Solar Energy
Technical and Financial Considerations

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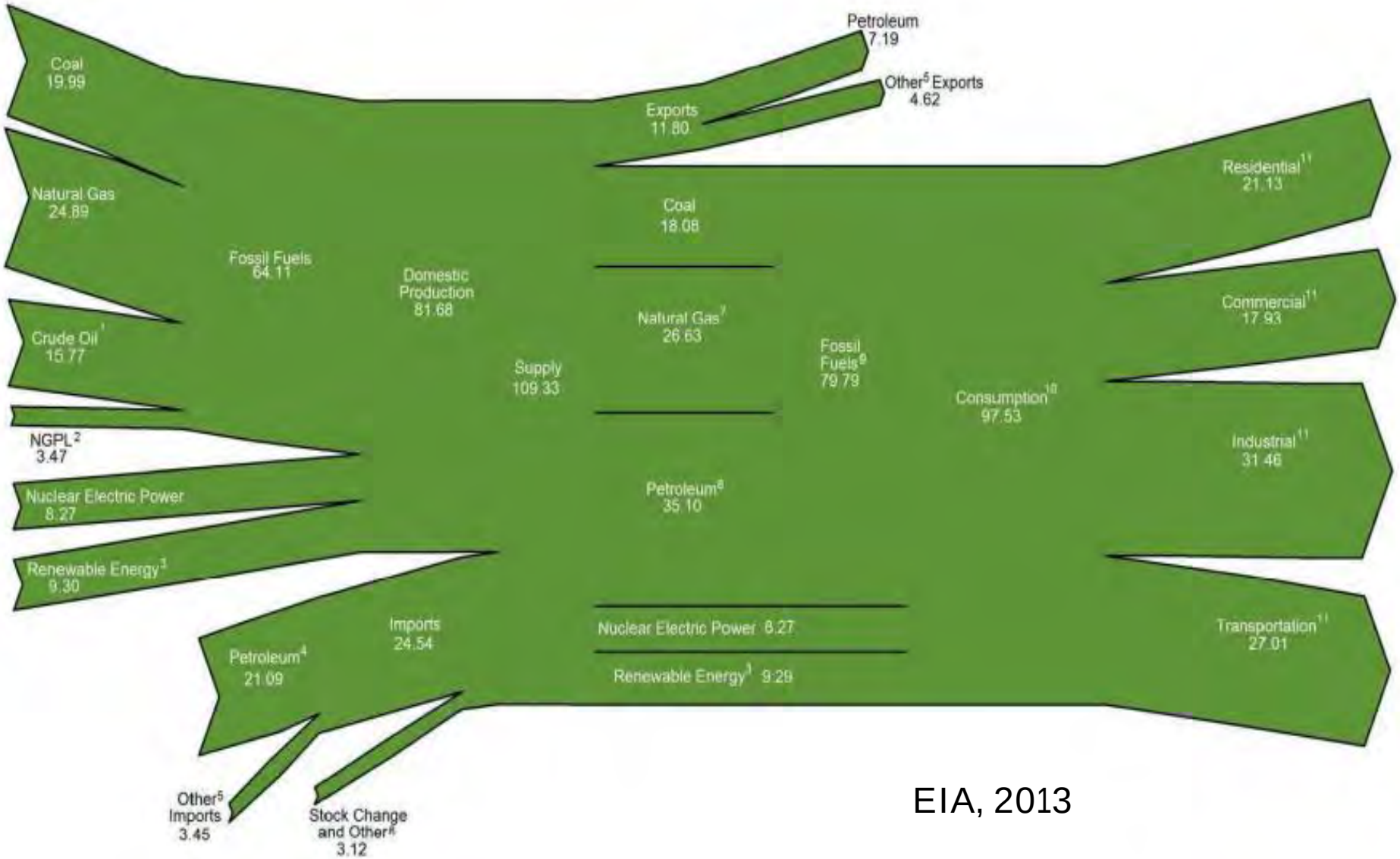
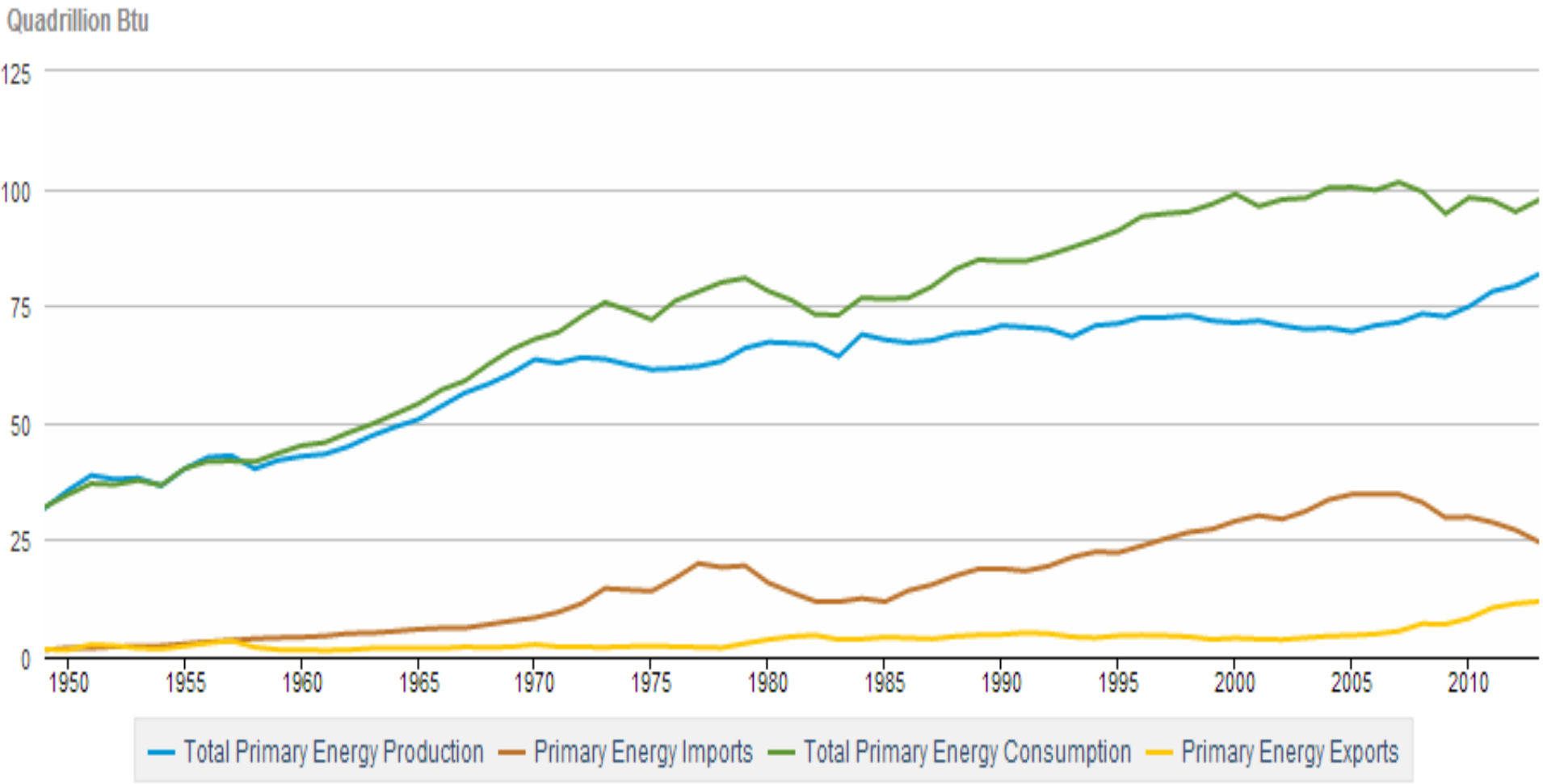
Iowa Strategic Goals Program
Ankeny, IA
April 28, 2015

U.S. Energy Flow, 2013
(Quadrillion Btu)



