Solar Technology and the Future

Sustainable Cities Network
First Solar Workshop

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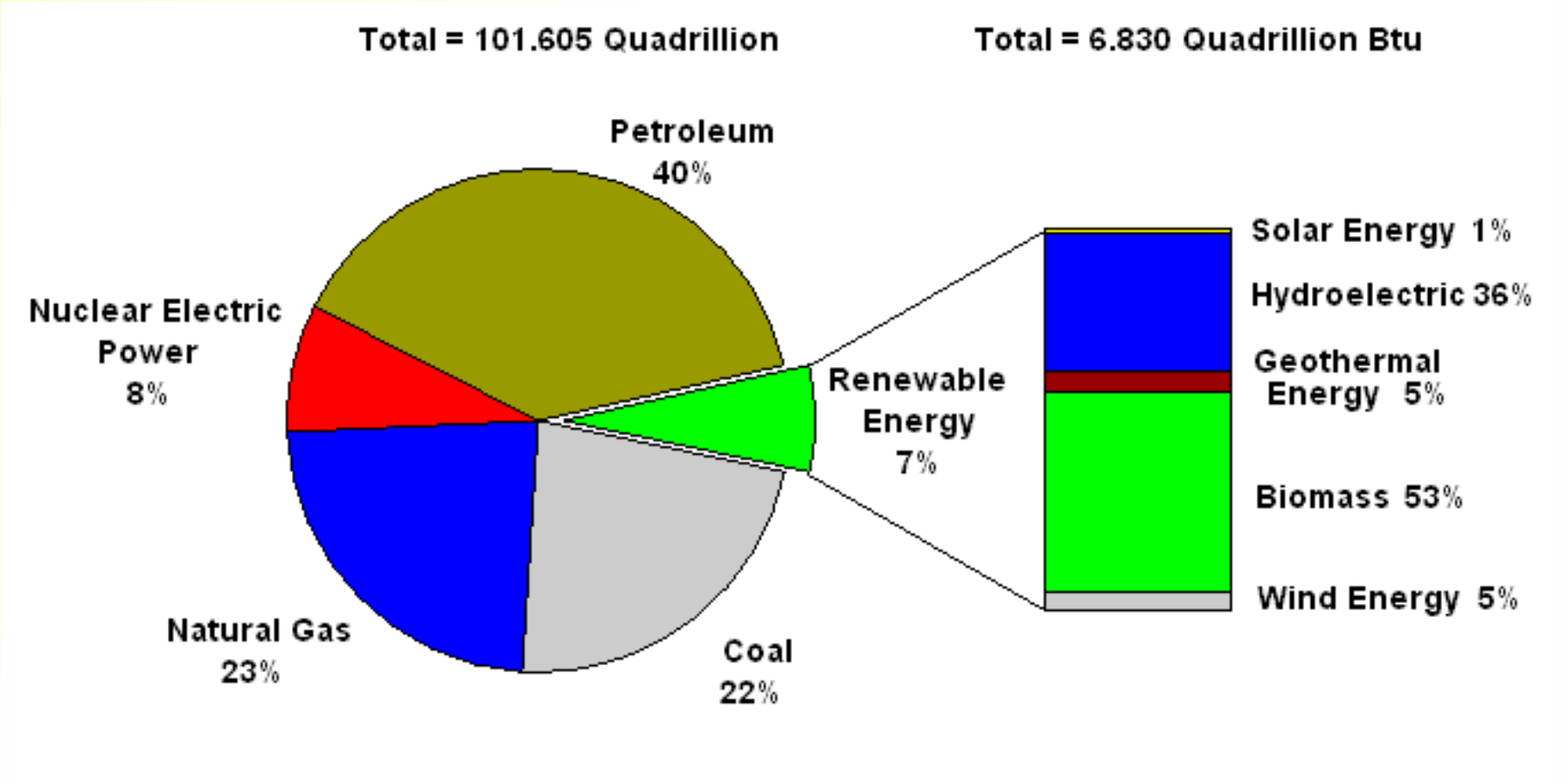
Outline

- Renewable Energy Sources
  - Motivation for adopting Renewables
- Solar power generation technologies
  - Concentrating Solar Thermal
  - Photovoltaics
  - High efficiency PV
- Types of PV
  - Current & emerging commercial
  - 3G - nanoPV

The Role of Renewable Energy Consumption in the Nation's Energy Supply, 2007

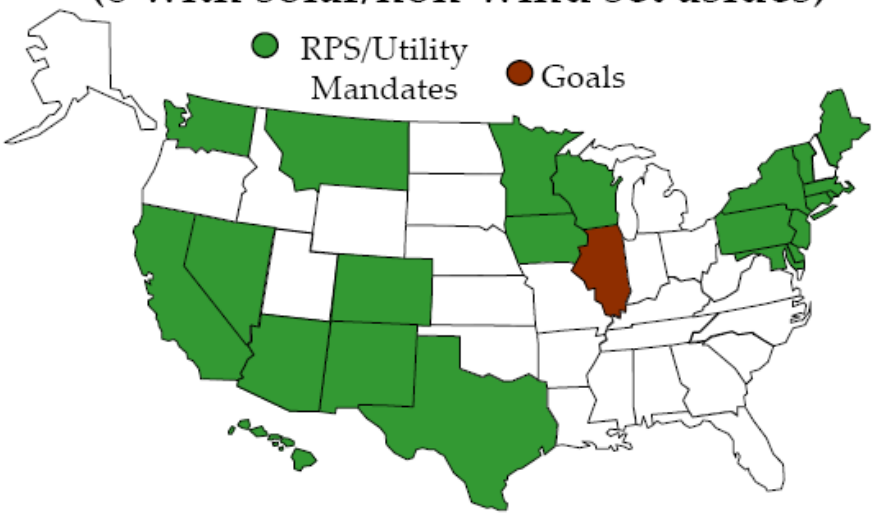


http://www.eia.doe.gov/cneaf/alternate/page/renew_energy_consump/figure1.html

Source: Energy Information Administration, Office of Coal, Nuclear, Electric and Alternate Fuels Chart data *Data For: 2007 Report Released: May 2008*

Renewables Portfolio Standards

As of January 2007, 22 states plus DC had renewable portfolio standards/utility RE mandates. (8 with solar/non-wind set aside)



1. The Illinois RPS is a goal with a cumulative 2% cap on rate increases resulting from compliance with the goal
2. In Minnesota the RPS is mandatory for the largest utility, Xcel, however, for the rest of the utilities/service providers it is a "good faith effort". Xcel met its 110 MW of biomass obligation as of 1/07 and must build or contract for 1,125 MW of wind by 2010.
3. Mid-American and Interstate Power & Light must contract 105 MW.

