Alternative Energy Systems:
Wind, Solar, Geothermal, and more

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Midwest Solar Training Network (MREA)
WAP Training Center, Wright College, Chicago
Global Scientist, Oak Park Education Foundation

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Learning Objectives

At the end of this program, participants will be able to:

1. *Prioritize among the alternatives & recognize how the physics of each translates into the costs & economics of each*
2. *Decide to use a Benchmark assessment to help develop a program*
3. *Make important distinctions between various alternative energy technologies and strategies, and decide on which to pursue*
4. *Refer to successful examples and sources for further learning and/or support*

This Afternoon

PART 1: THE MOST OVERLOOKED FUNDAMENTALS

- Prioritizing the three Big Energy topics in common use
- Alternative Energy is *Efficiency* first, *Sustainable sources* next
- Physics – fundamentals on Energy Efficiency, Wind, Solar, Geo-Thermal
- The Energy Audit: Where any Sustainable Energy upgrade should start

PART 2: FOUR TAKES on FOUR TYPES OF ALTERNATIVE ENERGY

- Combined Heat and Power: Depth on the most promising EE strategy
- Wind: An introduction to Small Wind systems
- Solar PV: A photo album tour of installations
- Geothermal: Some fundamentals and examples

PART 3: KEY INGREDIENTS

- Incentives and Financing - a glossary
- References & Sources for more information