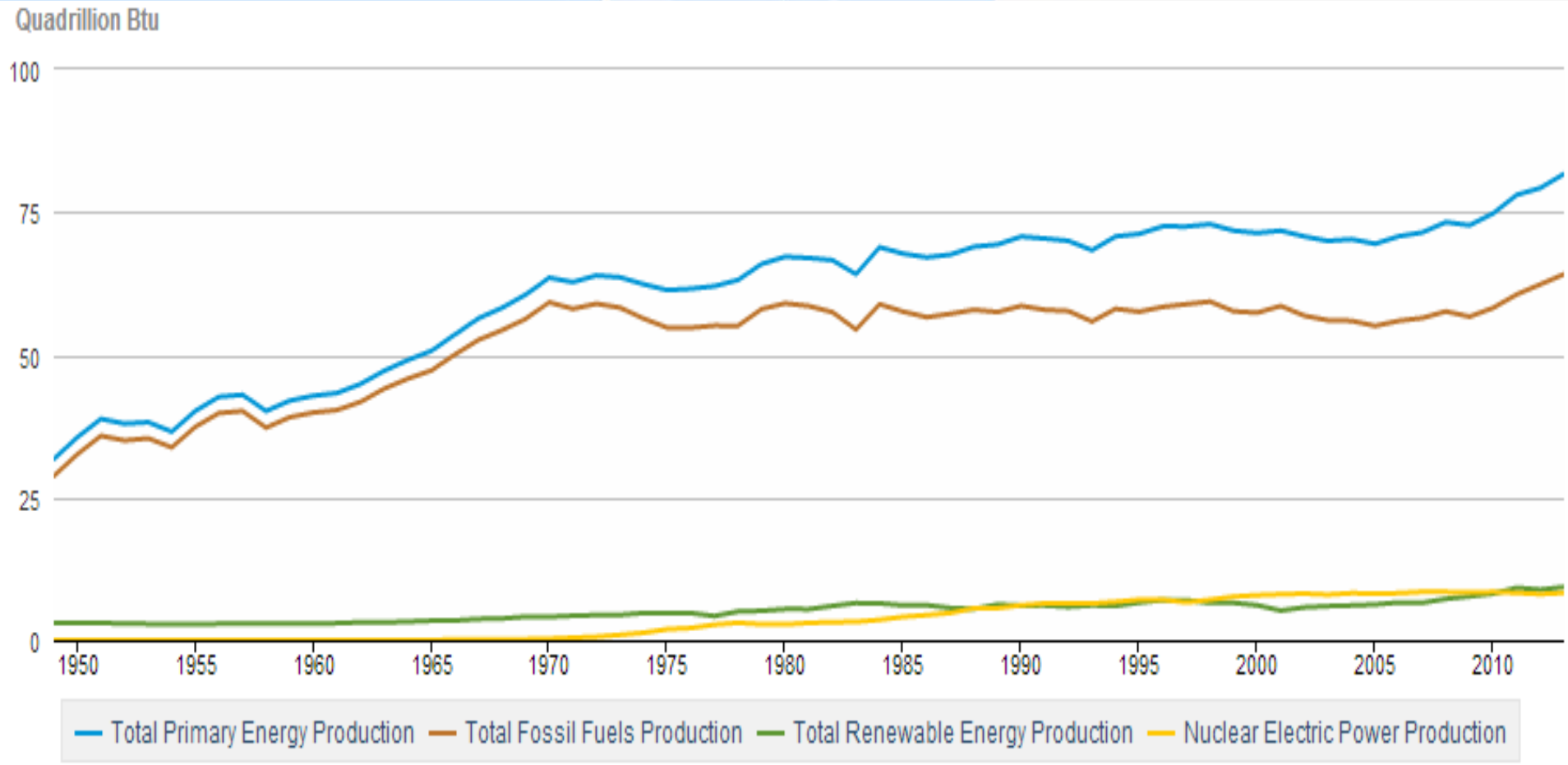
EIA, 2013

U.S. Energy Overview Trend, EIA 2013



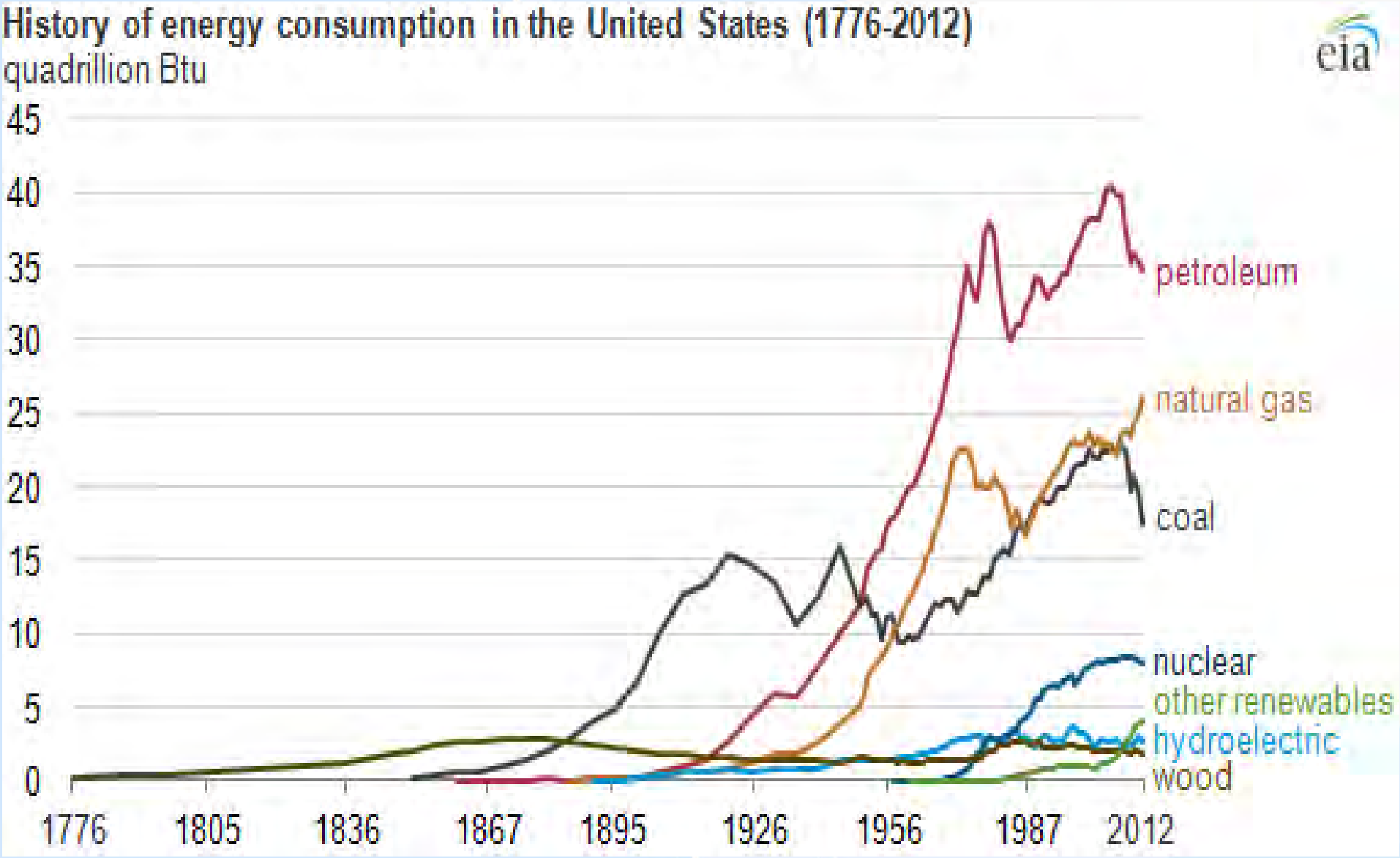
Data source: U.S. Energy Information Administration