Source: Navigant Consulting, Inc. January 2007, Database of State Incentives for Renewable Energy (DSIRE) and California Energy Commission.

RPS standards vary by the size of the requirement, the allowable resources, dates, use of technology tiers/multipliers and other factors.

	Target	Other
AZ	15% by 2025	4.5% distributed RE by 2012 (1/2 res.)
CA	20% by 2010; 33% by 2020	
CO	10% by 2015	0.4% solar by 2015
CT	10% by 2010 (7% tier 1)	
DC	11% by 2022	0.386% solar by 2022
DE	10% by 2019	
HI	20% by 2020	
IA	105 MW (2% by 1999)	
IL[1]	8% by 2013	
MA	4% by 2009 (+1%/year after)	
MD	7.5% by 2019	
ME	10% additional by 2017. Starts in 2007;increases 1%/year	Above the 30% for 2000. Includes some non-RE.
MN[2]	10% by 2015 (1% biomass)	
MT	15% by 2015	
NJ	6.5% by 2008 (4% tier 1), 20% by 2020	0.16% solar (95 MW) by 2008, 2% by 2020
NM	5% by 2006, 10% by 2011	
NV	20% by 2015	5% of RPS solar
NY	24% by 2013	0.154% customer-sited by 2013; includes 1% via green power
PA	18% by 2020 (8% is RE)	0.5% solar by 2020
RI	16% by 2019	
TX	5,880 MW by 2015	Includes 880MW pre-RPS & 500 MW non-wind
VT	New generation 2005-2012 RE	10% cap
WA	15% by 2020	
WI	10% by 2015	

NAVIGANT CONSULTING

ASU

How much solar power is there at the earth?

Solar constant ~ 1366 watts/m^2 (averaged over the Earth's surface)
Area of the Earth's disc ~ 1.28×10^{14} m^2,
Solar flux (average) ~ 680 W m-2

Total solar power incident on earth
174 petawatts (10^{15}) ==> 340 W/m^2

Total electrical power used on earth
~ 5 terawatts (10^{12})

The sun can supply 10^5 times or **100,000 times** the world's energy consumption
Useable is ~ 10,000 times

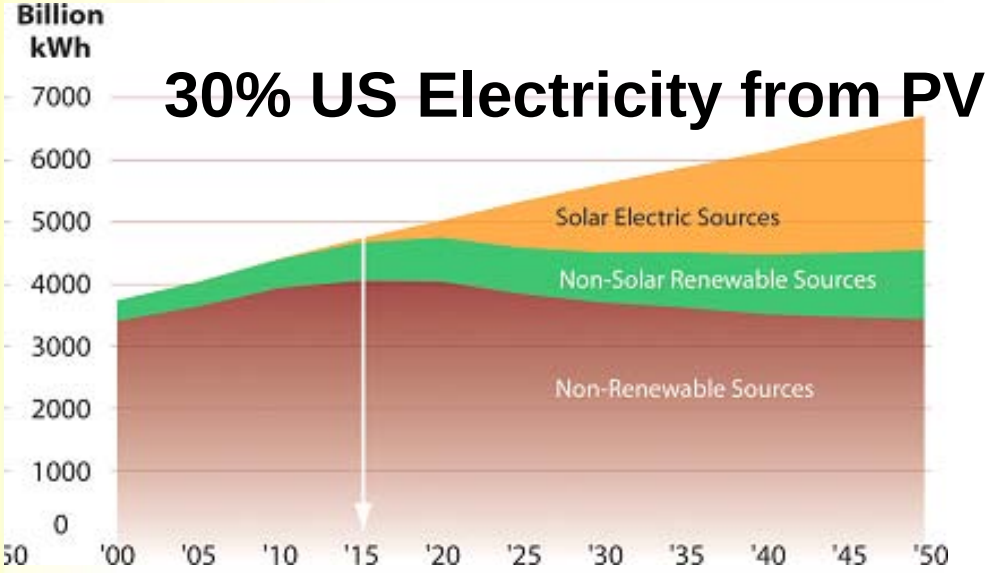
Other power sources are not as efficient

If you yelled for 8 years, 7 months and 6 days you would have produced enough sound energy to heat one cup of coffee

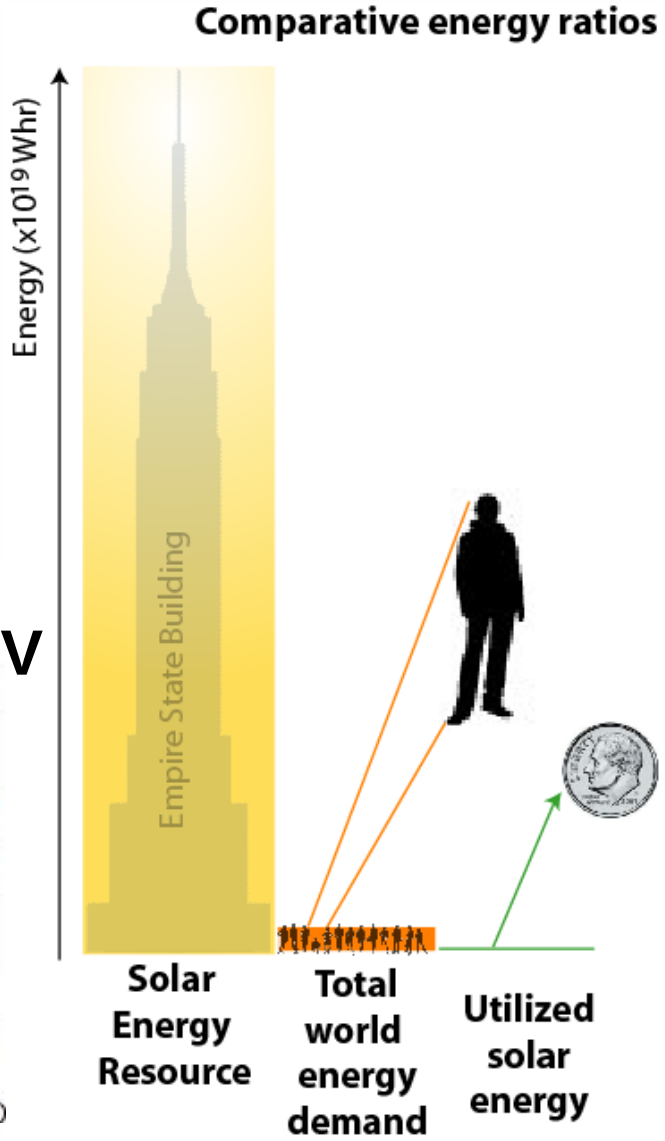
Solar Electricity Opportunity

Solar energy is a unique source of energy:

- Large resource - can meet entire energy demand
- Renewable
- Photovoltaics has high efficiency



30% US Electricity from PV



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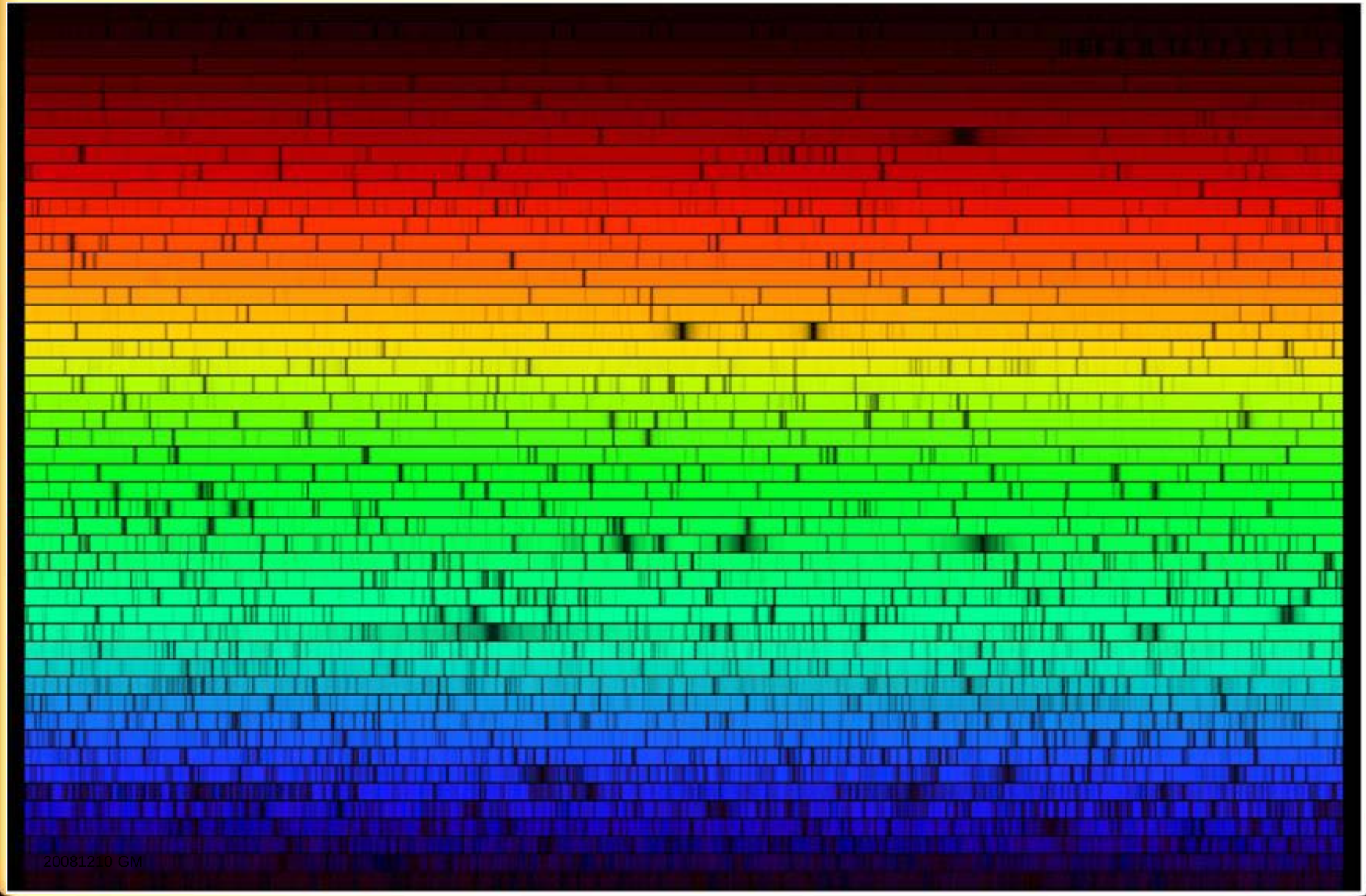
Lots of sun



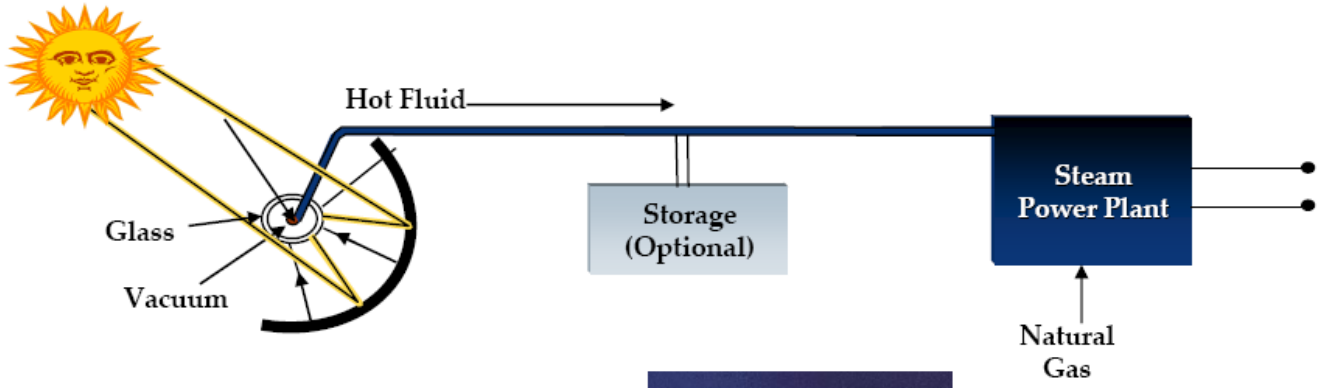
Solar Power Grid Installations

- Central Grid Installations
  - Concentrating Solar Thermal
    - Parabolic troughs
    - Power Towers
    - Solar Dish
  - Photovoltaics
    - Flat Plate
    - Concentrator PV
- Distributed Grid – Commercial & Residential
  - Photovoltaics

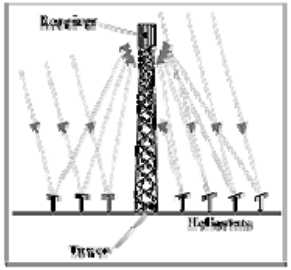
Concentrating Solar Thermal

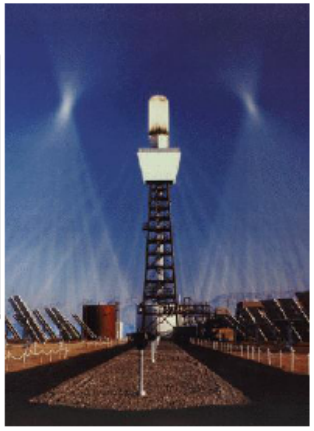
Concentrating Solar Thermal

STE processes use concentrated solar energy to raise the temperature of a heat transfer fluid and co-firing with NG or storage can sometimes be used to ensure dispatch capability.