Prioritizing

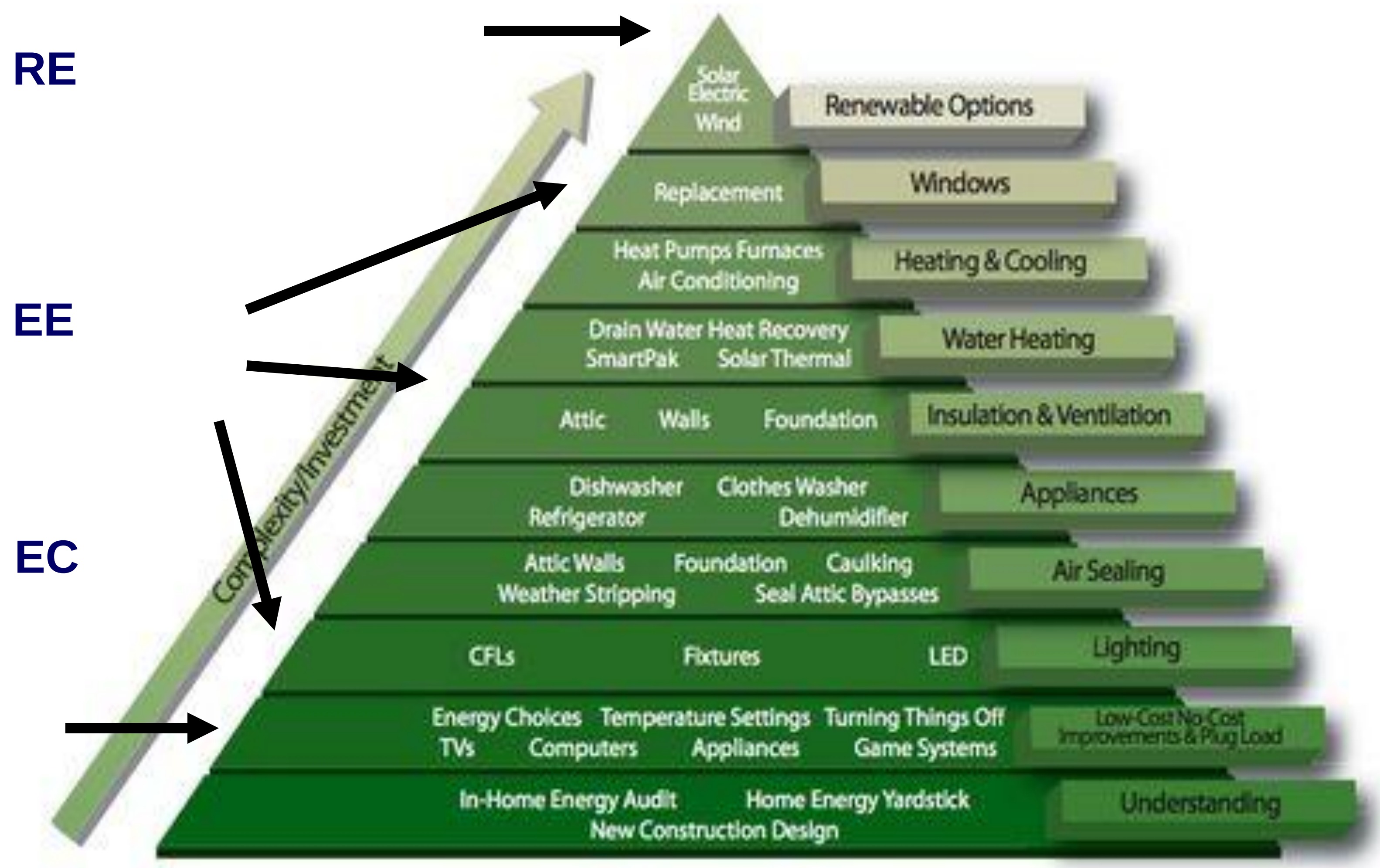
EC / EE / RE

- **Energy Conservation** (**EC**) is behavioral. It is what you do - or don't do - *by either intention or habit* - towards using less energy.

- **Energy Efficiency (EE)** is "built in." *Building in* more efficiency in any building means it is just as comfortable as before taking action, but you enjoy those benefits *while automatically using less energy.*

- **Renewable Energy (RE)** is harvesting energy directly from the sun or the wind or other renewable energy resources.

EC / EE / RE


RE
EE
EC
Complexity/Investment
Solar
Electric
Wind
Renewable Options
Replacement
Windows
Heat Pumps Furnaces
