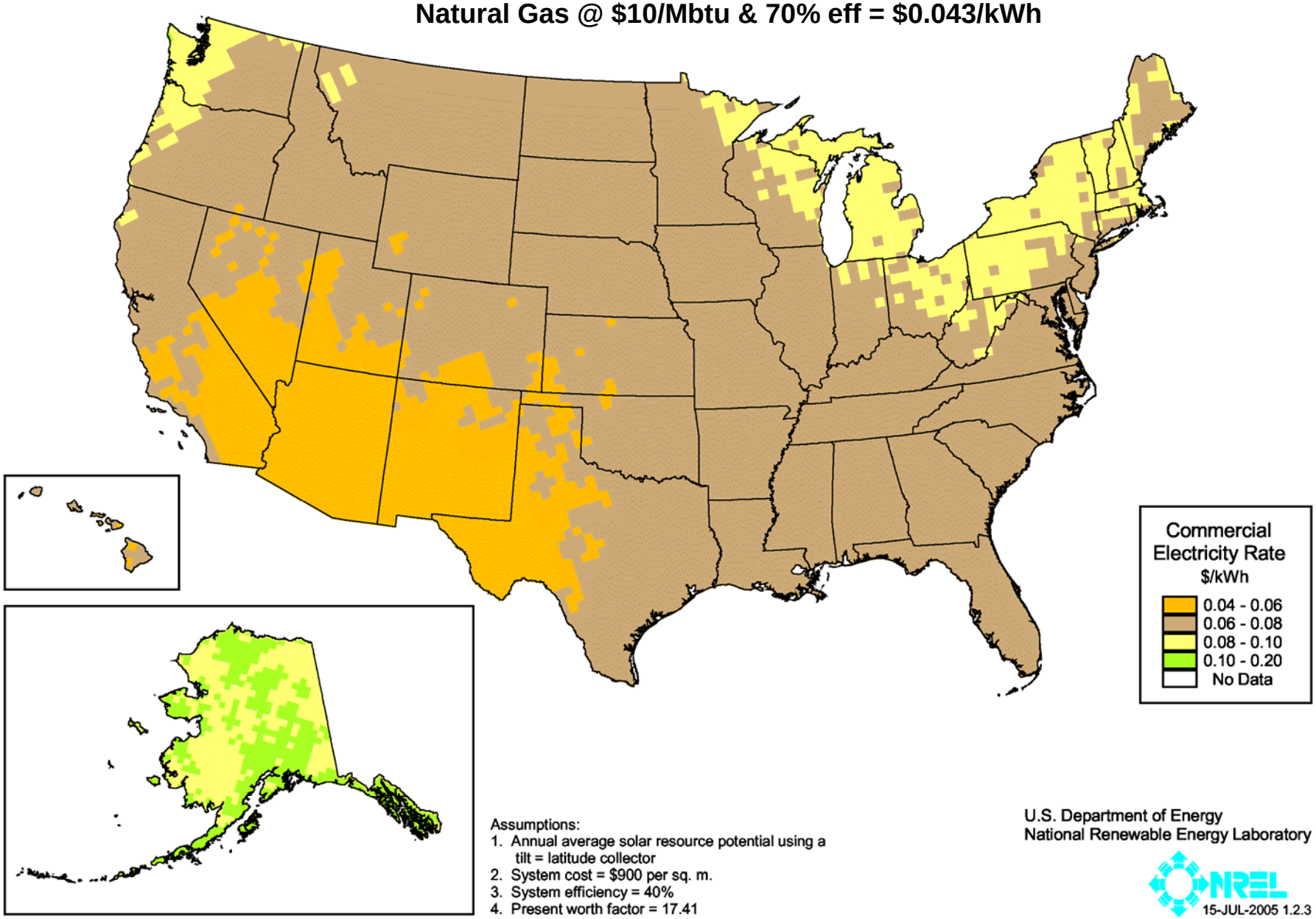
Technology Characteristics: Solar Water Heating

Hot Water as Fraction of Total Building Energy		
Office	9.0%	
Education	21.9%	
Health Care	26.2%	
lodging	40.4%	
public assembly	15.4%	
food service	11.2%	
food sales	4.3%	
warehouse	5.2%	
other 15.3	8.9%	
all	15.2%	
source: DOE/OBT Energy Databook		
SDHW Efficiency	0.4	
Cost	73	$/sf
O&M Cost	0.005	% of initial cost
Aux efficiency	0.8	

Efficiency Craig Christensen and Greg Barker, NREL
Cost RSMeans&Co.

Solar Hot Water: Electricity Rate Corresponding to Savings to Investment Ratio = 1

Natural Gas @ $10/Mbtu & 70% eff = $0.043/kWh



Assumptions:
1. Annual average solar resource potential using a tilt = latitude collector
2. System cost = $900 per sq. m.
3. System efficiency = 40%
4. Present worth factor = 17.41

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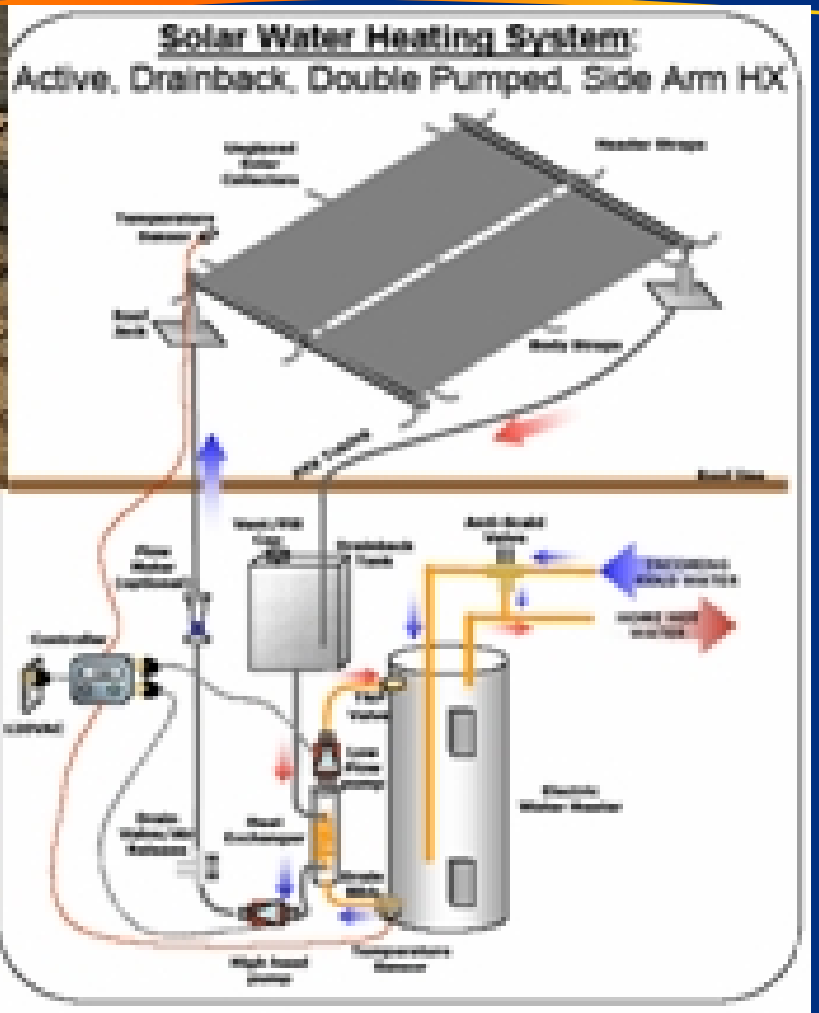
NREL
15-JUL-2005 1.2.3