U.S. Energy Production Trend, EIA 2013

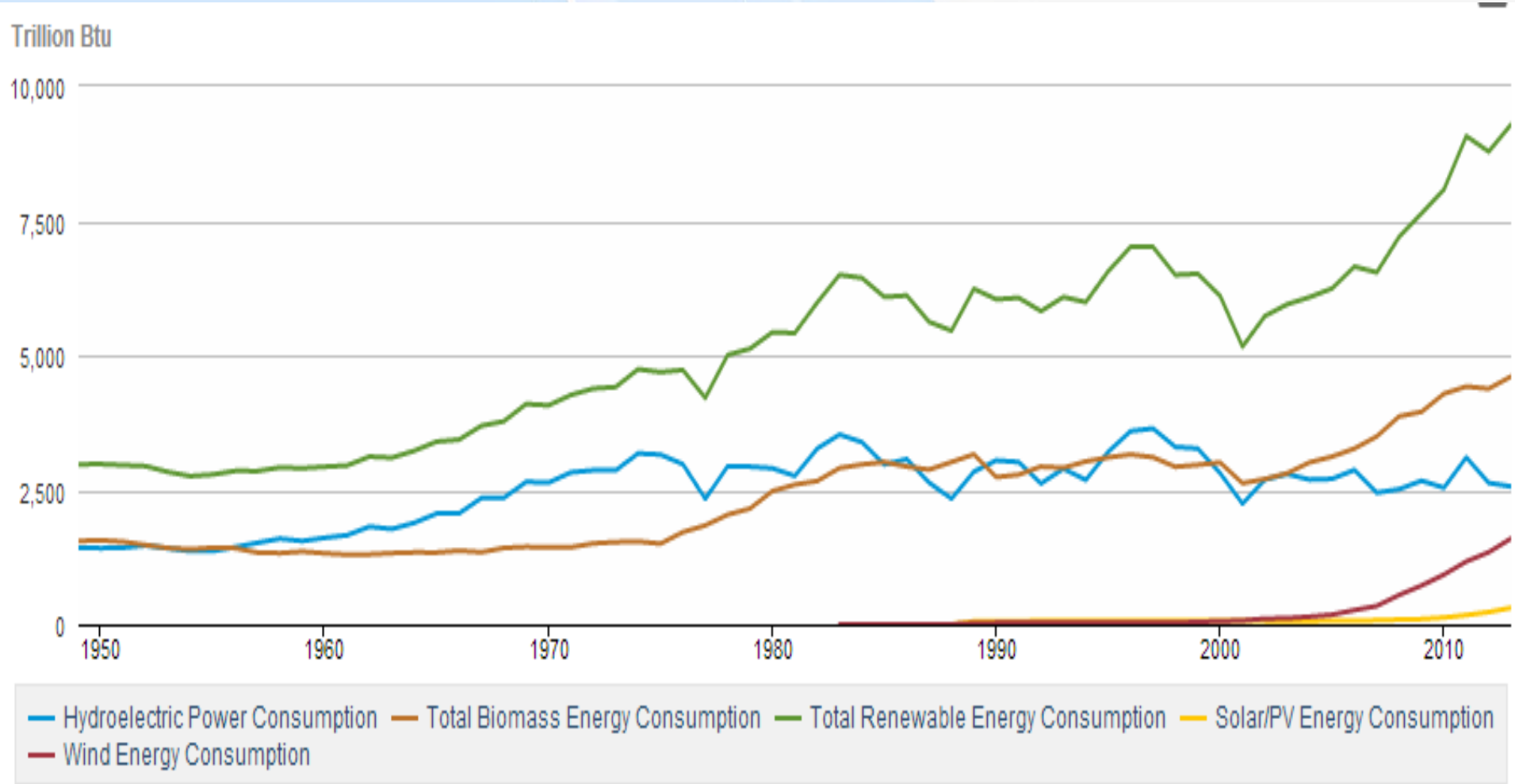


Data source: U.S. Energy Information Administration

U.S. Energy Consumption Trend, EIA 2013



U.S. Renewable Energy Usage, EIA 2013



Data source: U.S. Energy Information Administration

Solar Energy Introduction

- **Three general types of solar energy:**
  - Passive
    - Used for space heating and cooling
  - Active
    - Used for space heating and domestic hot water
  - Photovoltaic
    - Production of electricity from solar radiation

Solar Energy– Why Should We Care?

- **New worldwide solar PV capacity will exceed new wind farm capacity for the first time in 2013 by a 36.7 GW to 35.5 GW margin**
  - In 2012 – wind energy added 46.6 GW vs. 30.5 GW of PV
- **Predicted worldwide total installed capacity growth**
  - Wind energy from 5% in 2012 to 17% in 2030
  - Solar PV from 2% in 2012 to 16% by 2030

Bloomberg New Energy Finance, 9/26/2013

- **U.S. doubled PV generation of 2013 in 2014 (EIA)**
  - 12,303 GWh in 2014 compared to 6,048 GWh in 2013

Challenges/Opportunities for Solar Energy

- **Historically high capital cost ($7- $10 /installed watt)**
- **Recent opportunities**
  - 2009-2013 economic recession has depressed the world market for solar panels
  - World surplus of polycrystalline silicon
  - Record low panel cost (< $1 - $2/watt)
  - Installed cost $3 - $5 per installed watt
  - Numerous U.S. Federal, State, and utility based incentives
- **Market adjustment for imbalance between Supply and Demand**
  - U.S. based Solyndra bankruptcy, August 2011
  - Germany based Q-Cells bankruptcy, April 2012 (Germany's largest)
  - U.S. based Konarka Technologies bankruptcy, June 2012
  - China based Suntech Power Holdings bankruptcy, March 2013
  - Ernst & Young predict that half of solar manufacturers have or will file for bankruptcy

Challenges/Opportunities for Solar Energy

- **General lack of Iowa-specific data**
  - Relatively few solar PV installations; most are not monitored
- **General lack of specialized contractors**
  - North American Board of Certified Energy Practitioners (NABCEP)
    - Nine certified professionals in Iowa
      - (70 certified professionals in WI, 47 certified professionals in MN)
- **Urban based permitting issues**

Photovoltaic (PV) Solar Energy

- **PV is the physical process by which light is converted directly into electrical current when striking a suitable semiconductor device**
- **Specifically:**
  - Photons in sunlight are absorbed by semiconducting materials, such as silicon
  - Electrons are released from their atoms
  - The electrons flow through the semiconductor to producing a direct current (DC) electricity
- **Different semiconducting materials absorb different light wavelengths**
  - Tandem or stacked semiconductors permit a broader range of wavelengths to be absorbed and improved current flow
  - Techniques for "trapping" the light within the device instead of it reflecting out improves current flow

Photovoltaic Tandem Cell

Solar Energy Terminology

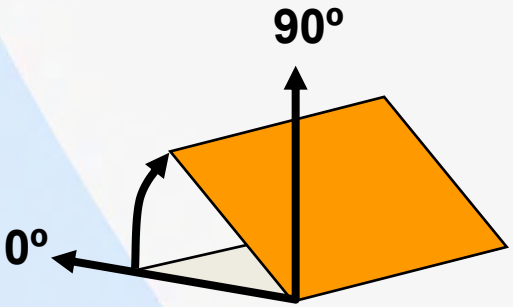
- **Irradiance**
  - the amount of solar power striking a surface
  - measured in watts per sq meter
  - clear sunny day = 1000 watts/sq meter
    - surface at right angle to sun
- **Insolation**
  - the amount of solar energy striking a surface
  - insolation = irradiance x time
  - Typical measurement = kWhr/sq meter/day

Solar Resource

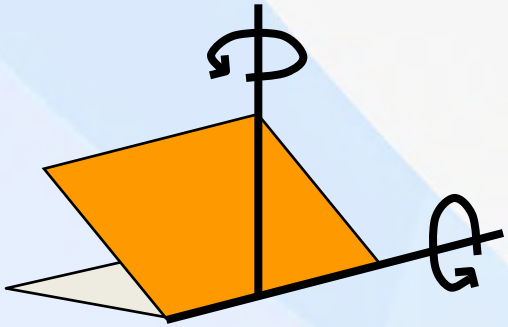
- **Solar Resource is the amount of solar power (irradiation) available in a particular location**
- **Global irradiance is impacted by several factors**
  - Season
    - sun angle
    - length of day
  - Atmospheric contaminants
    - agricultural dust, humidity, smog, volcanic activity, forest fires
  - Clouds
  - Elevation