Parabolic Trough





Power Tower

Solar Dish

Kramer Junction Co SEGS power plants

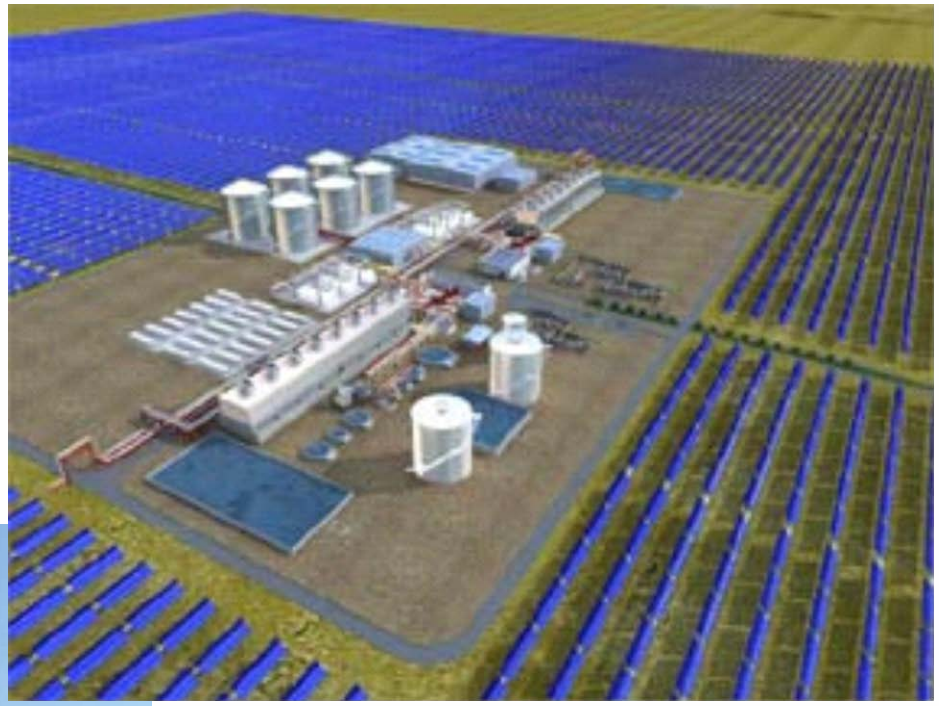
- Nine Kramer Junction solar electric gene
- rating system (SEGS) power plants
- parabolic trough collectors & heat-transfer fluid
- Capacity 354 MW
- Some plants have been operating for more than 20 years.

San Bernardino County, CA
Mojave Desert
Harper Lake & Daggett

Natural gas backup power => Need for Storage

Solana – APS/Abengoa Concentrating Solar Thermal Power Plant

- 280 MW capacity
- power 70,000 homes
- create 1,500 jobs
- employ 85 full-time workers
- avoids over 400,000 tons of greenhouse gases
- 1,920 acres [3 sq mi]
- 70 miles SW of Phoenix
- near Gila Bend, AZ



- 2,700 trough collectors
- Molten salt thermal storage = 6 hours
- PPA with APS - estimated $4 billion over next 30 years.

Solucar/Abengoa Solar Platform

Location: Seville, Solucar Spain
Name: PS10
Capacity: 11MW
Type: direct water heating
Completion: 2013

The 40-story (380ft) concrete tower collects sunlight from a field of over 624 - 120m^2 (1300ft^2 d~22ft) heliostats.

cooperation between institutions including Ciemat, the IDEA, and the University of Seville.

Stirling Energy Systems Solar Dish Arrays

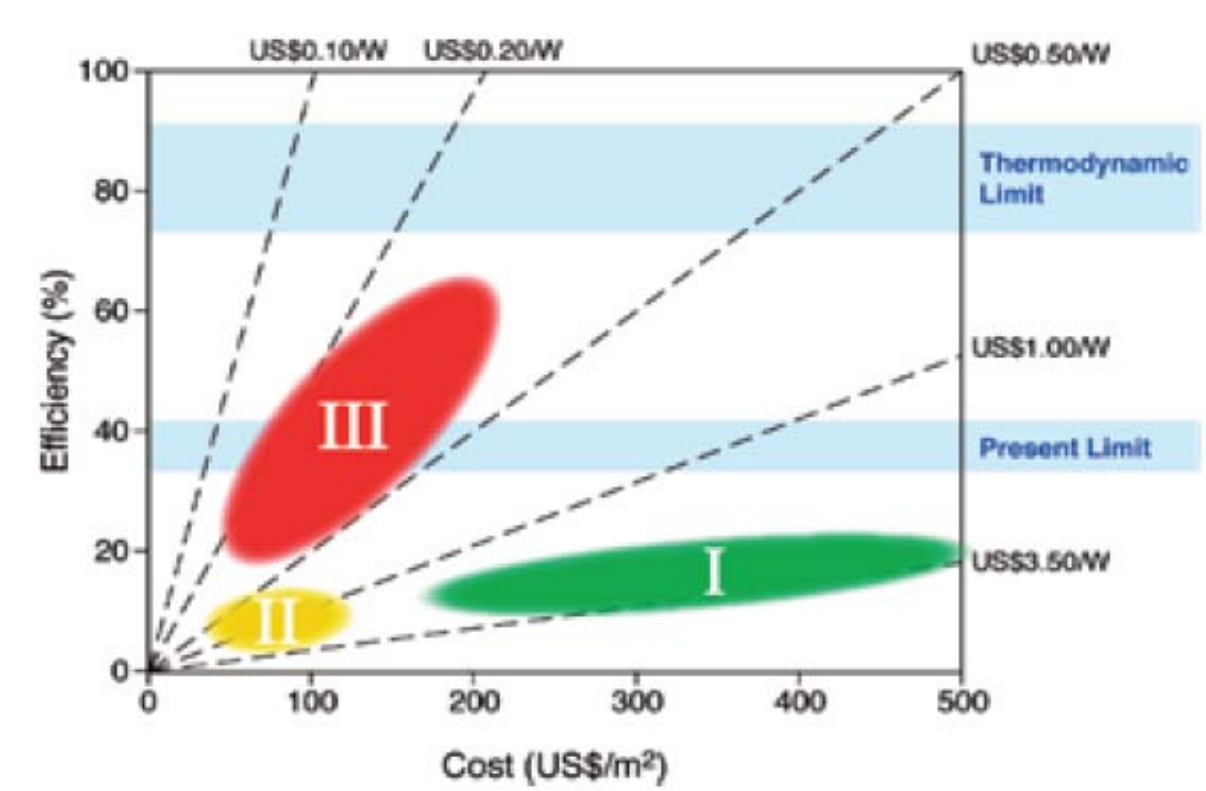
Efficiency > 30%

- Sunlight focused on a Stirling engine (Carnot Cycle)
- Expanding hydrogen gas creates a pressure wave on the pistons.
- Direct conversion to electricity