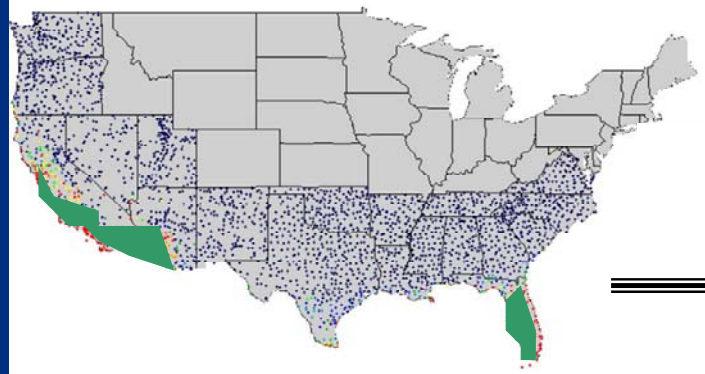
Polymer Systems



Freeze-tolerant PEX piping

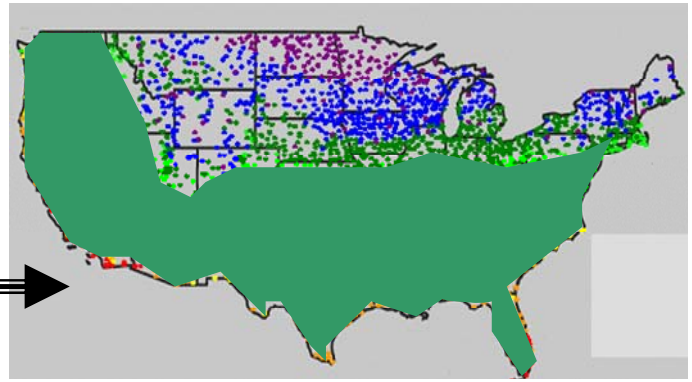
Safe/Non-wasteful areas=

Insulated copper pipe



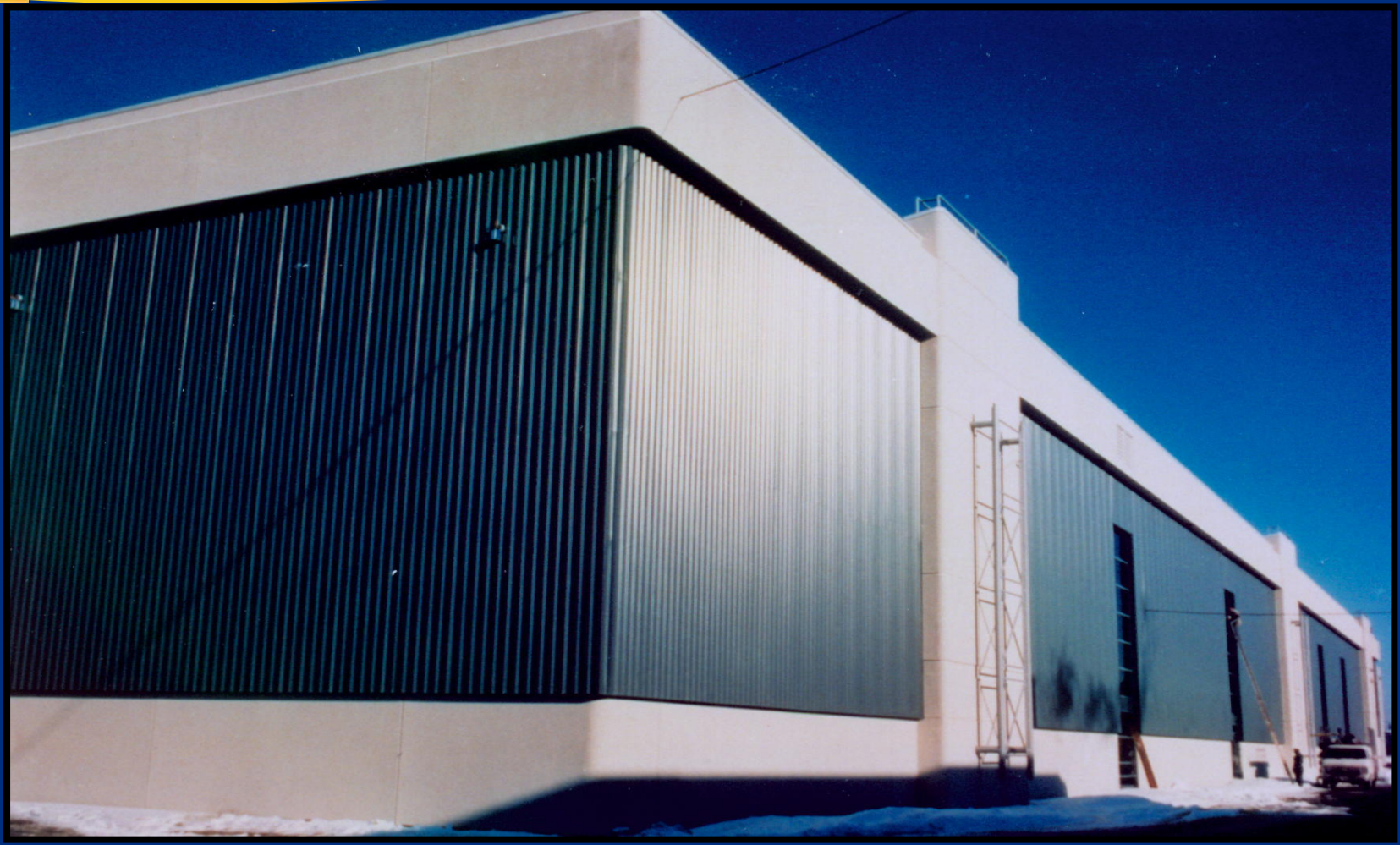
Limited by Pipe Freeze

Freeze Protection Valve + freezable piping



Limited by water consumption
BUT: collector/store freeze?
Untested, other affects?

Solar Ventilation Air Preheat



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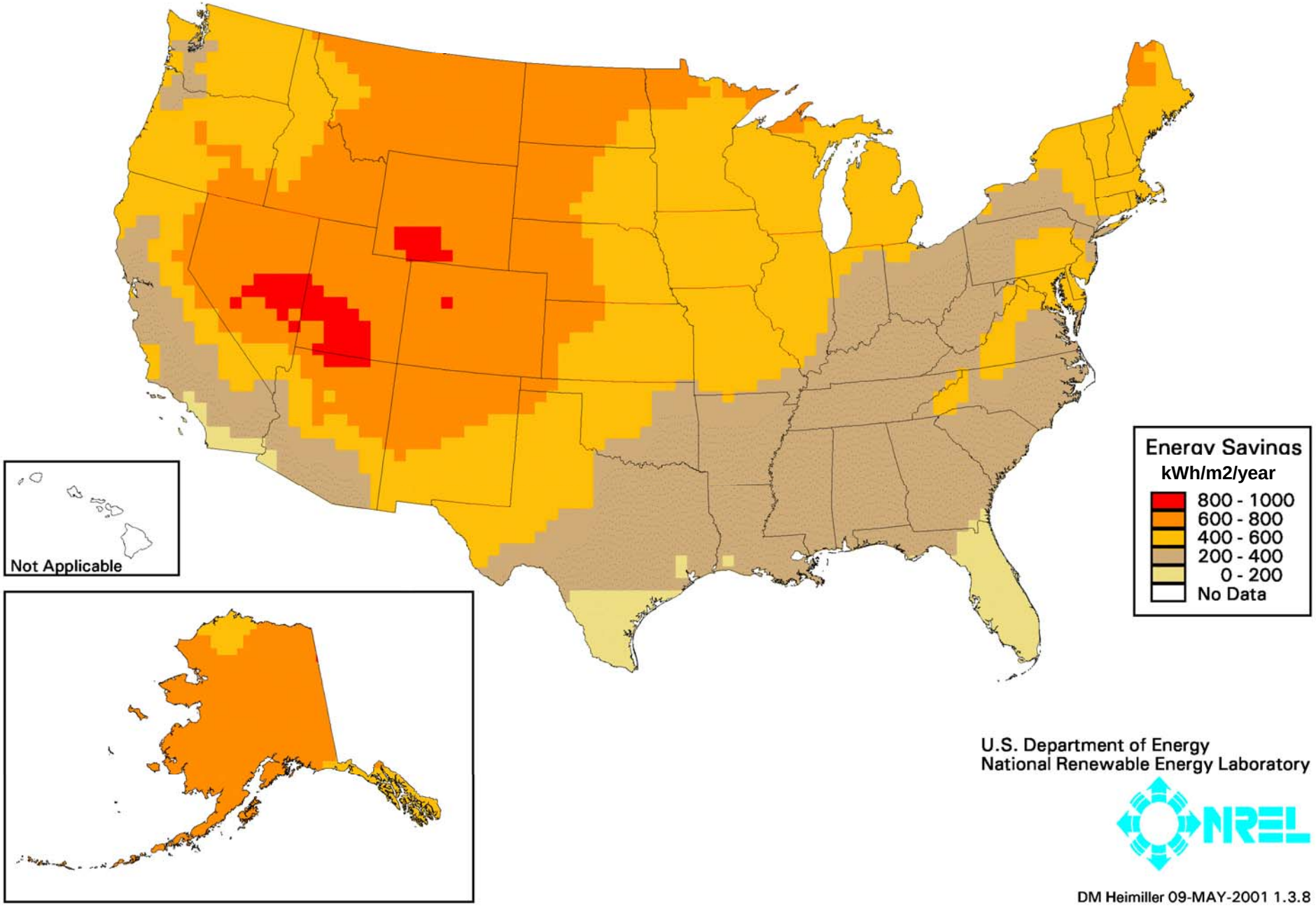
Solar Ventilation Air Preheat

Material Cost	$11.40	/sf
Installation Cost	$12.00	/sf
Other	$4.00	/sf
Initial Cost	27.4	$/sf
O&M Cost	0	
Flow Rate	4	CFM/sf

Cost: Conserval Engineering
Flow Rate: Chuck Kutscher, NREL

Energy Savings Utilitizing Solar Vent Preheating Technology



Concentrating Solar Heat and Power

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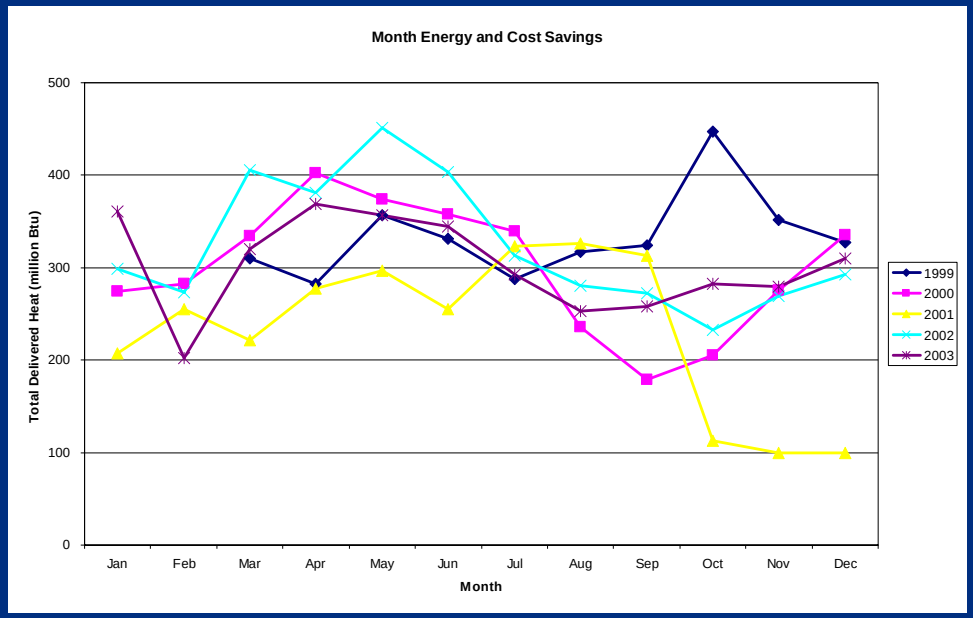
Industrial Process Heat Case Study: FCI Phoenix, AZ



17,040 square feet of parabolic trough collectors
23,000 gallon storage tank
Installed cost of $650,000
Delivered 1,161,803 kWh in 1999 (87.1% of the water heating load).
Saved $77,805 in 1999 Utility Costs