Air Conditioning
Heating & Cooling
Drain Water Heat Recovery
SmartPak
Solar Thermal
Water Heating
Attic
Walls
Foundation
Insulation & Ventilation
Dishwasher
Clothes Washer
Refrigerator
Dehumidifier
Appliances
Attic Walls
Foundation
Caulking
Weather Stripping
Seal Attic Bypasses
Air Sealing
CFLs
Fixtures
LED
Lighting
Energy Choices
Temperature Settings
Turning Things Off
TVs
Computers
Appliances
Game Systems
Low-Cost No-Cost
Improvements & Plug Load
In-Home Energy Audit
Home Energy Yardstick
New Construction Design
Understanding

Review of some fundamentals of Physics

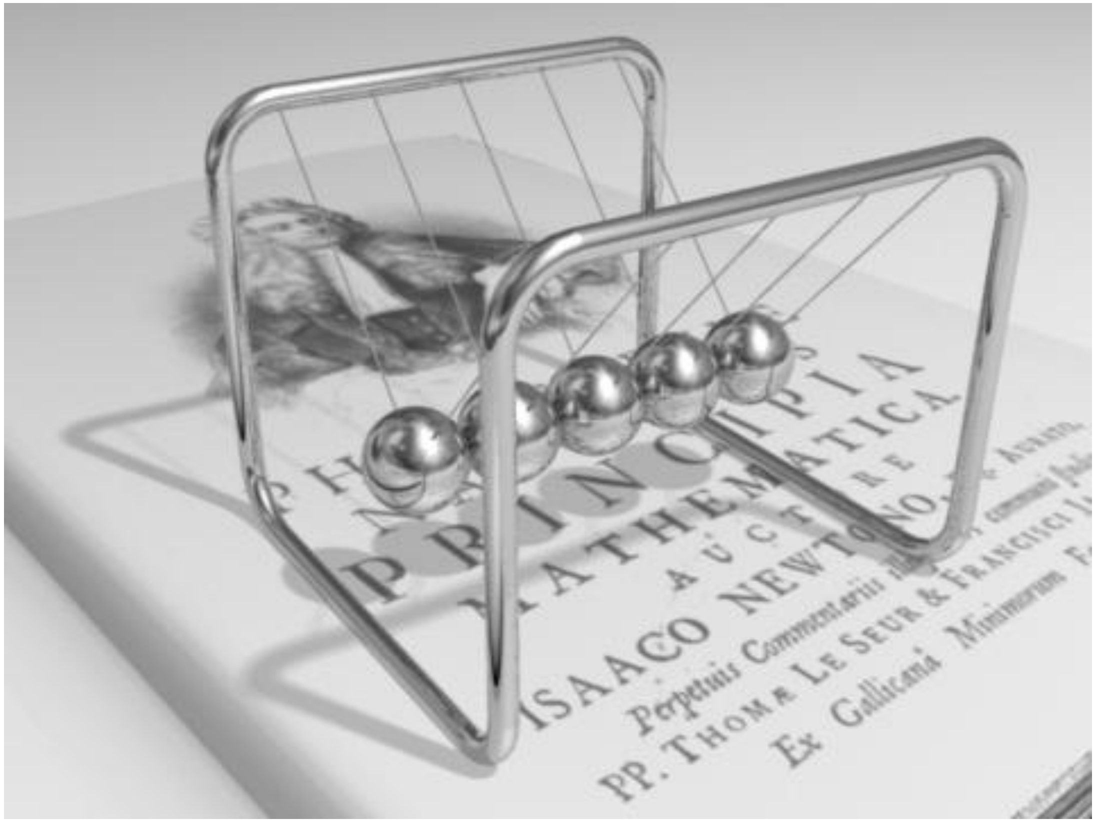
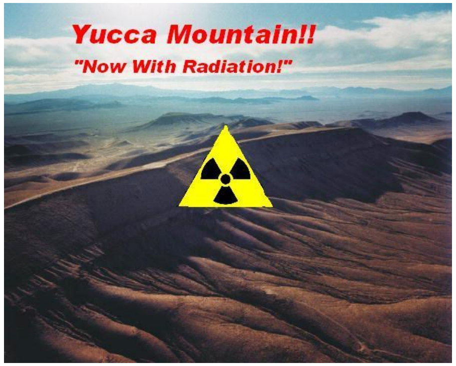