Contracts to build and operate two large power projects with San Diego Gas & Electric and So. Cal Edison
Up to 1,750 megawatts (MW) of power (the world's two largest solar power contracts ever granted).
Requires up to 70,000 SunCatchers
Technology being demonstrated in medium scale (1 MW)

Photovoltaics

Efficiency & Next Generation PV



31% Shockley–Queisser limit single-junction

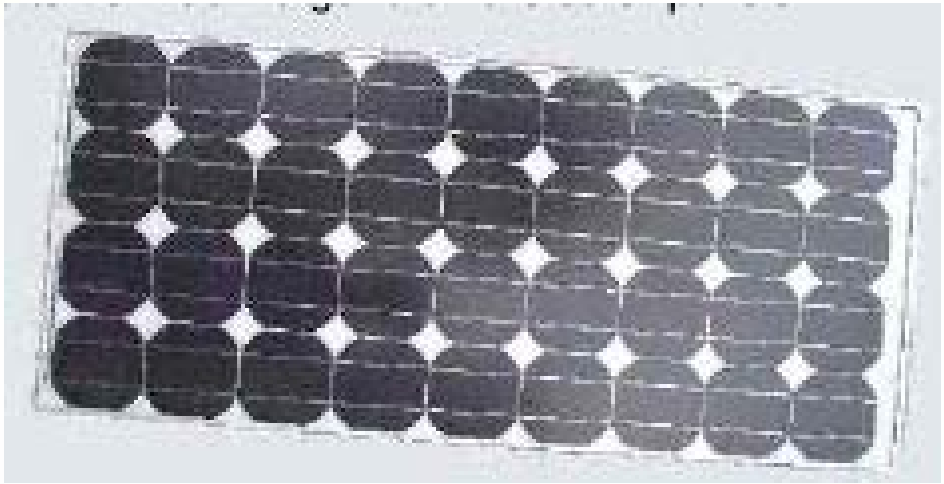
I – First Generation - primarily crystalline and poly-Silicon materials. => 85% of market

II – Second Generation – amorphous Si; CdTe, CIGS => small % of market

III – Third Generation – Concentrator & multijunction high efficiency cells

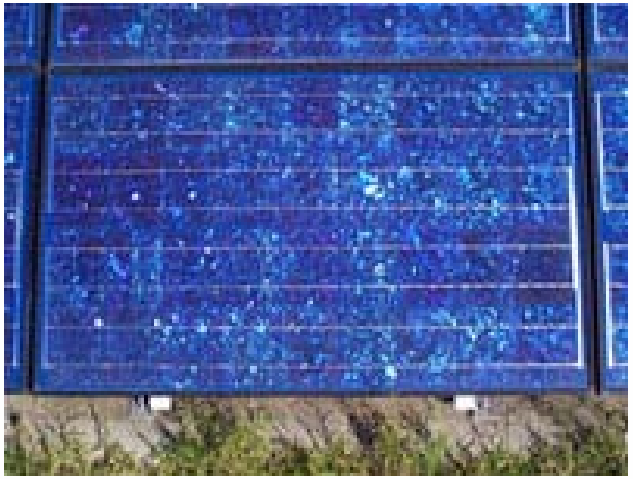
First Generation: Crystalline Si PV

- **Advantages**
  - well-established silicon IC technology
  - Si commercially available
  - readily manufactured
  - silicon abundant



crystalline

- **<u>Issues</u>**
  - thinner silicon
  - simpler Si purification
  - higher efficiency



polycrystalline

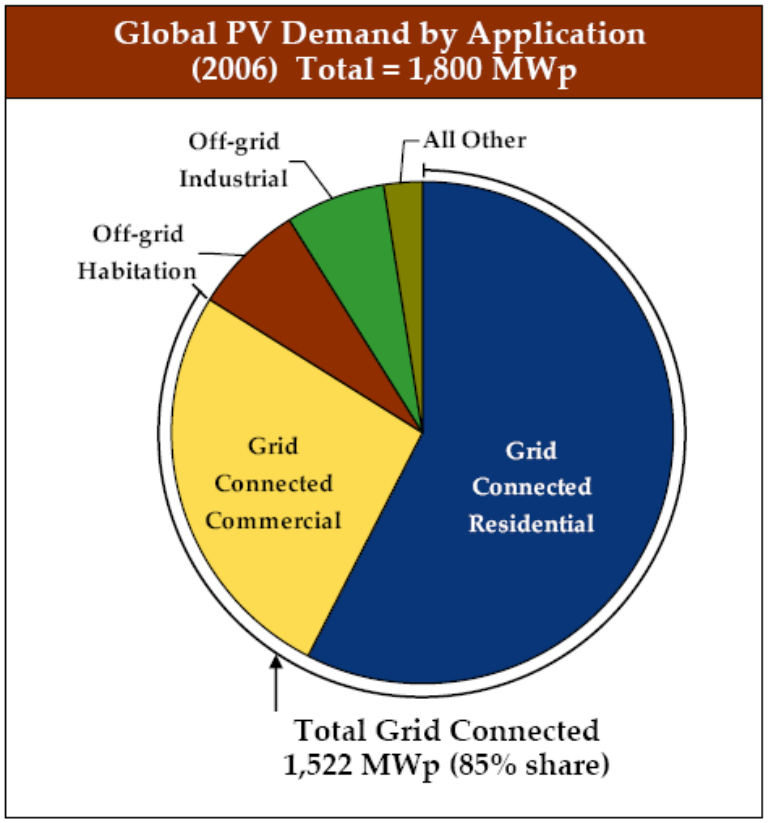
Grid-connected photovoltaics

There are three primary grid-connected PV applications that represented 85% of global installations in 2006…most were customer sited.

1. Central
(e.g. single-axis tracking)

2. Commercial Buildings

3. Residential Buildings



Source: Navigant Consulting PV Service Program, January 2007.