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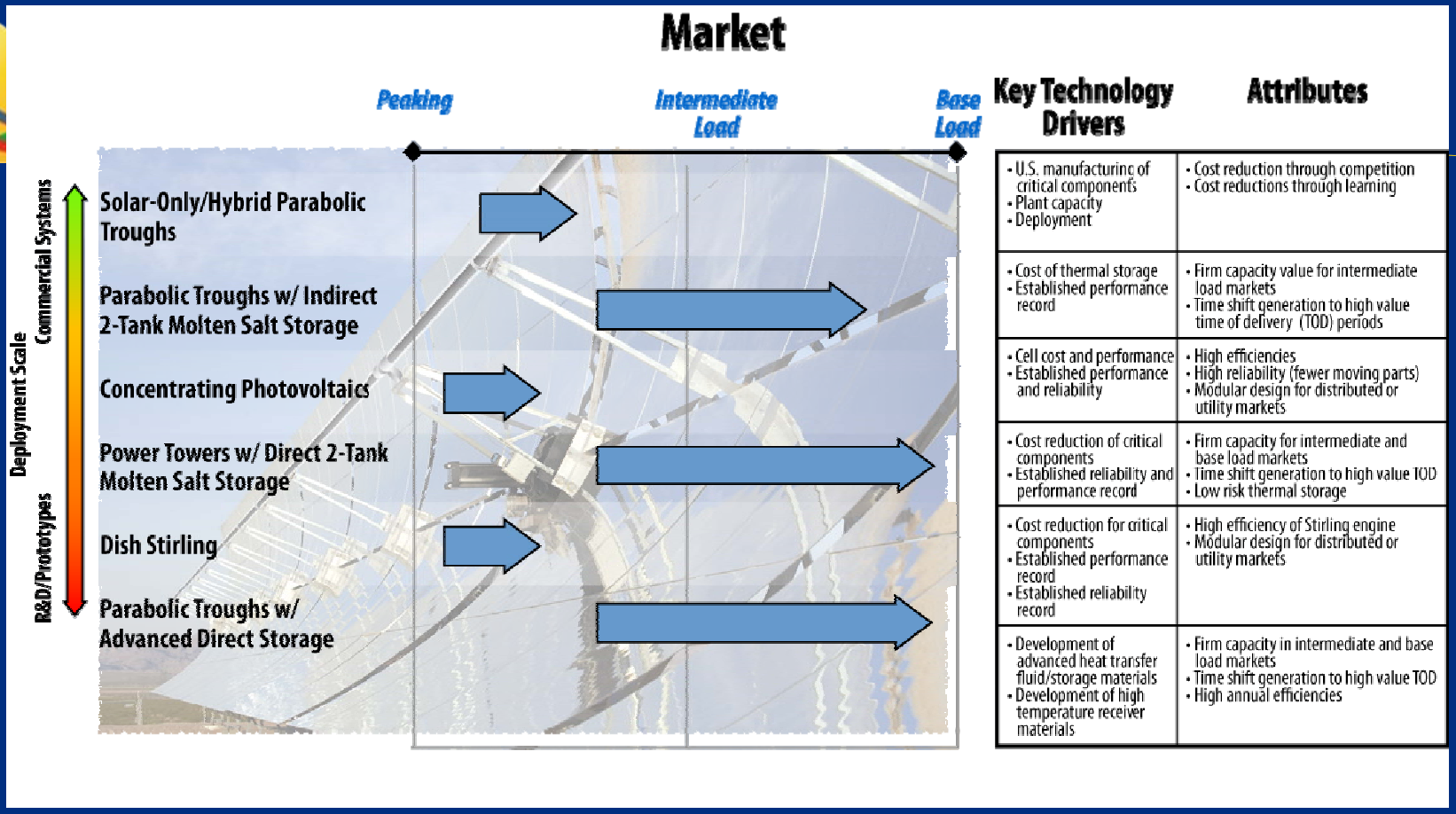
Concentrating Solar Heat/Power Technology Characteristics

Solar Thermal cost	60	$/sf
O&M cost	$0.127	$/therm/year
Efficiency	0.33	
Cost of thermal storage	$1,465	$/therm
Hours per day of solar collection	6	
Cogen Cost	1650	$/kW
cogen Efficiency	0.2	
Boiler Capacity Factor	0.85	
Hx effectiveness	0.7	
Federal Production tax credit	0.01	$/kwh

http://www.nrel.gov/csp/troughnet/pdfs/3516.pdf

Concentrating Solar Power R&D



Frontiers:

Mirror Materials/Optics
Thermal Storage
Hybrid Cooling
Heat Transfer Fluids

Source: NREL 2007

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Biomass Energy

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August 3-6, 2008

GIS Biomass Resource Information

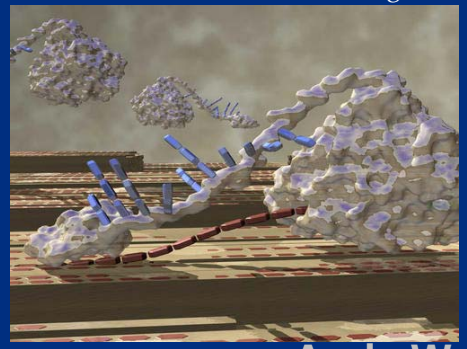
- Crop residues (dry tonnes/year): corn, wheat, soybeans, cotton, sorghum, barley, oats, rice, rye, canola, dry edible beans, dry edible peas, peanuts, potatoes, safflower, sunflower, sugarcane, and flaxseed..
- Orchard and Grape (dry tonnes/year):
- Forest residues (dry tonnes/year):
- Primary mill residues (dry tonnes/year)
- Secondary mill residues (dry tonnes/year):
- Urban wood waste;
- Methane emissions from landfills;
- Methane emissions from manure management; and
- Methane emissions from wastewater treatment.

Biomass – Technologies

Resource		Conversion Option	Technology Type
Solid Biomass	• Wood • Wood waste • Agricultural residues • Bagasse • Food processing residues • Animal wastes • Municipal Solid Waste (MSW) • Energy crops	Direct Combustion	Biomass-only Rankine (steam) Cycle
			Co-firing Rankine Cycle (primarily coal)
		Gasification	Biomass-only Rankine Cycle
			Biomass-only GT/IGCC
			Biomass-only IC Engine (ICE)
			Co-firing (coal or NG Rankine, IGCC, CCGT)
			Co-gasification of biomass and coal
		Liquefaction (Pyrolysis)	Biomass-only (Rankine, GT, ICE)
			Co-firing (Rankine, GT/GTCC, ICE)
Gaseous Biomass (biogas)	• Landfill gas • Methane from waste & wastewater treatment	Direct Combustion/ Conversion	Biomass-only Rankine Cycle
			Biomass-only GT, GTCC, ICE
			Biomass-only Fuel Cell

Note: GT = gas turbine, GTCC = gas turbine combined cycle; IGCC = integrated gasification combined cycle, ICE = internal combustion engine.

- National goals:
  - **Reduce gasoline usage by 20% in ten years**
  - **New feedstocks**
  - **Integrated biorefineries**



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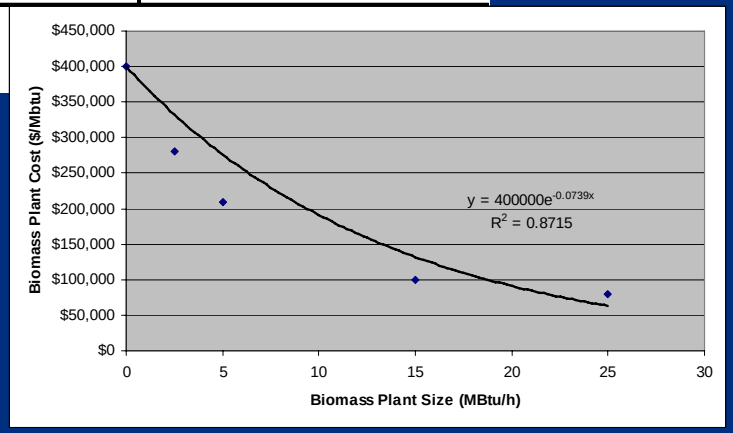
Technology Characterization Biomass Heat and Electricity

0A biodiesel combustion with conventional steam cycle		
Boiler Cost intercept	400000	$/MBH
Cogen Cost	1650	$/kW
Fuel Storage and Handling	250000	$/MBH
Boiler Efficiency	0.75	
Cogen Efficiency	0.3	
Boiler Capacity Factor	0.85	
Hx effectiveness	0.7	
avoided cost on-site waste	0	$/ton
fixed cost per ton purchased fuel	20	$/ton
trucking cost	0.1	$/sq mile/ton
Boiler O&M Cost	5000	$/yr/Mmbtuh
Cogen O&M Cost		
Cost of Biomass Operator $/year		



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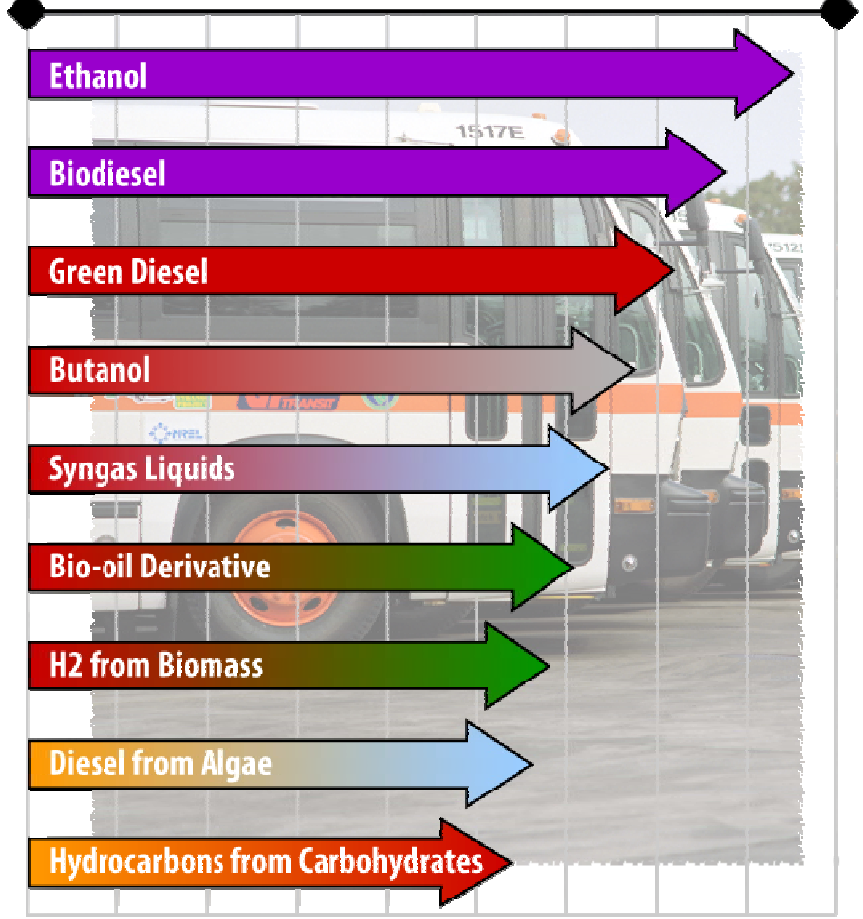
Biofuels R&D



Key Drivers	Attributes
New market for grain and agriculture products. Large supply of lignocellulose.	High octane gasoline blend stock from carbohydrates.
New market for excess oils, fats, and greases.	Petroleum compatible and biodegradable.
Lower cost and higher product quality than FAME.	Utilize existing assets. High quality jet fuel or diesel.
New market for grain and agriculture products. Large supply of lignocellulose.	Better gasoline blending properties than ethanol.
Integration of biomass with Coal, Coke, Shale, or Heavy Oils.	High quality jet fuel or diesel. Reduced criteria for sequestration, and economy of scale (in combination with fossil).
Technical fit with woody biomass and liquid bio-crude.	Potential to integrate into existing large scale refinery and pipeline infrastructure.
Potential transportation fuel from any fuel/power source.	Ideal feed for fuel cells, and lowest tail pipe emissions.
Lg. source of biomass on non-arable land, and capture of CO^2.	High quality jet fuel or diesel yield per acre, with both off-shore and on-shore potential.
Better compatibility with petroleum products.	Potential for higher reaction rates than fermentation, and potential as H2 carrier.