Solar Thermal & PV Definitions

- **Tilt**
  - the angle between the plane perpendicular to the solar collector surface and the horizon
  - zero degrees tilt corresponds to a horizontal collector surface, and 90 degrees is a vertical surface
- **Tracker**
  - device to automatically optimize the angle of a solar collector relative to the sun
  - single or dual axis (e.g., rotation around a horizontal and/or vertical axis)



Tilt



Tracking

Optimum Tilt Angle – Des Moines, IA

(from vertical / from horizontal)

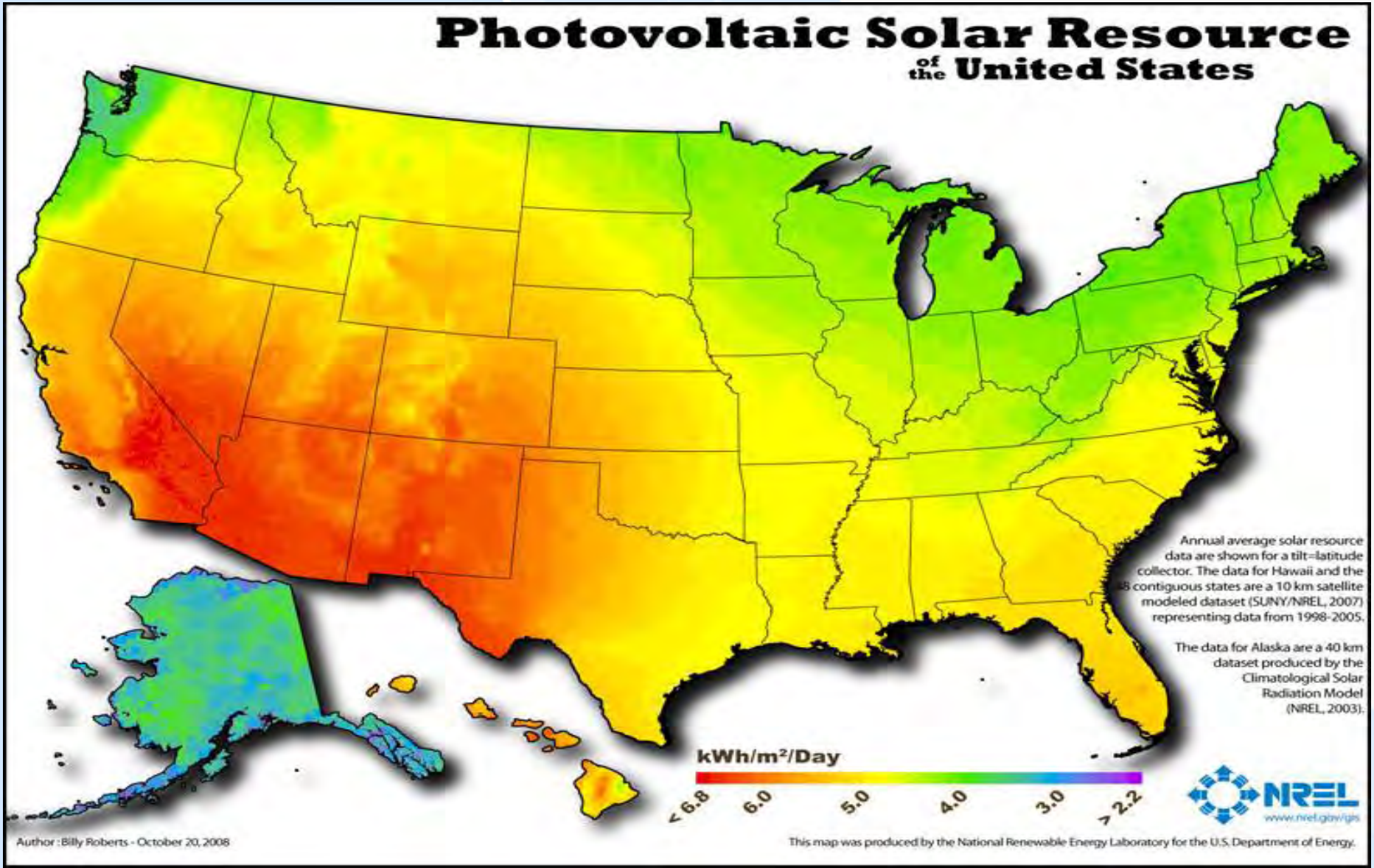
Winter- 24/66º

Fall/Spring- 48/42º

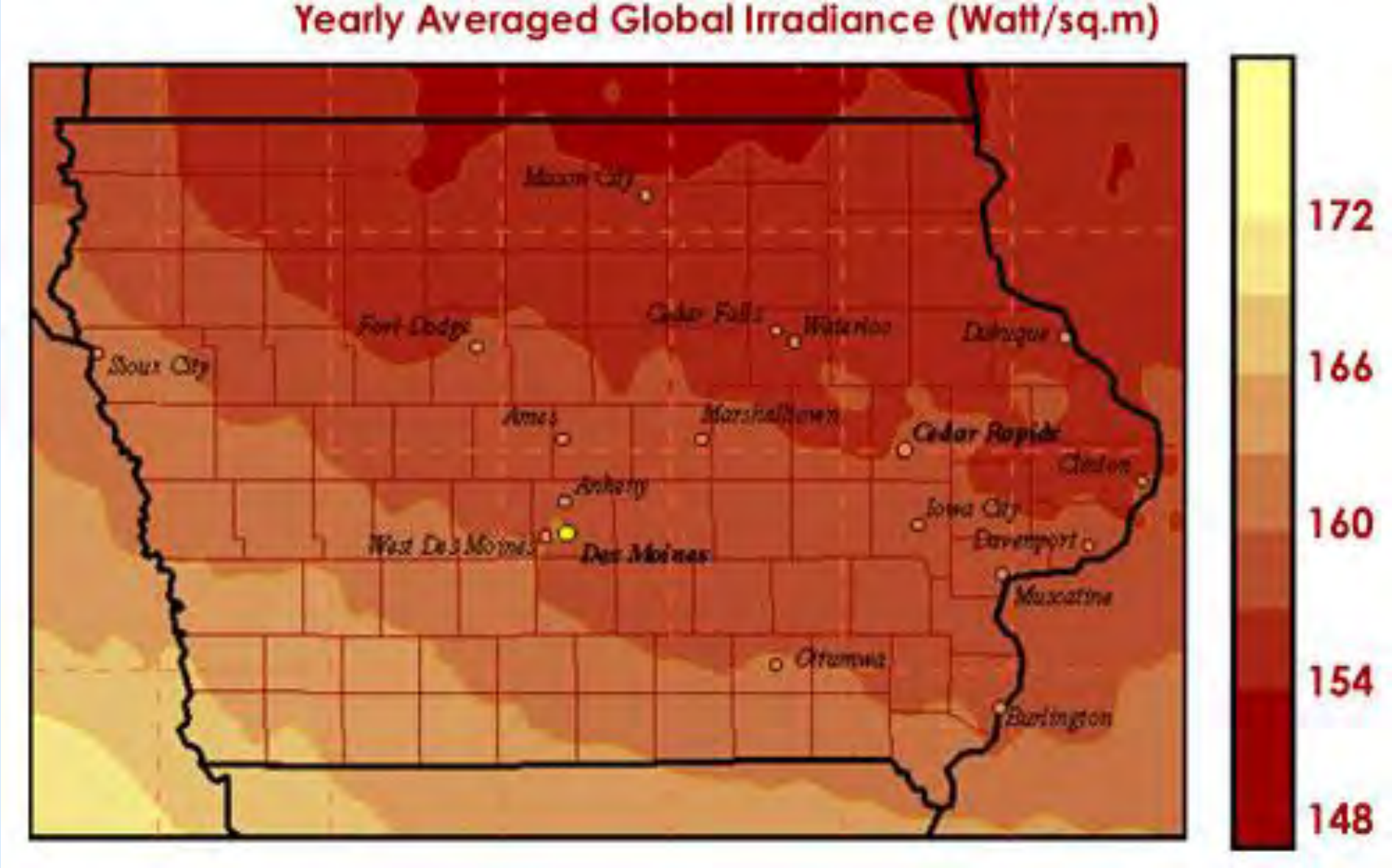
Summer – 72/18º

Jan	Feb	Mar	Apr	May	Jun
32/58°	40/50°	48/42°	56/34°	64/26°	72/18°
Jul	Aug	Sep	Oct	Nov	Dec
64/26°	56/34°	48/42°	40/50°	32/58°	24/66°