Incentives to adopt renewables

Factors for adoption
- legislation
- incentives
- cost of electricity

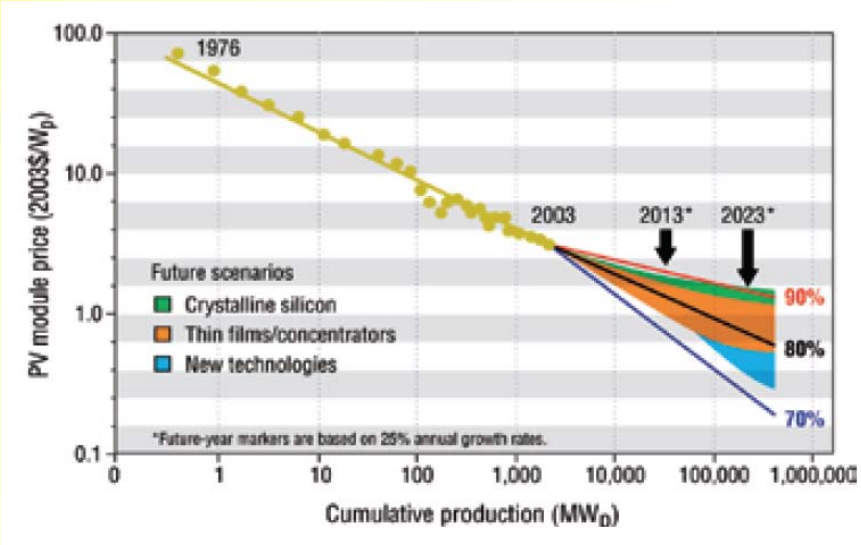
Renewable Portfolio Standards
→ Arizona: 4.5% distributed RE by 2012 and 15% by 2025

FIGURE 1: SOLAR SUBSIDY COSTS

SYSTEM SIZE	10 kW	50 kW	100 kW
System Cost - approximate	$70,000	$350,000	$700,000
Utility Rebate, $2.50/watt, max $50,000	$25,000	$125,000	$250,000
Federal Tax Credit, 30%	$21,000	$105,000	$210,000
State Tax Credit, 10%, max $25,000	$7,000	$25,000	$25,000
Depreciation 5 years, 34% Federal Tax rate, 6% state, 50% accelerated depreciation in 2008	$11,900	$59,500	$119,00
Reduction Utility Bill in Year One	$1,671	$8,355	$16,710
Total System Cost in Year One	$3,429	$27,145	$79,290
Total System Cost Paid by You - % of Total Cost	5%	8%	12%

Source: Solar Power Arizona LLC – www.solarpowerarizona.com/businesses.html

Worldwide PV Installations by Year



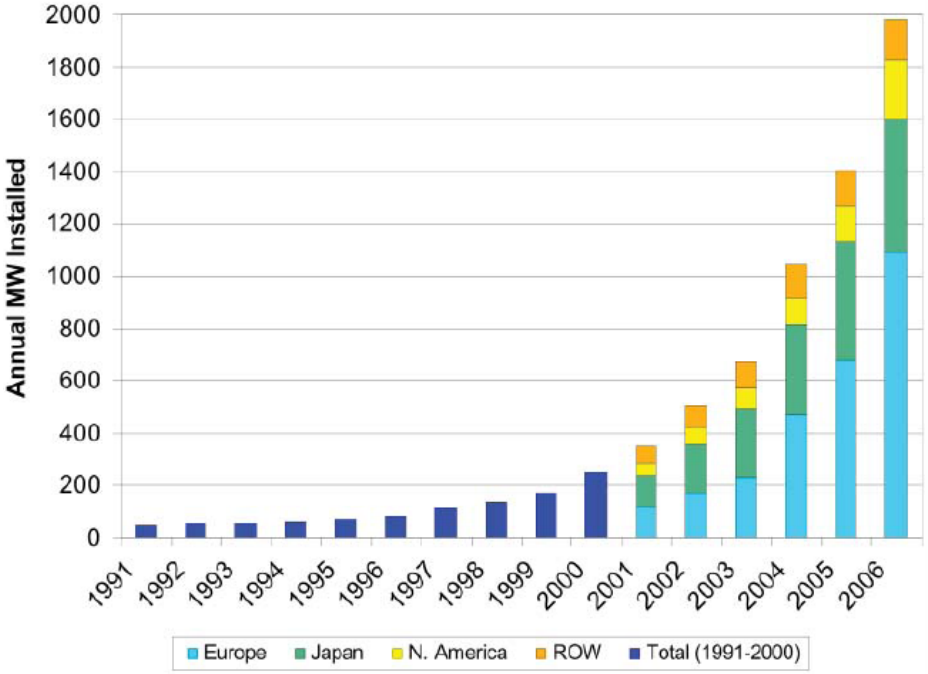


Figure 1
Global PV Installations by Year, 1991-2006. Data for the years 1991-2000 are expressed as worldwide totals, while other data specify where the PV was deployed. (Data source: Navigant Consulting PV Service Practice)

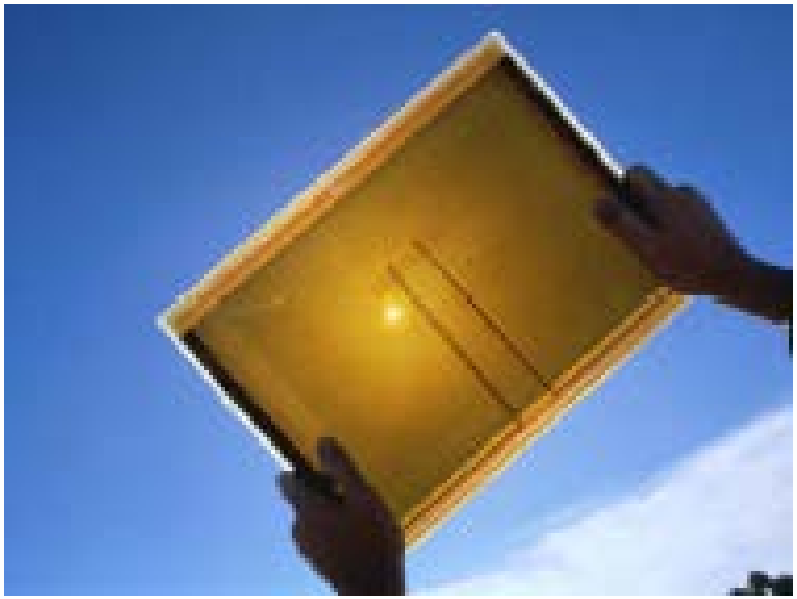
Industry growing at ~35% per year –
??? Economic Crisis impact ???