Renewable Fuels & Low GHG Emissions

Organizations Leading the R&D

- Grain/Agriculture
- Coal
- Chemical
- Petroleum
- Forestry
- Academia & Startups

Source: NREL 2007

Frontiers in Biomass Energy

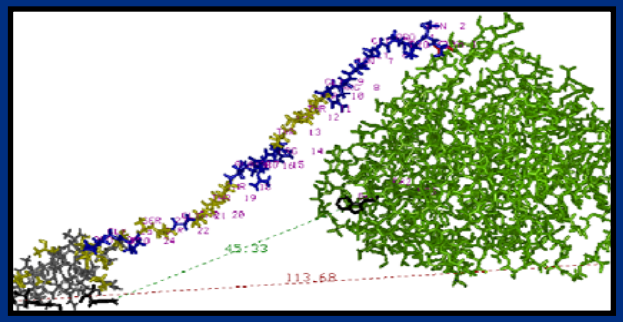
Existing

Ethanol – Produced from grain, used as blending component

Biodiesel – Transesterified vegetable oils blended with diesel

Near Term

Ethanol – Produced from cellulosic material



Long Term

Butanol – more efficient than ethanol

Hydrogenation-Derived Renewable Diesel/Gasoline – fats, waste oils, virgin oils processed pure or blended with crude oil using petroleum refinery or similar operations

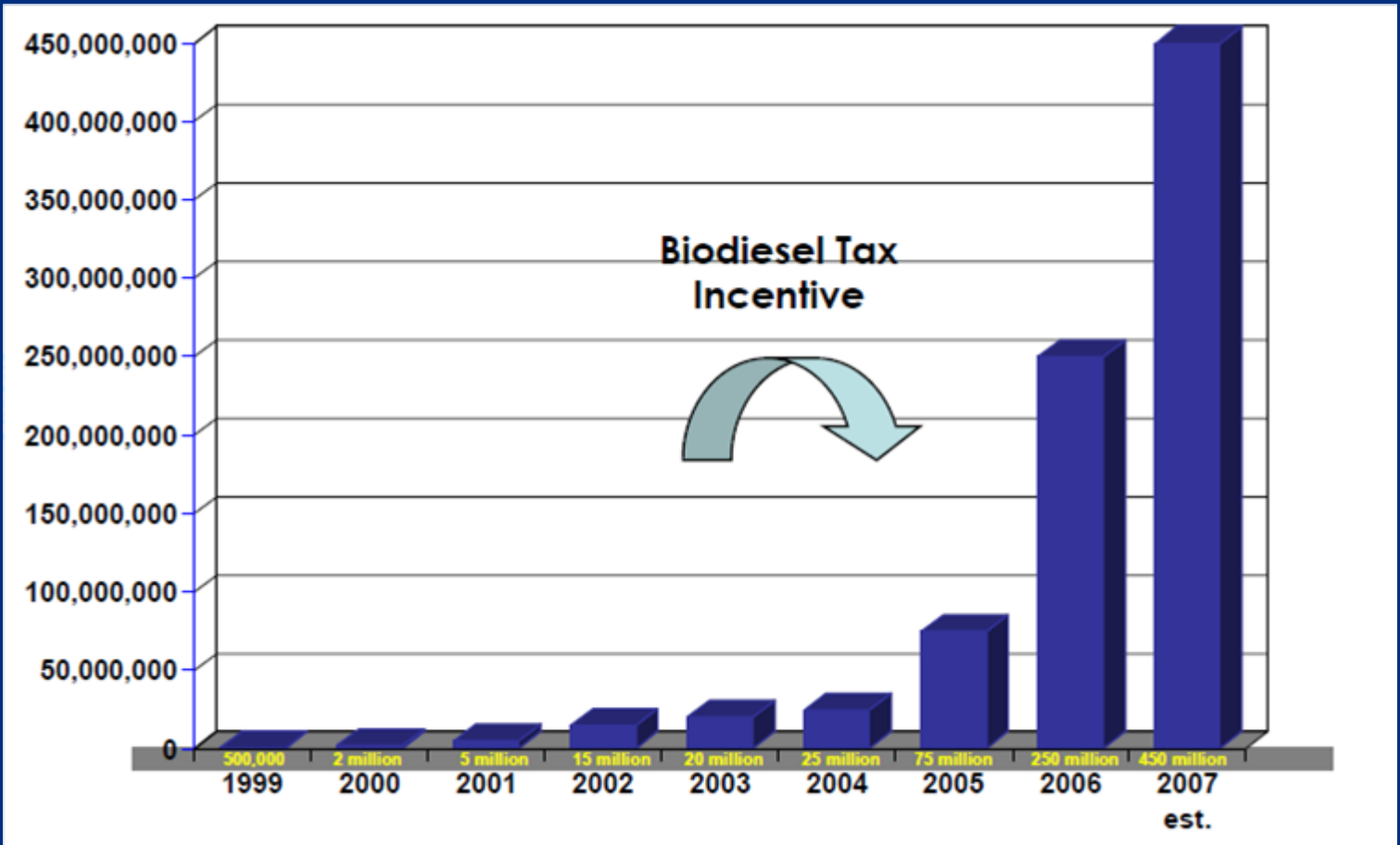
Fuels From Synthesis Gas – for conversion to Fischer Tropsch liquids, MeOH/DME, or mixed alcohols

Pyrolysis Liquids – as a boiler fuel or an alternative feedstock to petroleum refinery or gasification facility, also a future source of aromatics and/or phenols

Algae – as alternative source of triglycerides for biodiesel or green diesel

Alkanes – from hydrogenation of carbohydrates, lignin, or triglycerides

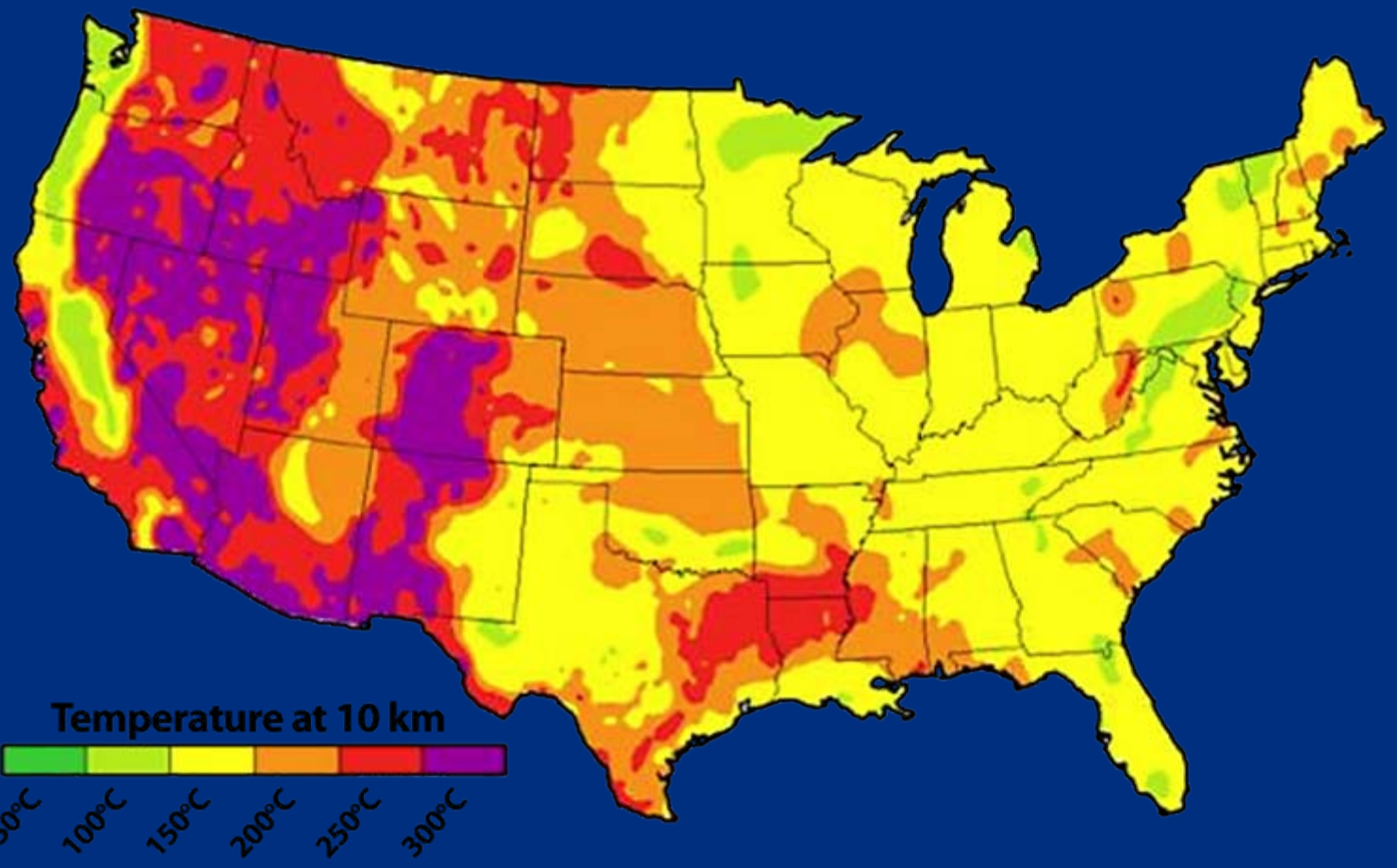
Growth of biodiesel (gal/year)