U.S. Solar Resource



Iowa's Solar Resource



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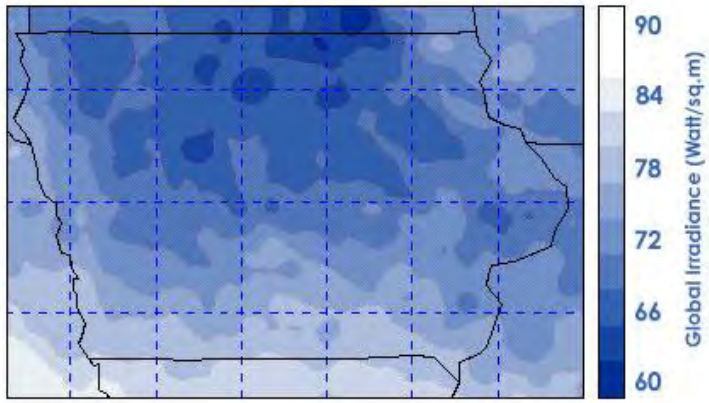
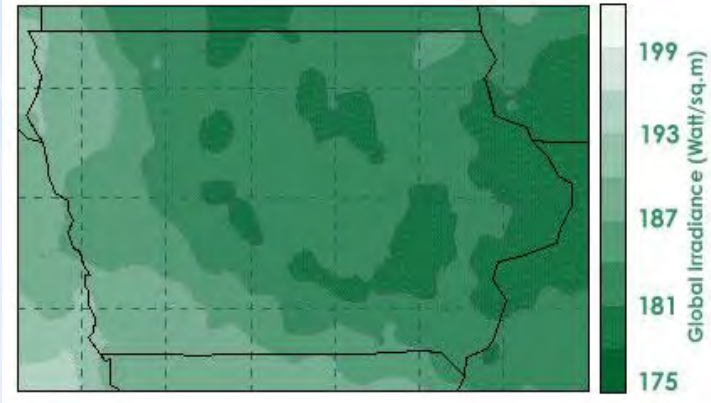
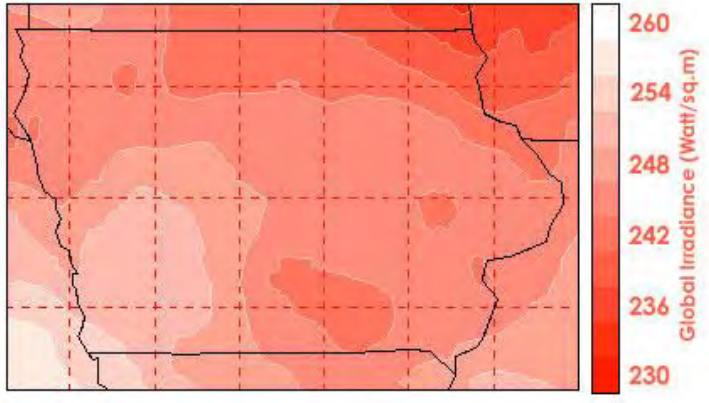