ASU Stadium Parking Structure PV Array

Bonny & Lee will discuss

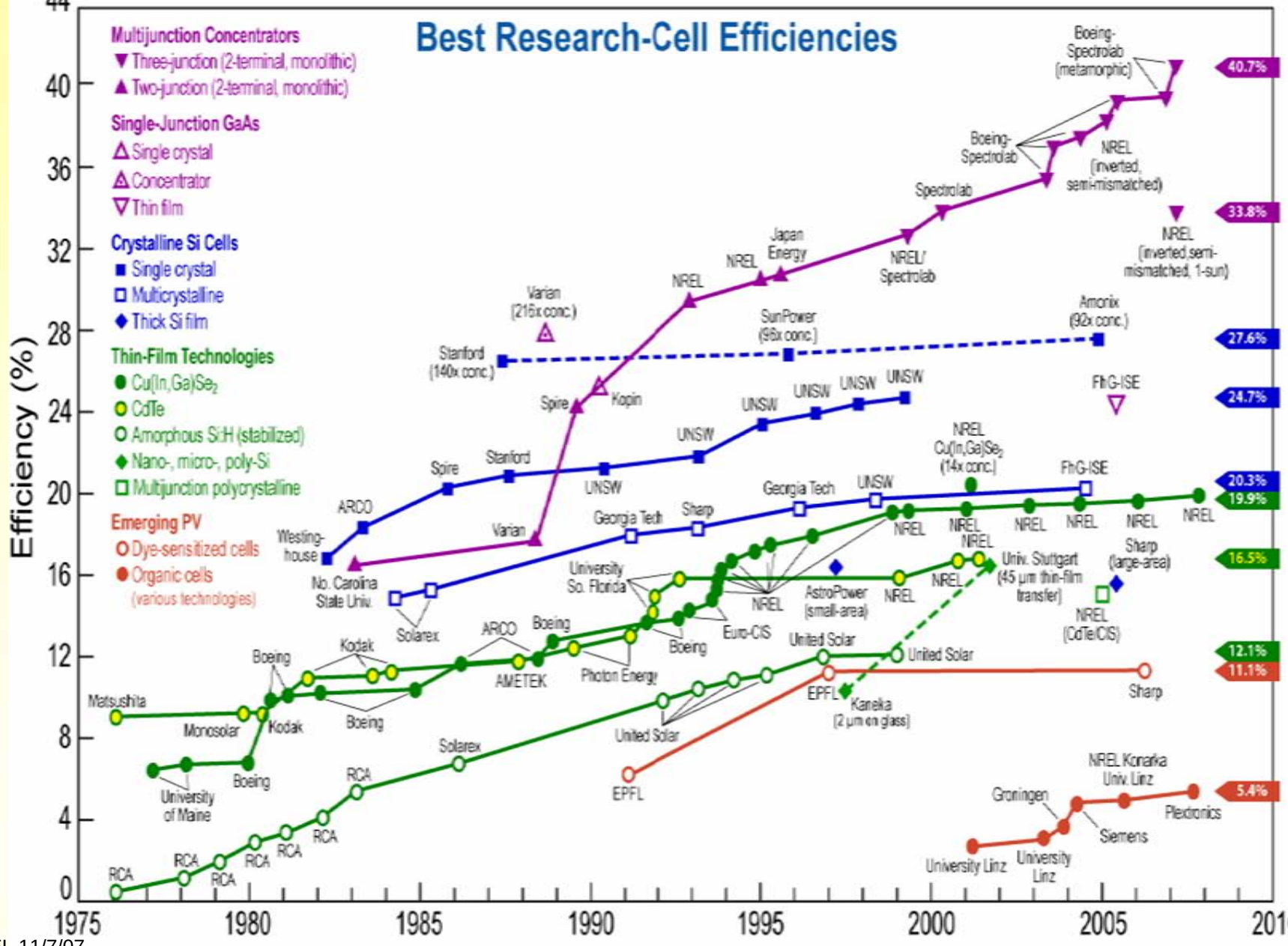
Second Generation: Thin-Film PV

- **Advantages**
  - low materials cost
  - large manufacturing unit
  - fully integrated modules
  - aesthetics
  - ruggedness



- **<u>Thin-film Technologies</u>**
- **Silicon**
  - Amorphous a-Si
  - Microcrystalline μc-Si
  - (poly- or multi-) crystalline c-Si
- **Chalcogenide (polycrystalline)**
  - Cadmium telluride CdTe
  - Copper indium gallium diselenide CIS, CIGS [$Cu\ (In,Ga)\ (Se,S)_2$]
- **Organics, Dye-sensitized**

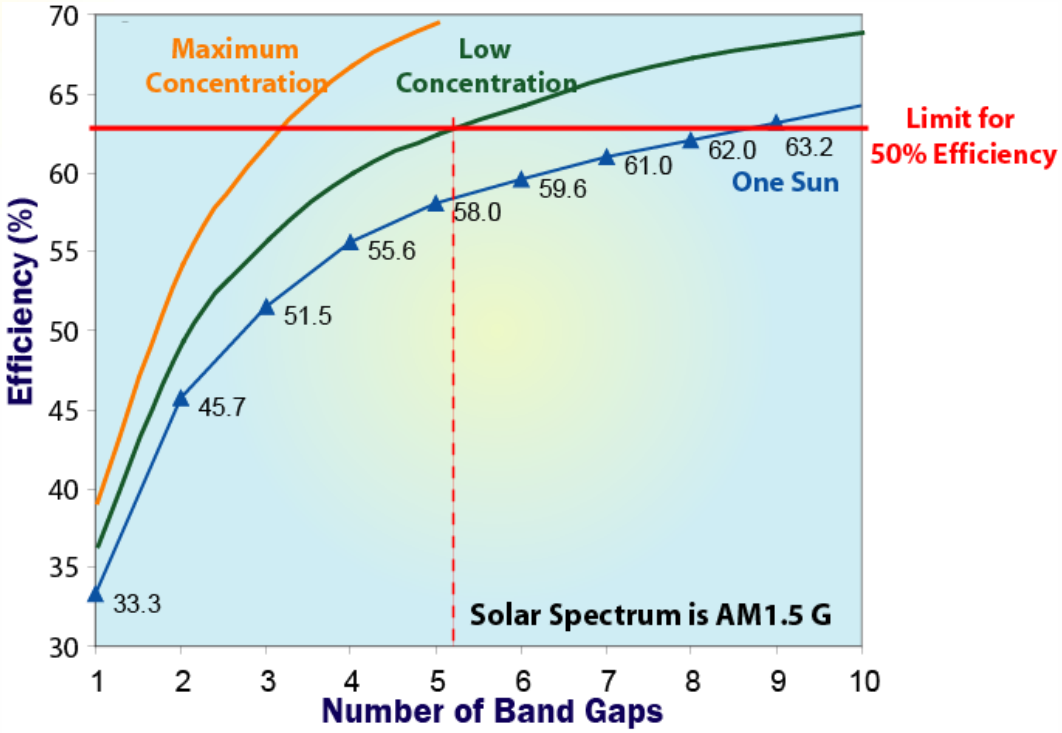
Best Solar Cell Efficiencies



Paths to High Efficiency Solar Cells

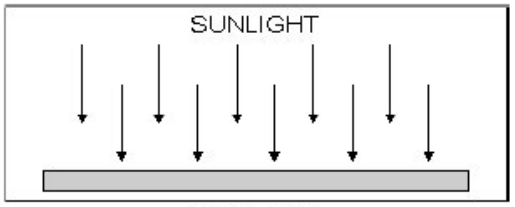
Efficiency depends on:

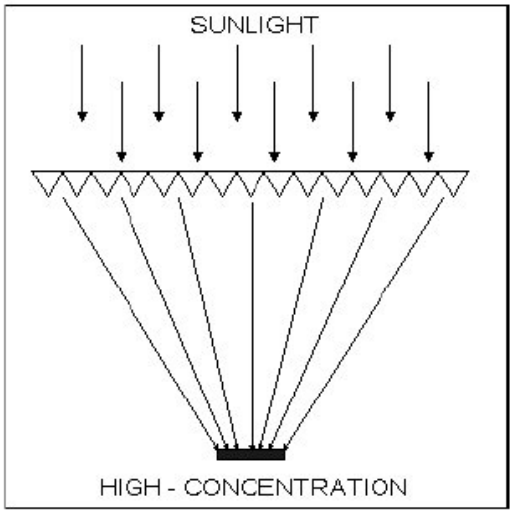
1. Concentration of the incident sunlight
2. Theoretical efficiency of solar cell (number of junctions)



Concentrating Photovoltaics (CPV)

Concentrator photovoltaics (CPV) use lenses or reflective collectors to focus solar energy (typically > 100 suns) on a reduced area of solar cell material that is more efficient.



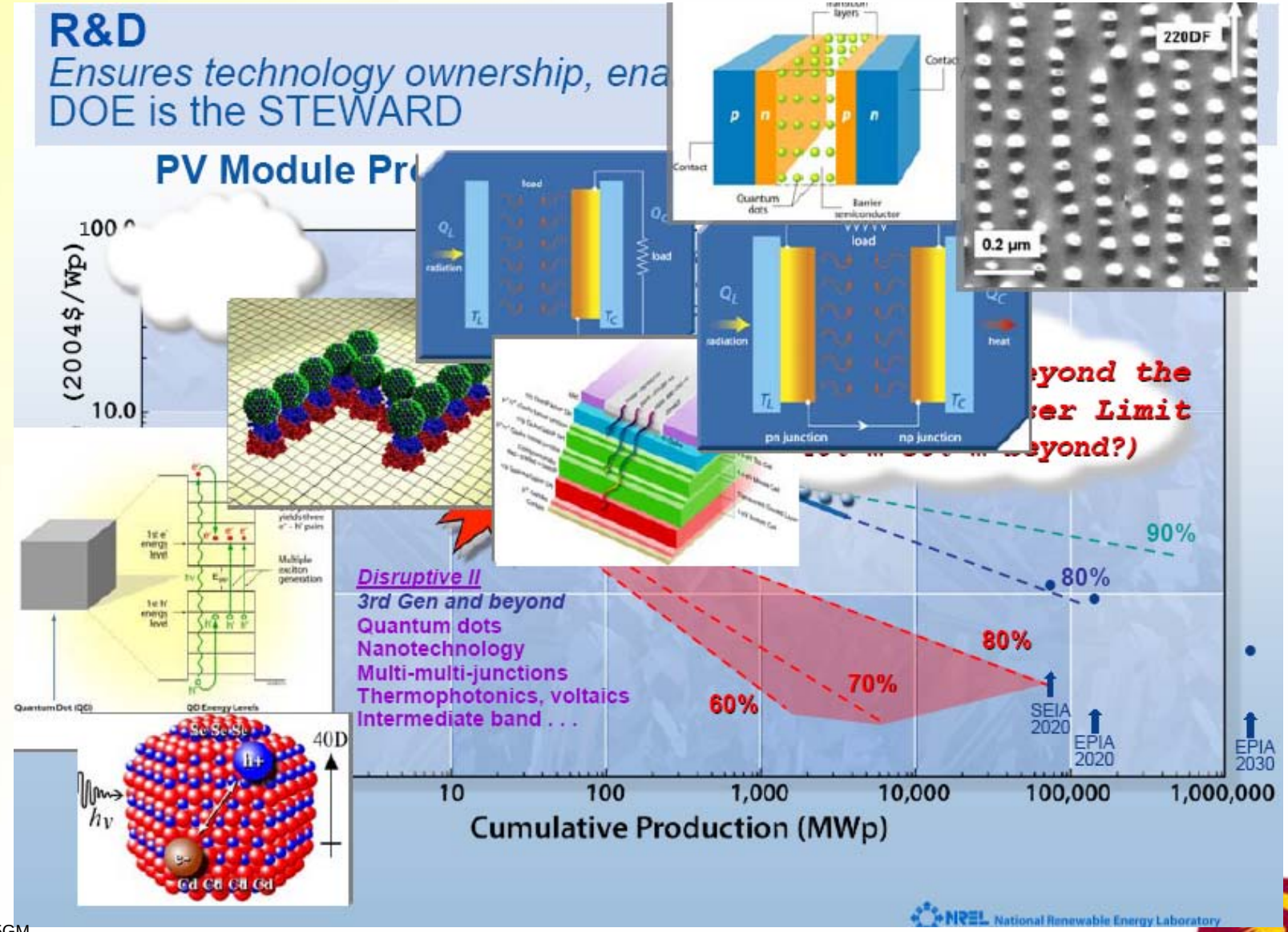


From www.amonix.com

Arizona Public Service photo: Prescott 35 kW, single axis tracking system.

Accurate 2-axis tracker needed

Future Solar Cells will be nano-enabled



Take-Away Thoughts

- Solar is here and its hot!
- Energy Conservation & Renewables is the winning strategy
- The solar energy field is most effectively approached by integrating science, technology, supply chain and Policy under a Sustainability framework
- Wide adoption of Renewable Energy requires public awareness
- The workforce of the future must have this interdisciplinarity without sacrificing depth in the basic sciences.

Thank you