US Market for diesel fuel = 60 Billion Gallons/year

http://www.biodiesel.org/pdf_files/fuelfactsheets/Production_Graph_Slide.pdf (2-5-2006)

The U.S. Geothermal Resource



Source: MIT Study- The Future of Geothermal Energy

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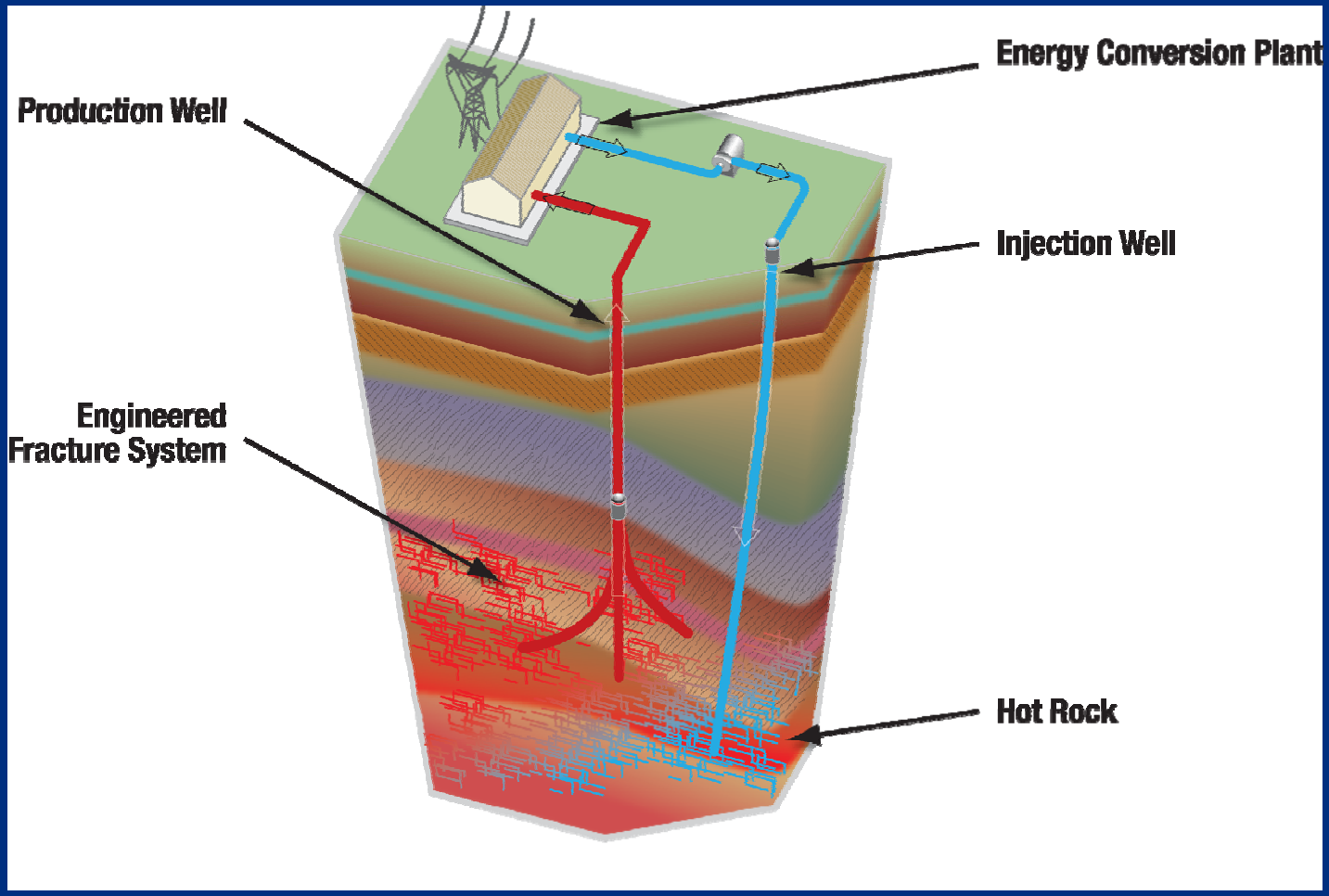
Enhanced Geothermal System



Source: NREL

Frontiers in Geothermal Energy

- **Most requirements to make Enhanced Geothermal Systems (EGS) work economically over a wide area of the country are in effect, with remaining goals easily within reach.**
  - **Low temperature energy conversion cycles**
  - **Better performing, lower cost components**
  - **Innovative materials**
  - **Analysis to define technology path to Enhanced Geothermal Systems**
- **Capable of providing at least 100 GWe within 50 years by using advanced EGS technology.**

DOE-sponsored study released in January 2007. Panel of 18 internationally recognized experts, led by MIT.

Daylighting

Daylighting at East Range Warehouse
Schofield Barracks, Hawaii

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Technology Characteristics: Daylighting

skylight transmittance	0.7	
lightwell transmittance	0.5	
Coefficient of Utilization Daylight	0.55	
Coefficient of Utilization Elec Light	0.55	
Luminous Efficacy Elec Light	100	lumens/watt
Roof U-value	0.1	btu/hr/F
Skylight Uvalue	0.5	btu/hr/F
Cooling COP	3.5	
Heating Efficiency	0.8	
Skylight Cost	25	$/sf
Controls cost	0.25	$/sf floor area

Advances in Daylighting

Shades and reflectors

Fiber Optics

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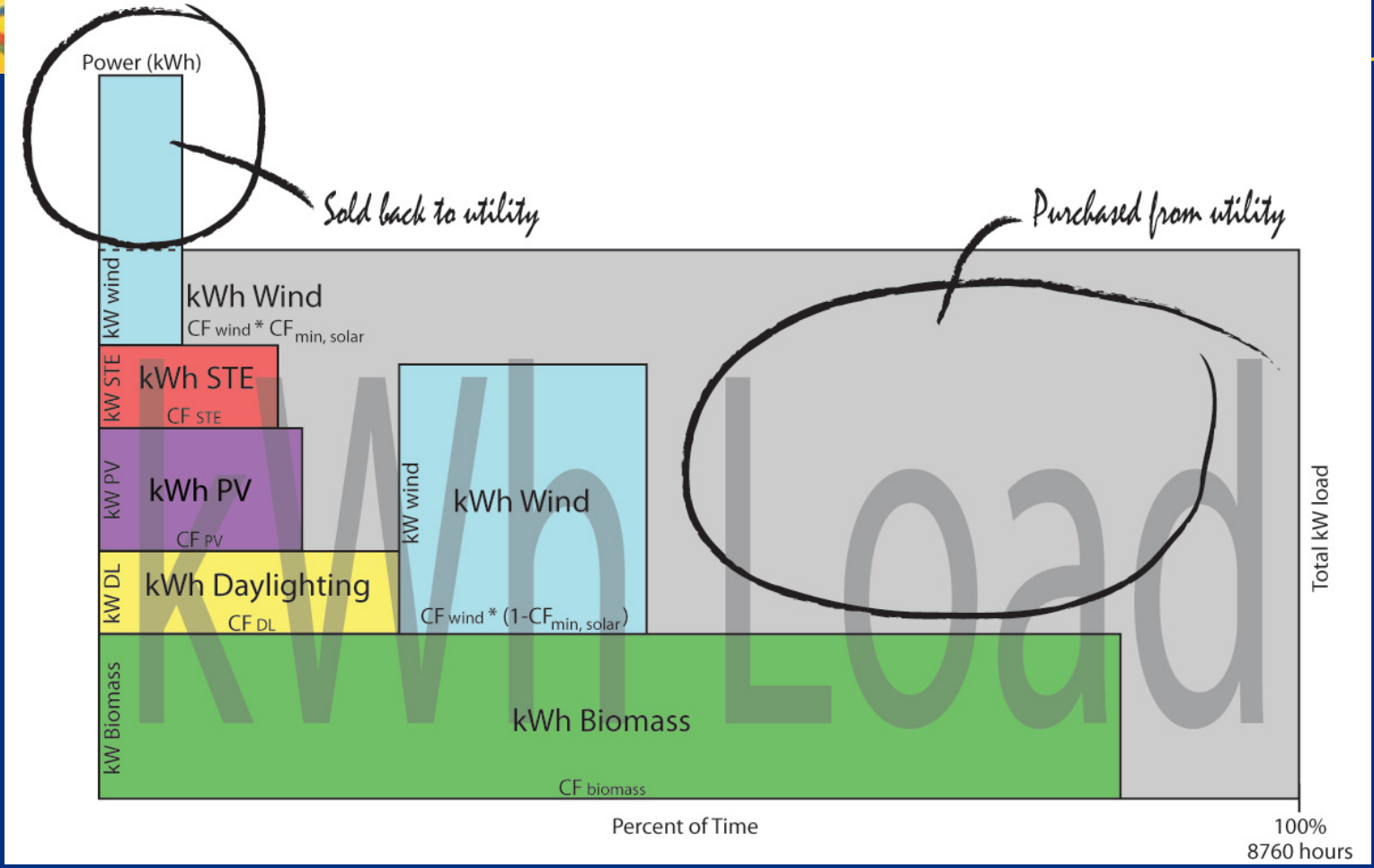
How RE technologies fit together at a site.