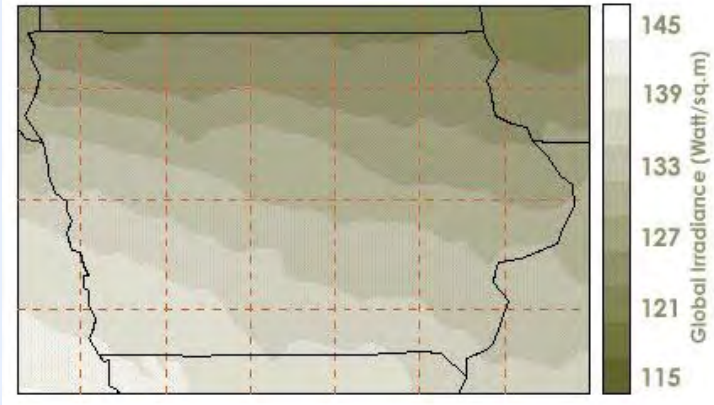
WINTER



SPRING



SUMMER

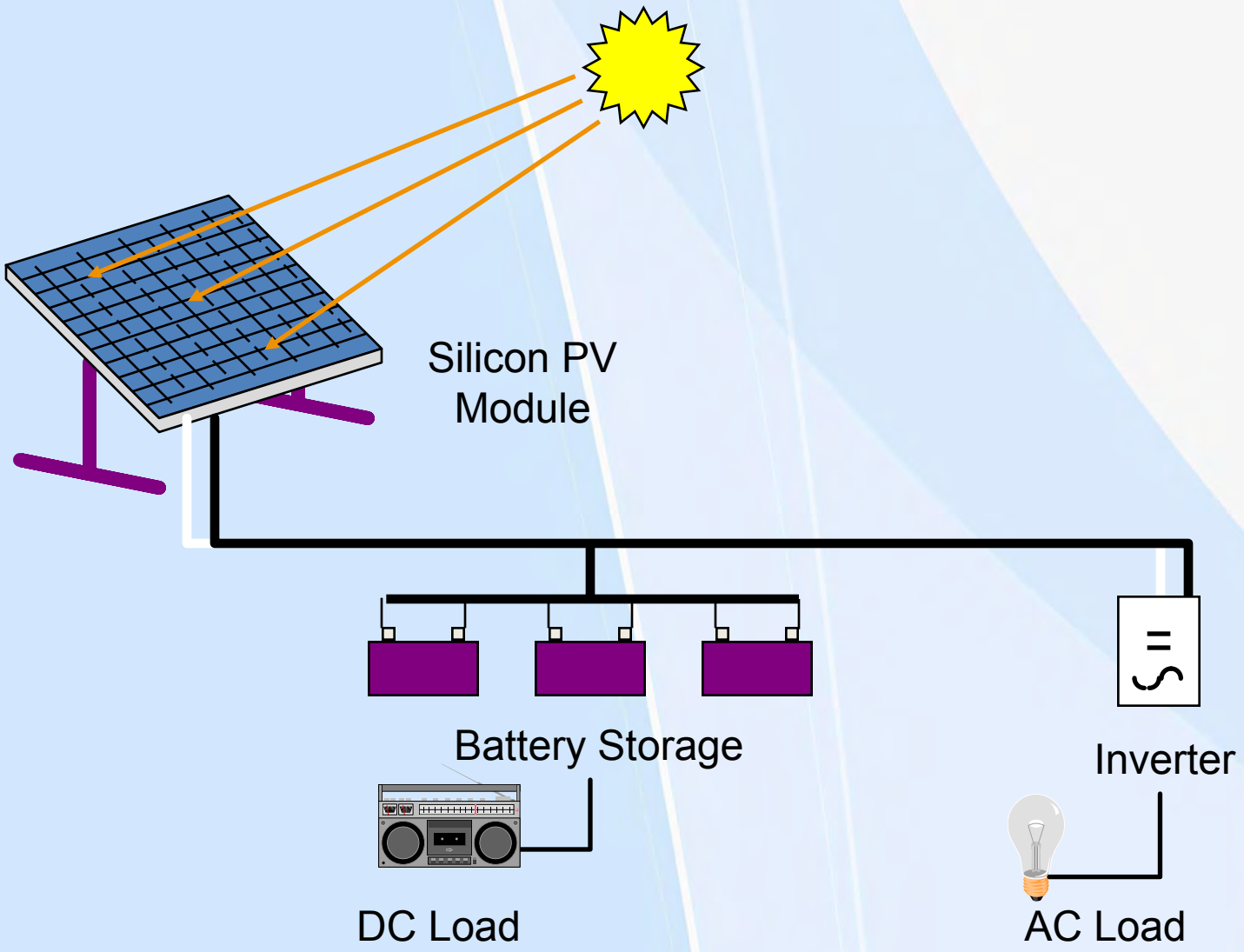


FALL

PV System Components

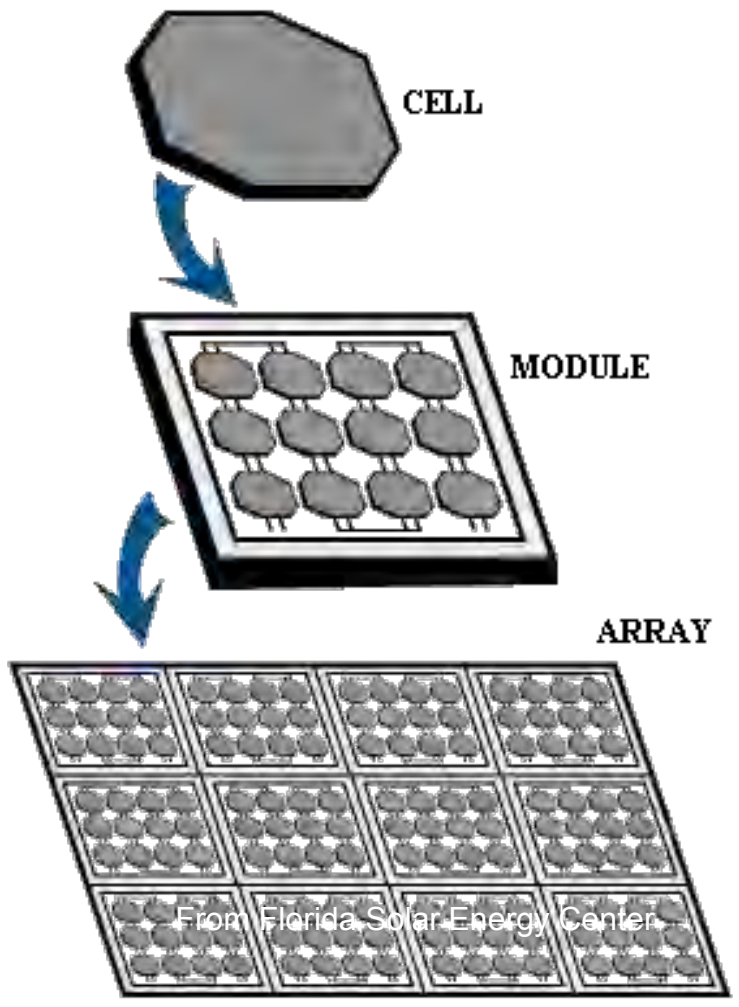
- **Cells, Modules or Arrays**
- **Mounting structures**
  - ground or roof mounted
  - fixed or tracking capabilities
- **Energy conversion**
  - power inverter (dc to ac)
- **Switches, wiring, protective devices**
- **Energy storage devices**
  - battery banks
  - grid connection

Solar Energy: Photovoltaic



Photovoltaic Building Blocks

- **PV cell**
  - basic unit of PV system
  - rated 1-4 watts @ ½ vdc
- **PV module**
  - series of connected cells
  - 10 – 320 watts @ 6 – 36 vdc
- **PV array**
  - series of connected modules
  - up to 600 vdc



Typical PV Modules

Single-crystalline

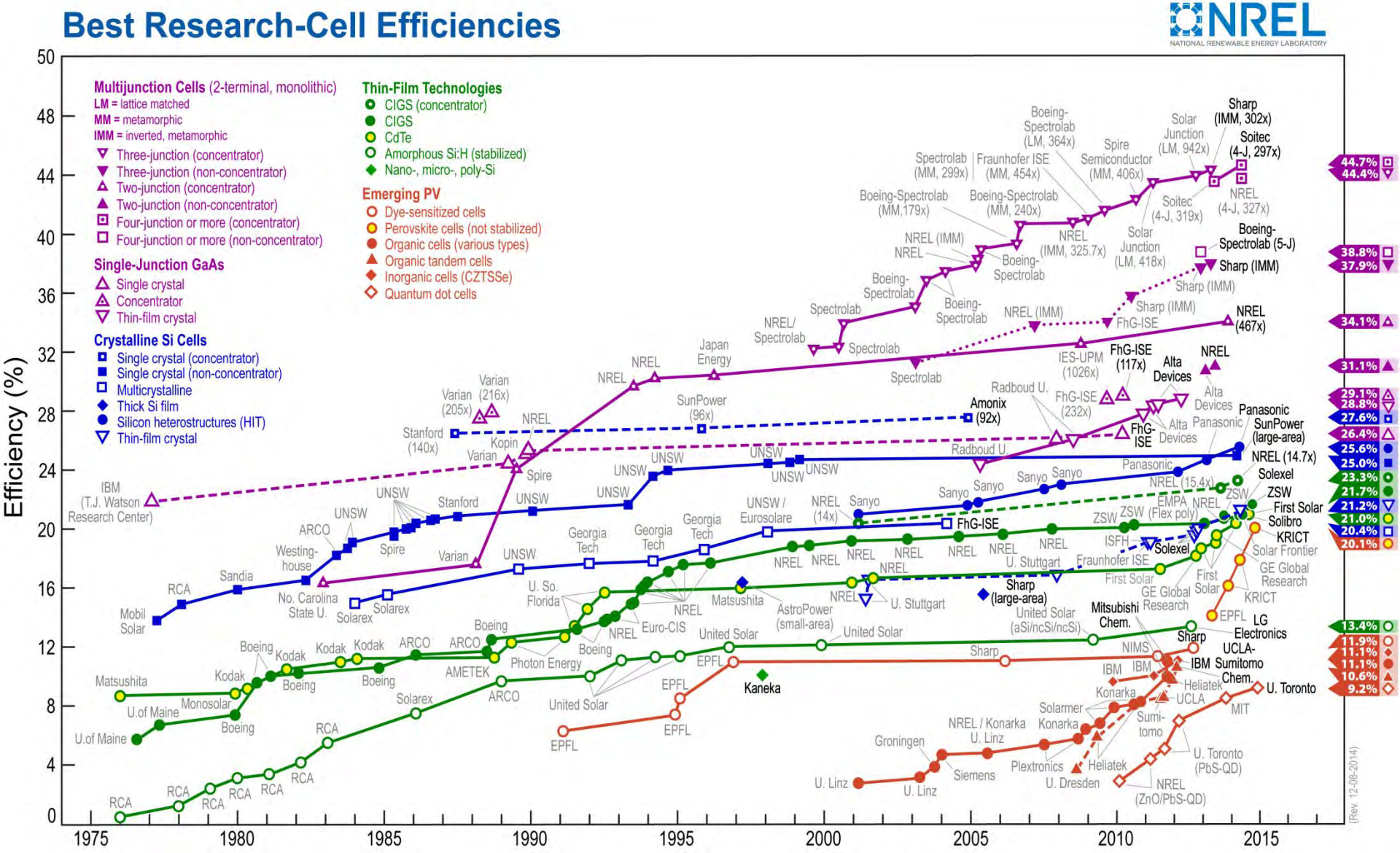
Multi-crystalline

Thin Film Amorphous Silicon

PV Cell Types and Performance

Cell Type	Module Efficiency (%)
Single crystalline silicon	12 – 25%
Multi-crystalline silicon	9 – 20%
Multi-junction hybrids w/concentrators	40 – 44%
Thin Films	
Amorphous silicon	5 – 13%
Copper Indium diSelenide	7.5 – 22%
Cadmium Telluride	7 – 21%