To get to "Net Zero", sold back to utility must equal purchased from utility

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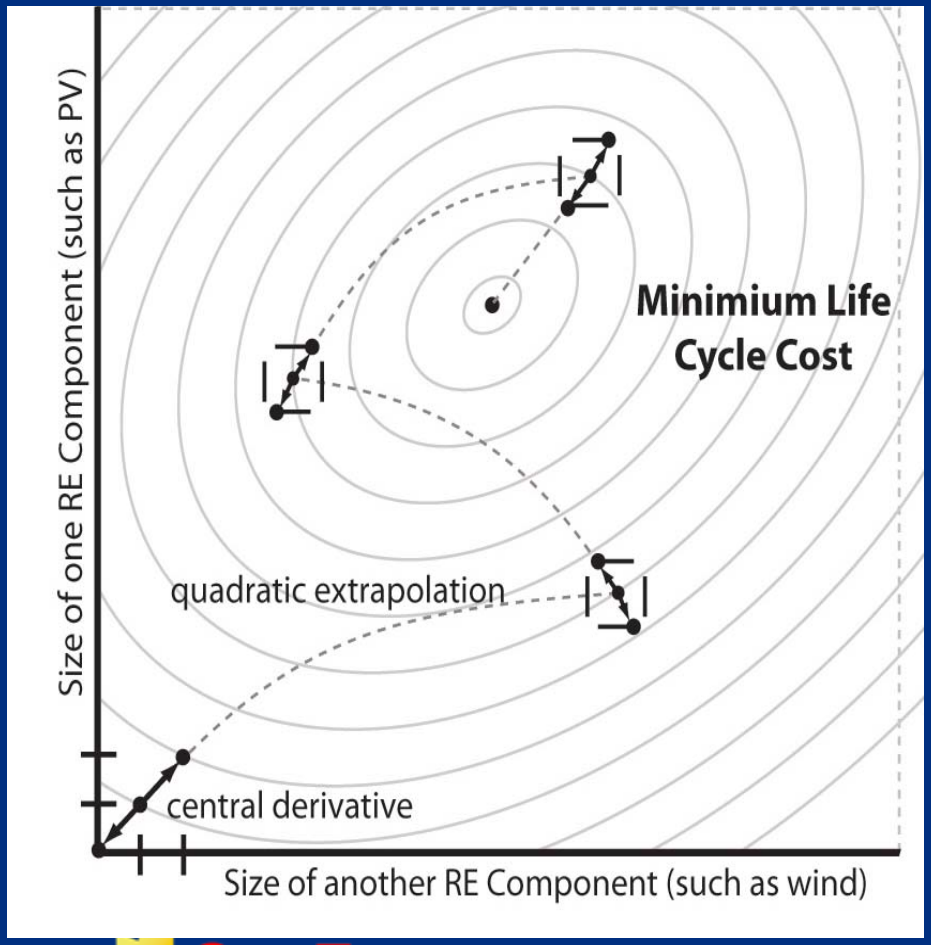
Optimization Problem



Identify the least cost combination of renewable energy technologies for a facility

Objective: Minimize Life Cycle Cost ($)

Variables: Size of Each Technology (kW of PV, kW of wind, etc)

Constraint: % renewable use: 7.5%...25%...up to 100% (Net Zero)

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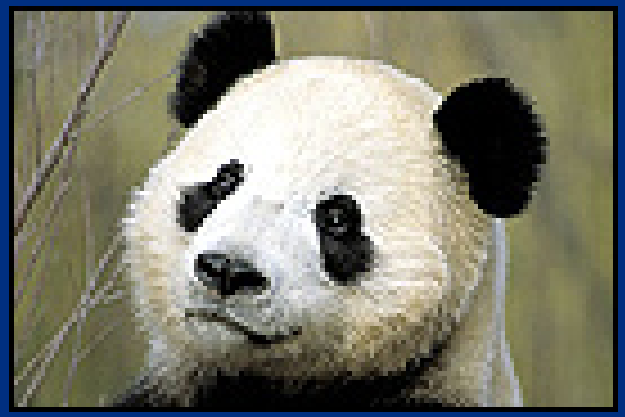
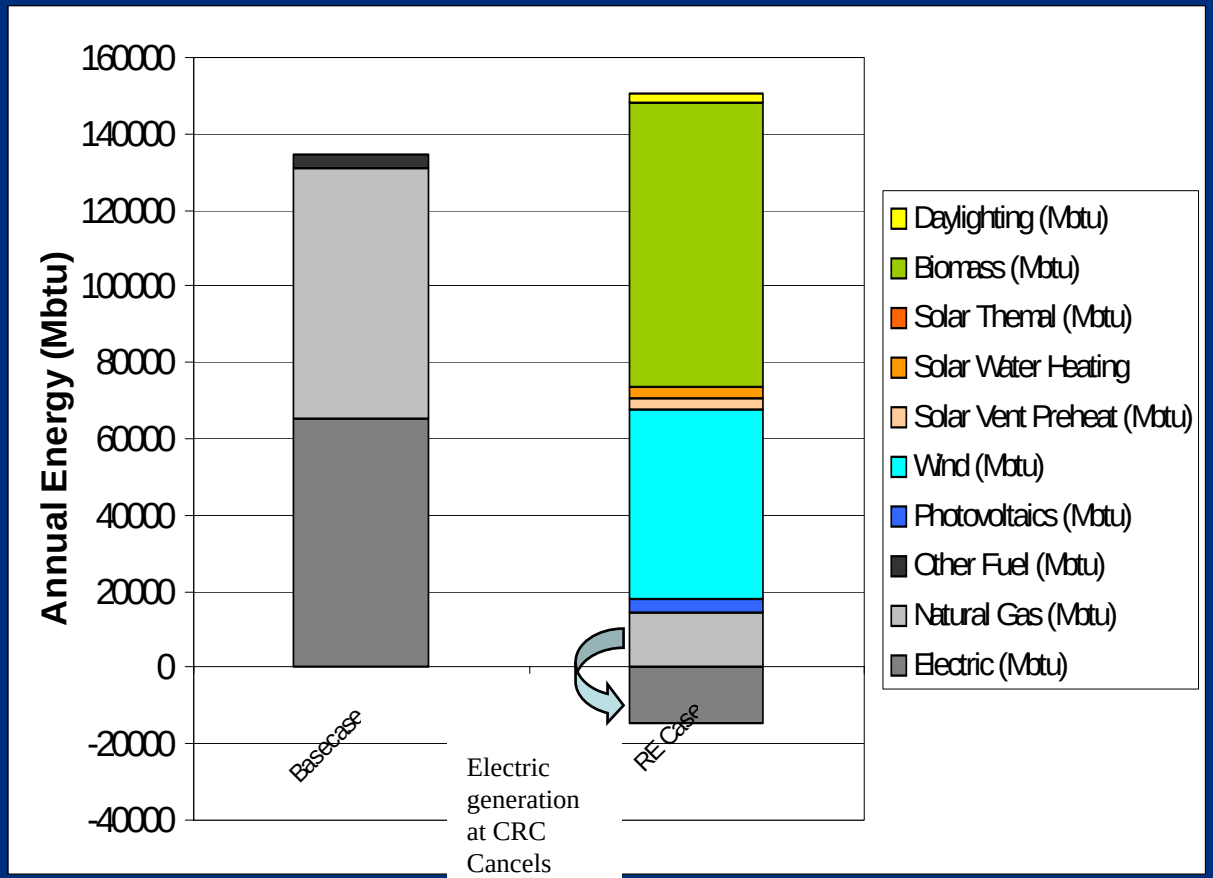
REO Example: Net Zero Zoo
National Zoological Park (NZP) and Conservation Research Center (CRC)





Electric generation at CRC Cancels remaining gas use at NZP

Zoo Entrance
Tai Shan the Panda

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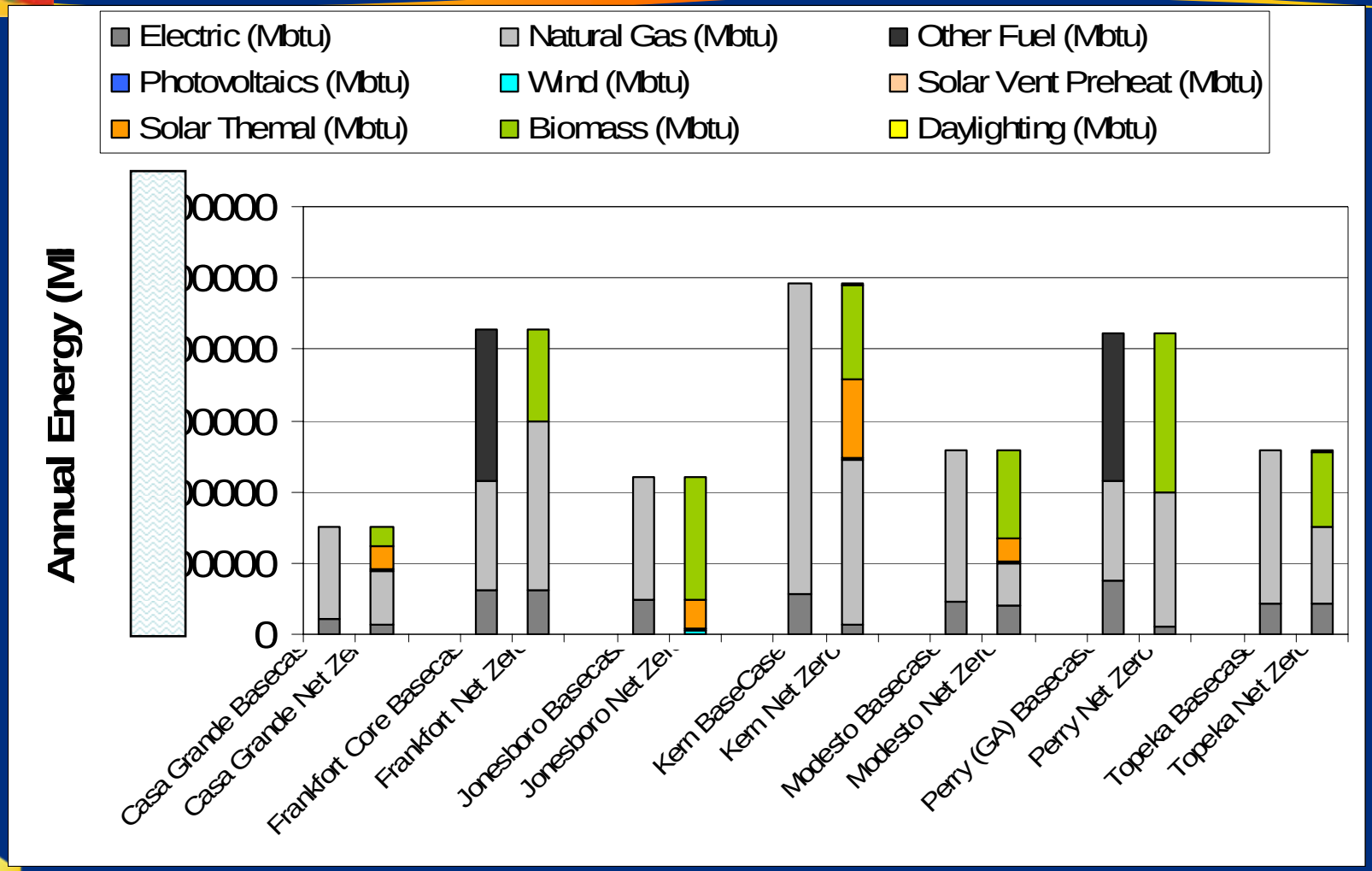
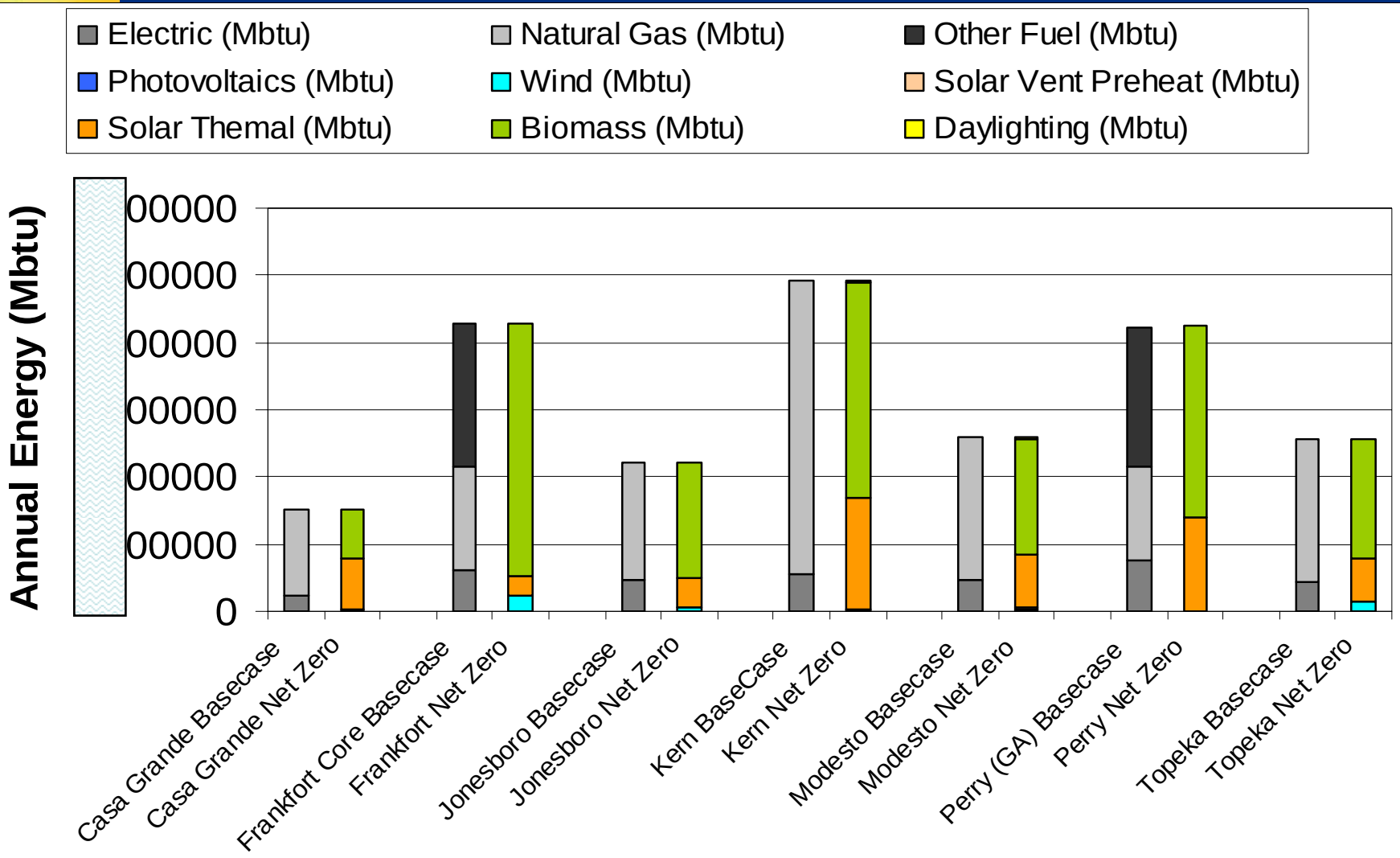
REO Example: Frito Lay North America Minimum Life Cycle Cost (no constraints)



REO Example: Frito Lay North America Minimum Life Cycle Cost (Net Zero constraint)



"All the News That's Fit to Print"

The New York Times

VOL. CLVII . . . . No. 54,129 + © 2007 The New York Times THURSDAY, NOVEMBER 15, 2007

In Eco-Friendly Factory, Low-Guilt Potato Chips

Frito-Lay's Venture Joins the Rush to Be Green

By ANDREW MARTIN

CASA GRANDE, Ariz. — At Frito-Lay's factory here, more than 500,000 pounds of potatoes arrive every day from New Mexico to be washed, sliced, fried, seasoned and portioned into bags of Lay's and Ruffles chips. The process devours enormous amounts of energy, and creates vast amounts of wastewater, starch and potato peelings.

Now, Frito-Lay is embarking on an ambitious plan to change the way this factory operates, and in the process, create a new type of snack: the environmentally benign chip.

Its goal is to take the Casa Grande plant off the power grid, or nearly so, and run it almost entirely on renewable fuels and recycled water. Net zero, as the concept is called, has the backing of the highest levels of corporate executives at PepsiCo, the parent of Frito-Lay.

There are benefits besides the potential energy savings. Like many other large corporations, PepsiCo is striving to establish its green credentials as consumers become more focused on climate change. There are marketing opportunities, too. The company, for example, intends to advertise that its popular SunChips snacks are made using solar energy.

"We don't know what the complete payoff for net zero is going to be," said Indra K. Nooyi, PepsiCo's chairman and chief executive. "If this works even to 50 or 60 percent of its potential, that is fantastic, and it's so much better than what we already have."

From coast to coast, more companies are thinking about how much fossil fuel they use and ways to conserve energy. Venture capital money is also pouring into fledgling green technology.

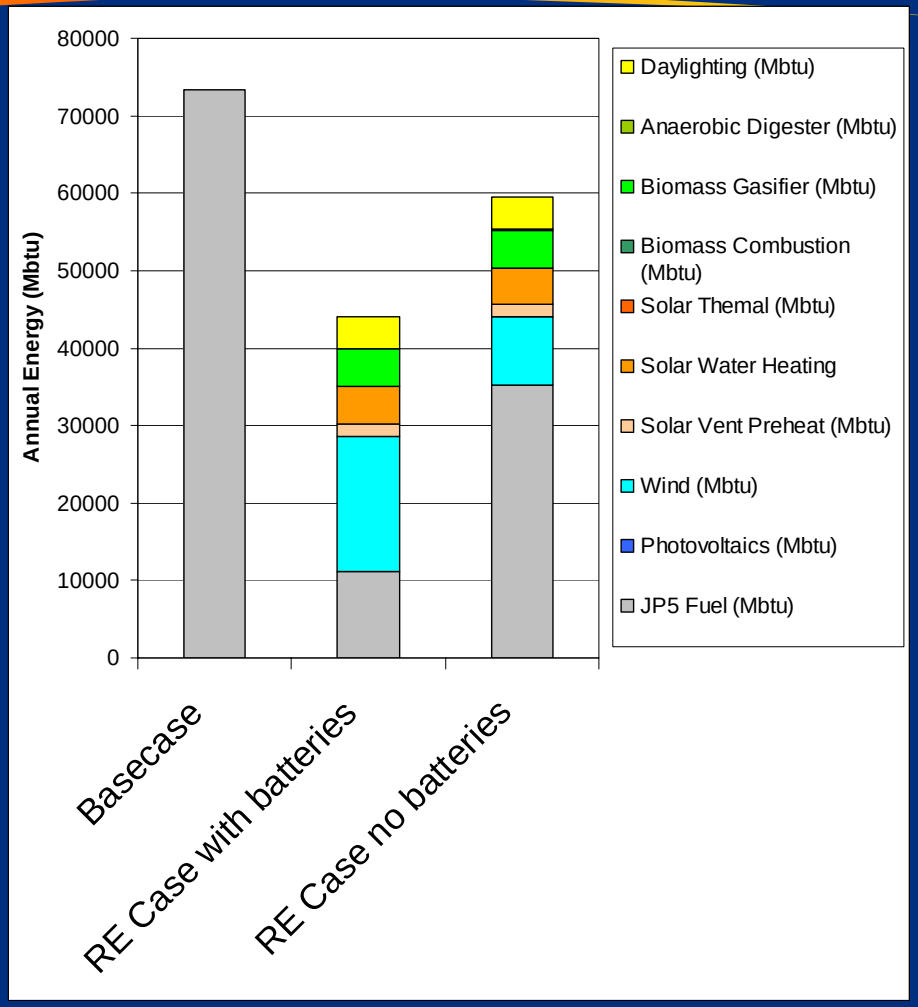
Only a few years ago, Andy Walker, a government engineer, pleaded with companies to tackle the problems but got blank stares. "Now, my phone is ringing off the hook," said Mr. Walker, who works at the National Renewable Energy Laboratory of the Department of Energy in Colorado.

But advocacy groups contend that for all the interest in saving energy, many companies also exaggerate small improvements for marketing purposes.