PV Cell Types and Performance



PV Solar Module Hail Damage

July 2014, Paul Rekow

PV Inverters

PV Ground Racking Systems

PV Roof Racking Options

Typical PV System Losses

Type	Loss (%)
Wiring	2%
Module Mismatch	2%
Inverter	4 - 10%
Soiling	4 – 8%
Orientation (tilt & shading)	0 – 15%
Total	12 – 37%

Note: Cell temperatures above 25 C may decrease performance

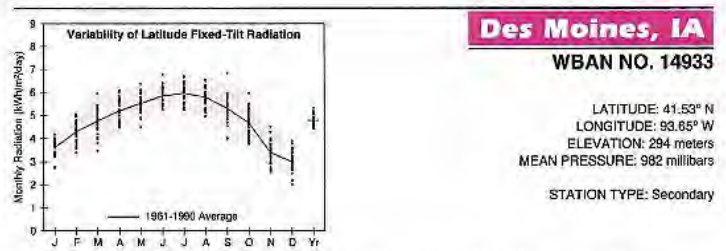
Photovoltaic Energy

- **Advantages**
  - Excellent for remote applications
  - No moving parts
  - Very durable components
  - Flexible sizing of systems
    - Modular expansion can be simple
  - Can be installed on or off a building
  - Commercial systems are well tested**; industry standards exist**

- **Disadvantages**
  - Perceived high cost relative to other renewable systems
  - Significant roof or land areas required for large systems
  - Battery storage required for off-grid systems
    - Batteries are expensive and can be hazardous
  - Can be unsightly
    - Generally will be installed on south or west facing roof
  - Building permits and inspections are likely to be required

PV Design Aid

- **NREL solar radiation data sheets**
- **Data from Weather Bureau Army Navy (WBAN) stations**
  - monthly and annual max, min. and averages of solar radiation (kWh/sq m/day)
  - uncertainty of data (+/- %)
  - flat-plate (fixed or tracking) & concentrating collectors



Des Moines, IA

WBAN NO. 14933

LATITUDE: 41.53° N
LONGITUDE: 93.65° W
ELEVATION: 294 meters
MEAN PRESSURE: 982 millibars

STATION TYPE: Secondary

Solar Radiation for Flat-Plate Collectors Facing South at a Fixed Tilt (kWh/m²/day), Uncertainty ±9%

Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	2.0	2.9	3.8	4.9	5.8	6.5	6.5	5.7	4.4	3.2	2.1	1.7	4.1
	Min/Max	1.7/2.2	2.5/3.2	3.0/4.4	4.3/5.6	4.8/6.7	5.8/7.5	5.8/7.3	4.9/6.3	3.6/5.5	2.8/3.9	1.7/2.4	1.4/2.0	3.9/4.5
Latitude -15	Average	3.2	3.9	4.6	5.3	5.9	6.4	6.5	6.0	5.2	4.4	3.1	2.6	4.8
	Min/Max	2.4/3.6	3.2/4.6	3.4/5.7	4.6/6.2	4.8/6.8	5.7/7.4	5.7/7.3	5.2/6.8	4.0/6.7	3.6/5.5	2.4/4.0	1.9/3.3	4.4/5.3
Latitude	Average	3.6	4.3	4.7	5.2	5.5	5.8	6.0	5.8	5.3	4.7	3.4	3.0	4.8
	Min/Max	2.7/4.2	3.4/5.0	3.5/5.9	4.5/6.1	4.5/6.4	5.3/6.8	5.2/6.7	5.0/6.5	4.0/6.8	3.8/6.0	2.6/4.5	2.0/3.9	4.4/5.3
Latitude +15	Average	3.9	4.4	4.7	4.8	4.9	5.1	5.2	5.3	5.1	4.7	3.6	3.2	4.6
	Min/Max	2.8/4.6	3.5/5.2	3.3/5.9	4.1/5.6	4.0/5.6	4.6/5.8	4.6/5.8	4.5/5.9	3.8/6.6	3.8/6.1	2.6/4.8	2.1/4.3	4.2/5.1
90	Average	3.7	4.0	3.6	3.2	2.8	2.7	2.8	3.2	3.6	3.9	3.2	3.1	3.3
	Min/Max	2.6/4.4	3.0/4.8	2.5/4.5	2.7/3.6	2.4/3.1	2.5/2.9	2.5/3.0	2.8/3.6	2.7/4.7	3.0/5.1	2.4/4.4	1.9/4.2	3.0/3.6

Solar Radiation for 1-Axis Tracking Flat-Plate Collectors with a North-South Axis (kWh/m²/day), Uncertainty ±9%

Axis Tilt (°)		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
0	Average	3.0	4.0	5.1	6.5	7.6	8.6	8.6	7.7	6.2	4.7	2.9	2.4	5.6
	Min/Max	2.2/3.4	3.1/4.8	3.7/6.5	5.4/7.8	6.0/9.1	7.2/10.3	7.3/10.1	6.4/8.8	4.5/8.3	3.7/6.1	2.2/3.9	1.7/3.1	5.2/6.4
Latitude -15	Average	3.8	4.9	5.8	6.9	7.7	8.6	8.7	8.0	6.8	5.5	3.7	3.1	6.1
	Min/Max	2.8/4.5	3.7/5.9	4.1/7.4	5.7/8.3	6.0/9.4	7.2/10.3	7.4/10.2	6.7/9.2	4.9/9.2	4.3/7.2	2.7/5.0	2.0/4.1	5.6/7.0
Latitude	Average	4.2	5.2	5.9	6.8	7.5	8.2	8.4	7.9	6.8	5.8	4.0	3.4	6.2
	Min/Max	3.0/5.0	3.9/6.3	4.1/7.7	5.6/8.3	5.8/9.1	6.9/9.9	7.1/9.9	6.5/9.1	4.8/9.3	4.4/7.6	2.9/5.4	2.2/4.6	5.7/7.1
Latitude +15	Average	4.4	5.3	5.8	6.5	7.1	7.7	7.9	7.5	6.7	5.8	4.1	3.6	6.0
	Min/Max	3.1/5.3	3.9/6.4	4.0/7.6	5.3/7.9	5.5/8.6	6.4/9.3	6.7/9.3	6.2/8.6	4.7/9.1	4.4/7.7	2.9/5.6	2.3/4.9	5.3/6.9

Solar Radiation for 2-Axis Tracking Flat-Plate Collectors (kWh/m²/day), Uncertainty ±9%

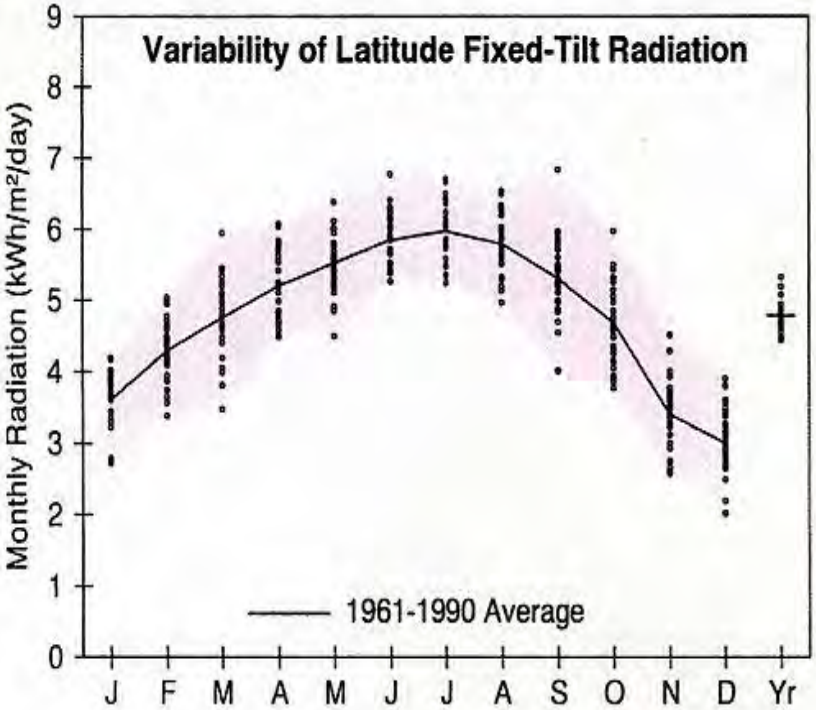
Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
2-Axis	Average	4.5	5.3	5.9	6.9	7.8	8.8	8.9	8.1	6.9	5.8	4.1	3.7	6.4
	Min/Max	3.1/5.3	3.9/6.4	4.1/7.7	5.7/8.4	6.1/9.5	7.3/10.6	7.5/10.4	6.7/9.3	4.9/9.3	4.5/7.7	3.0/5.7	2.3/4.9	5.9/7.3

Direct Beam Solar Radiation for Concentrating Collectors (kWh/m²/day), Uncertainty ±8%

Tracker		Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
1-Axis, E-W Horiz Axis	Average	2.6	2.8	2.8	3.1	3.6	4.2	4.3	3.9	3.4	3.2	2.4	2.1	3.2
	Min/Max	1.4/3.3	1.7/3.8	1.6/4.4	2.2/4.4	2.2/5.0	3.0/5.9	3.2/5.5	2.8/4.8	1.9/5.4	2.3/4.7	1.2/3.6	1.0/3.0	2.7/4.0
1-Axis, N-S Horiz Axis	Average	1.8	2.4	3.1	4.0	4.7	5.6	5.7	5.3	4.1	3.2	1.8	1.4	3.6
	Min/Max	1.0/2.3	1.5/3.4	1.7/4.8	2.9/5.7	3.0/6.6	3.8/7.7	4.2/7.4	3.7/6.4	2.3/6.5	2.2/4.7	0.9/2.8	0.6/2.0	3.1/4.5
1-Axis, N-S Tilt=Latitude	Average	2.8	3.3	3.7	4.3	4.7	5.3	5.5	5.3	4.7	4.1	2.7	2.2	4.0
	Min/Max	1.5/3.5	2.0/4.6	2.1/5.8	3.1/6.0	3.0/6.5	3.6/7.3	4.1/7.1	3.8/6.6	2.6/7.4	2.8/6.0	1.3/4.1	1.0/3.2	3.5/5.1
2-Axis	Average	3.0	3.4	3.7	4.4	4.9	5.7	5.9	5.4	4.7	4.1	2.8	2.4	4.2
	Min/Max	1.6/3.8	2.1/4.7	2.1/5.8	3.2/6.1	3.2/6.8	3.9/7.9	4.3/7.6	3.9/6.8	2.6/7.4	2.9/6.0	1.4/4.3	1.0/3.5	3.6/5.3

Average Climatic Conditions

Element	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Year
Temperature (°C)	-7.0	-4.1	2.9	10.5	16.8	22.1	24.8	23.3	18.4	11.9	3.9	-4.2	9.9
Daily Minimum Temp	-11.8	-9.1	-2.4	4.4	10.8	16.2	19.2	17.6	12.5	5.9	-1.2	-8.8	4.4
Daily Maximum Temp	-2.2	0.9	8.3	16.6	22.8	27.9	30.4	29.0	24.2	17.9	8.9	0.3	15.4
Record Minimum Temp	-31.1	-28.9	-30.0	-12.8	-1.1	3.3	8.3	4.4	-3.3	-10.0	-20.0	-30.0	-31.1
Record Maximum Temp	18.3	22.8	32.8	33.9	36.7	39.4	40.6	42.2	38.3	35.0	24.4	20.6	42.2
HDD, Base 18.3°C	786	627	477	238	92	6	0	6	39	207	433	699	3609
CDD, Base 18.3°C	0	0	0	3	45	189	200	159	41	8	0	0	576
Relative Humidity (%)	71	71	68	63	63	68	68	70	71	67	71	75	68
Wind Speed (m/s)	5.1	5.0	5.5	5.5	4.8	4.4	3.9	3.8	4.1	4.4	4.8	4.5	4.7



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Latitude -15	Average	3.2	3.9	4.6	5.3	5.9	6.4	6.5	6.0	5.2	4.4	3.1	2.6	4.8
	Min/Max	2.4/3.6	3.2/4.6	3.4/5.7	4.6/6.2	4.8/6.8	5.7/7.4	5.7/7.3	5.2/6.8	4.0/6.7	3.6/5.5	2.4/4.0	1.9/3.3	4.4/5.3
Latitude	Average	3.6	4.3	4.7	5.2	5.5	5.8	6.0	5.8	5.3	4.7	3.4	3.0	4.8
	Min/Max	2.7/4.2	3.4/5.0	3.5/5.9	4.5/6.1	4.5/6.4	5.3/6.8	5.2/6.7	5.0/6.5	4.0/6.8	3.8/6.0	2.6/4.5	2.0/3.9	4.4/5.3
Latitude +15	Average	3.9	4.4	4.7	4.8	4.9	5.1	5.2	5.3	5.1	4.7	3.6	3.2	4.6
	Min/Max	2.8/4.6	3.5/5.2	3.3/5.9	4.1/5.6	4.0/5.6	4.6/5.8	4.6/5.8	4.5/5.9	3.8/6.6	3.8/6.1	2.6/4.8	2.1/4.3	4.2/5.1
90	Average	3.7	4.0	3.6	3.2	2.8	2.7	2.8	3.2	3.6	3.9	3.2	3.1	3.3
	Min/Max	2.6/4.4	3.0/4.8	2.5/4.5	2.7/3.6	2.4/3.1	2.5/2.9	2.5/3.0	2.8/3.6	2.7/4.7	3.0/5.1	2.4/4.4	1.9/4.2	3.0/3.6

Simple PV System Sizing Example

- **Assumptions**
  - Location: Des Moines, IA
  - Roof orientation = 0° due south; tilt = 22.5^o (pitch 5 on 12)
  - PV module peak rating : 200 watts
  - System Losses = 15%
  - Daily energy demand = 30 kWh (avg of 900 kWh/month)
- **Look Up**
  - Average annual daily insolation = 4.6 kWh/m^2/day or 4.6 solar hrs.
- **Calculate Module Output**
  - Energy = (4.6 hrs. x 200 watts x 0.85)/1000 W/kW = 0.782 kWh
- **Determine System Array Size**
  - Module Quantity = 30 kWh/0.782 kWh/module = 38.4 modules
  - System Rating = 38 modules x 0.2 kW = 7.6 kW
- **NREL – PVWatts**
  - http://pvwatts.nrel.gov

Know the Real Benefit of Your PV System

- **Set the Stage – Large residential, REC customer**
  - 2014 energy usage = 53,560 kWh
    - Approximately 50% electric heat load during winter
      - Electric heat rate = $0.055/kWh
      - Remainder at $0.137/kWh/first 1200 kWh & $0.095/kWh thereafter
  - 2014 electric bill sum = $2,291.49
- **Installation of 29.7 kW PV array, Feb 2015**
  - Construction cost = $90,900
  - Predicted annual generation = 41,210 kWh
- **The Unknowns**
  - Favored electric heat rate is voided with addition of PV
  - Net metering without banking and monthly settlement
  - $0.05/kWh purchase price of excess generation
- **The Outcome**
  - Mismatch between the energy demand and the solar resource
  - 2014 electric bill sum would have become = $2,550 or an 11% increase with the installed PV array

Solar PV - Wind Hybrid System

Luther College, Decorah, IA

- 280 kW solar PV array
- 1,250 solar modules
- 355,000 kWh/yr
- $1.2 million construction
- 2 acres of land
- August 24, 2012 on-line

Eagle Point
SOLAR
EAGLE POINT 2
Farmers Electric
Cooperative
SUNSTATION

Iowa Energy Center Stationary PV

Iowa Energy Center Tracker PV

Iowa Energy Center Tracker PV

? Questions ?

Iowa Energy Center

www.iowaenergycenter.org

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