"Now I think there's a transi-

Continued on Page A22

REO Example: Minimize Life Cycle Cost US Navy San Nicolas Island CA



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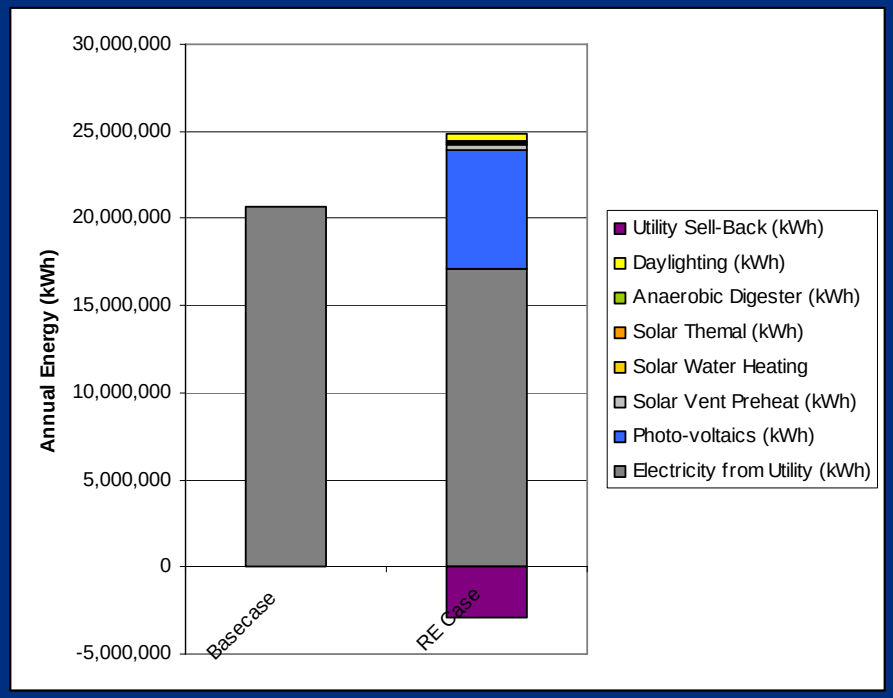
REO Example: Minimize Life Cycle Cost ESPC at DOE WIPP Facility, NM



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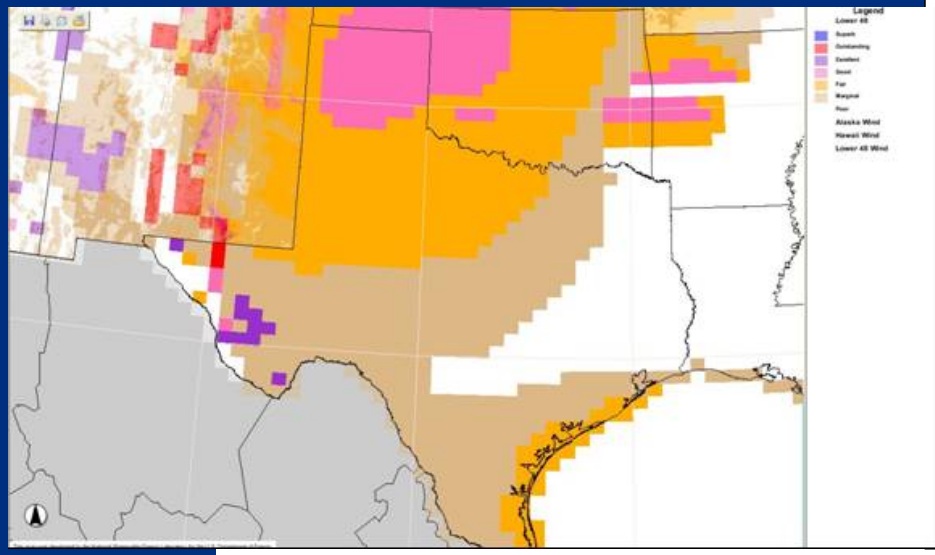
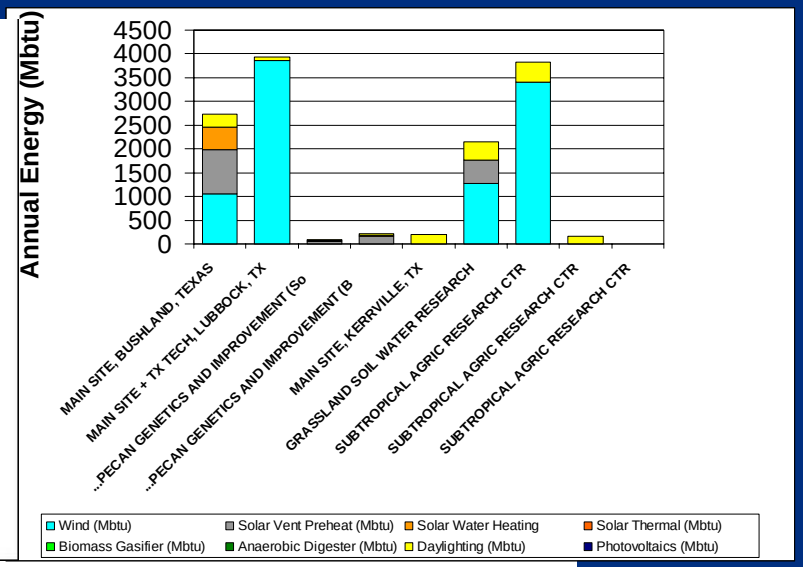
REO Example: USDA Agricultural Research Stations in TX

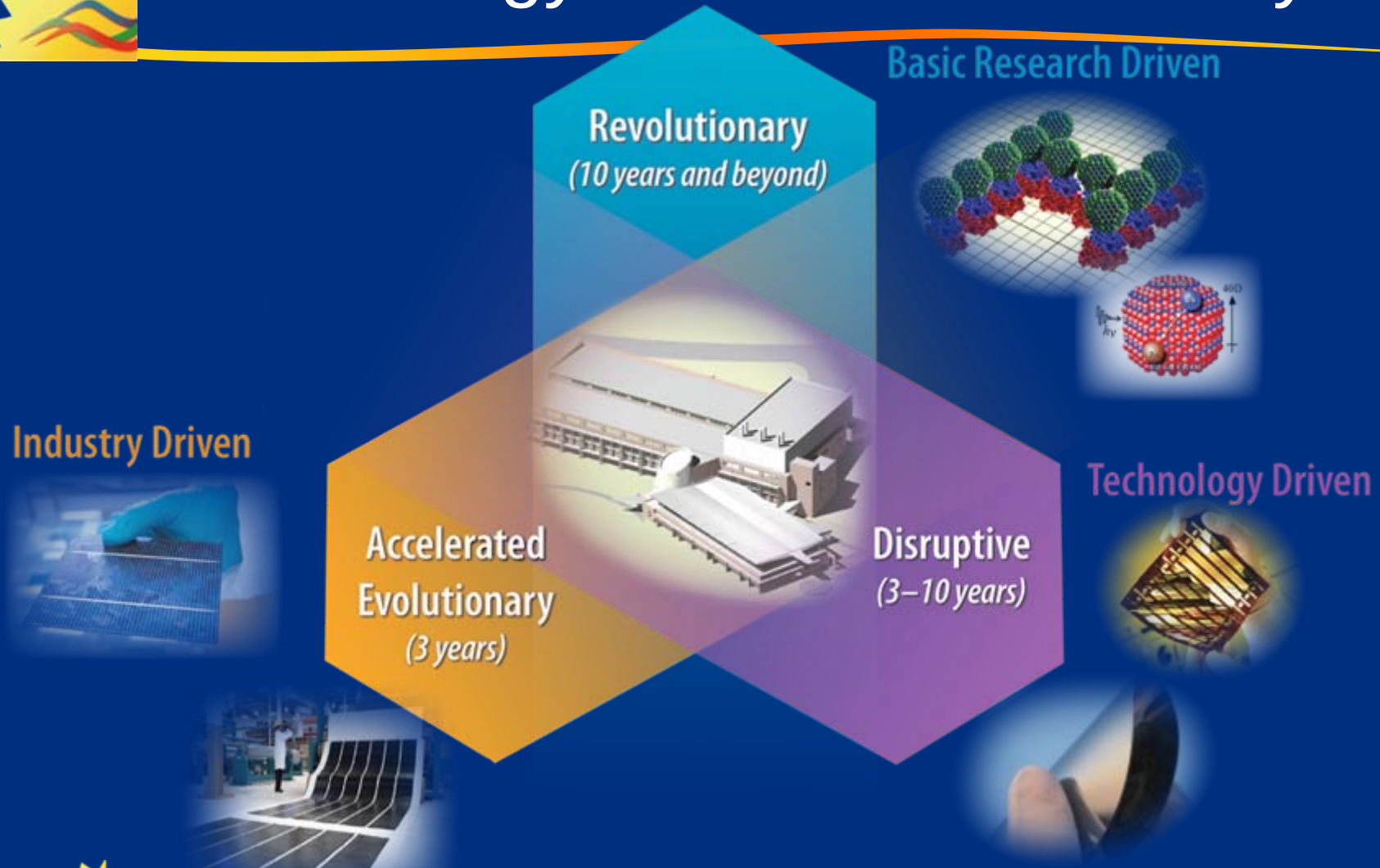




. **Renewable Energy Cost and Savings Summary (sum of all facilities)**

Initial Cost for Renewable Energy Projects ($)	$4,104,797
Annual Electric Savings (kWh/year)	3,165,878
Annual Gas/Fuel Savings (therms/year)	20,730
Annual Cost Savings ($/year)	$290,934
Simple Payback Period (years)	14.1 years
Rate of Return	7.7%

Achieving the Right Balance:
Technology Investment Pathways



Source: NREL 2007

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Mandates

- Energy Policy Act, Oct 2005
- Sec. 203: Renewable electricity consumption not less than 3% in FY 2007-2009; 5% in FY 2010-2012; 7.5% in FY 2013
- Sec. 204:expand the use of renewable energy in activities; purchasing electricity from renewable energy sources; install 2,000 solar energy systems by 2000 and 20,000 by 2010
- OUSD Policy Memo,18 Nov 05
- Increase the amount of renewable energy to 25% of total energy consumed by the year 2025.
- Executive Order 13423
- Sec. 2 (b) 50% of current renewable energy purchases must come from new renewable sources.
- EISA 2007 Solar Hot Water on Federal Buildings

Incentives

- Energy Policy Act of 2005
  - 30% investment tax credit
  - Accelerated Depreciation
- State and Utility Incentives
- Net Metering Policies

Financing Mechanisms

- Appropriations
- Energy Savings Performance Contracting
- Utility Energy Service Contracts
- Enhanced Use Lease
- Power Purchase Agreements

For More Information

Thank You!

- Andy Walker
- National Renewable Energy Laboratory
  andy_walker@nrel.gov

Don’t forget to fill out and drop off your session evaluations!