Image source: http://commons.wikimedia.org/

The 1st Law of Thermodynamics

- Energy cannot be created nor destroyed. It can only be changed from one form to another, or moved from one mass or medium to another.
  - *Where does energy come from, ultimately?*
  - *On an ongoing basis, where does our planet get its energy?*
  - *And where does energy disappear to? Where does it go?*
- We convert stored solar energy into heat energy when we burn oil and coal, and we convert Earth's latent radioactive material into heat when we use Uranium!



But the fuels we burn are not "energy"

- The fuels we burn are energy-laden materials.
- These fuels are finite in supply.
- As we use them, we will eventually, totally use them up.
- In addition to storing energy, these materials store other stuff, too.
- As these materials burn, their byproducts become "waste."
- Combustion waste can include:
  - Carbon Dioxide,
  - Sulfur Dioxide,
  - Nitrogen Oxides,
  - Carbon Monoxide,
  - Particulates,
  - Water Vapor, and
  - lots of other stuff –
  - like . . . .

. . . . waste heat!

Besides the familiar waste consequences of conventional fuels, **WASTE HEAT offers to be a very available resource.**

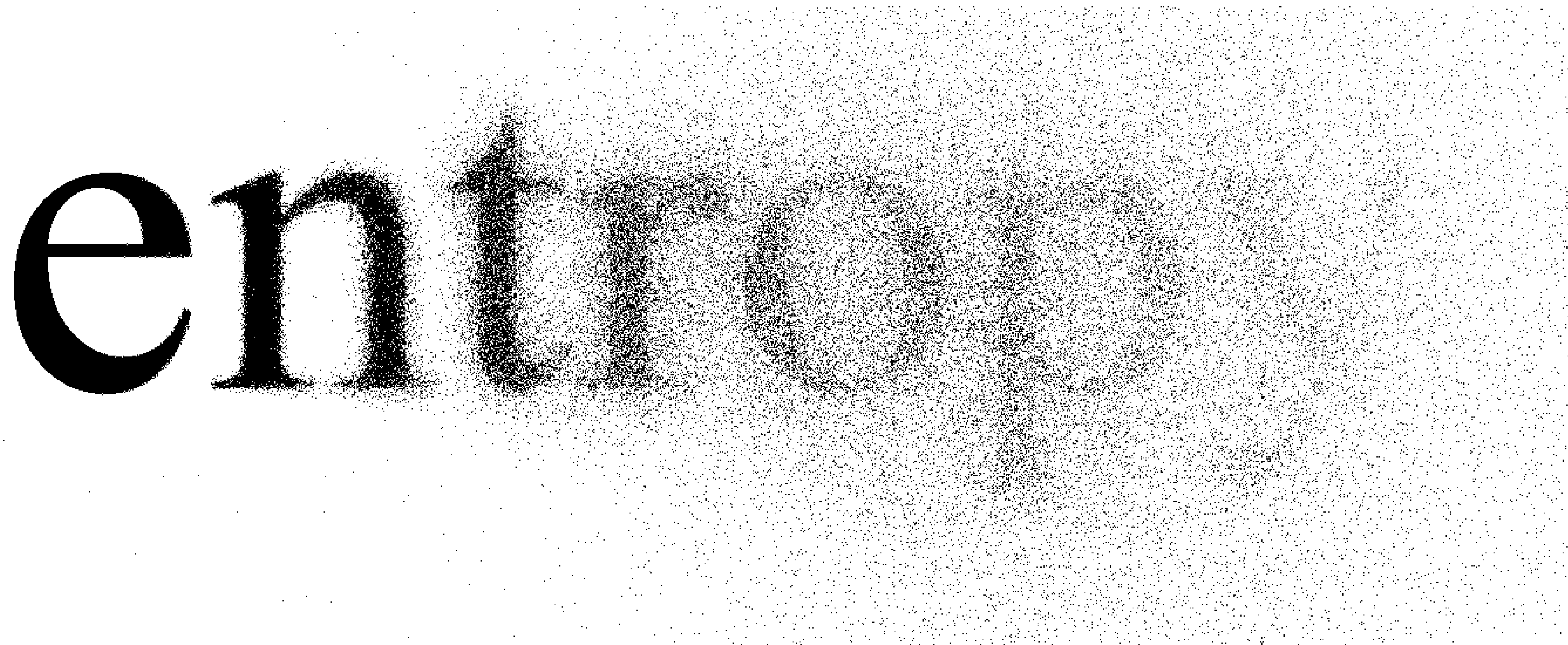
Alternative Energy…

- We don't consume energy.   We CONVERT it!
- *We often, however, consume the MATERIALS*
  - *in which energy is stored.*

- When we consume energy-laden resources, we leave behind "waste" in some form or another.
- *But "Waste" is simply something we don't need or want.*
  - *"**Waste**" is often seen simply as "**pollution**" but finding value in any waste turns waste into a resource.*

- The antidote to the inevitable waste and pollution that use of conventional fossil & nuclear fuels leads to is – use alternatives!
- *Using Alternative Energy Systems and Sources offers solutions.*
  - *"**Alternative Energy**" includes both more efficient use of conventional fuels PLUS using **sustainable** or **renewable** energy systems*

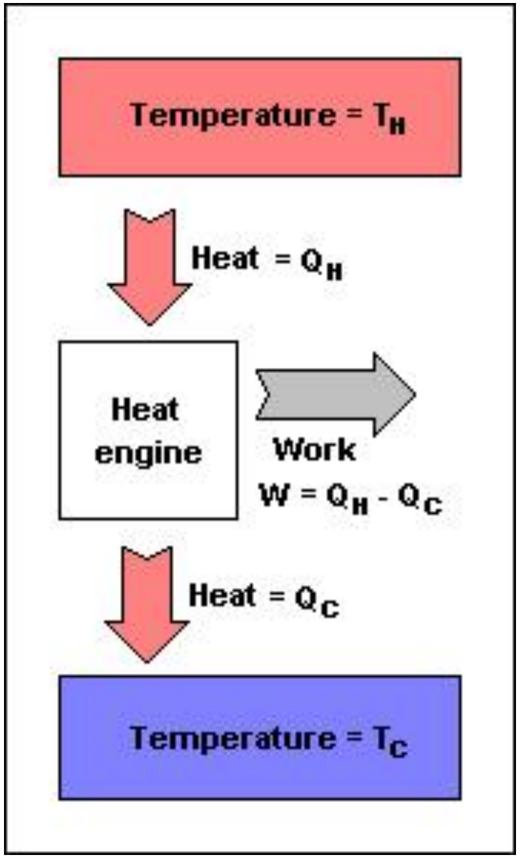
The 2nd Law of Thermodynamics



- The "**lost**" **energy** leaves the energy conversion "**system**" and cannot be recovered by the "**system**."
- The **energy** "**lost**" each time at conversion is known as **entropy**.

Entropy

- The “Carnot” cycle ignores the 2nd Law by not acknowledging waste



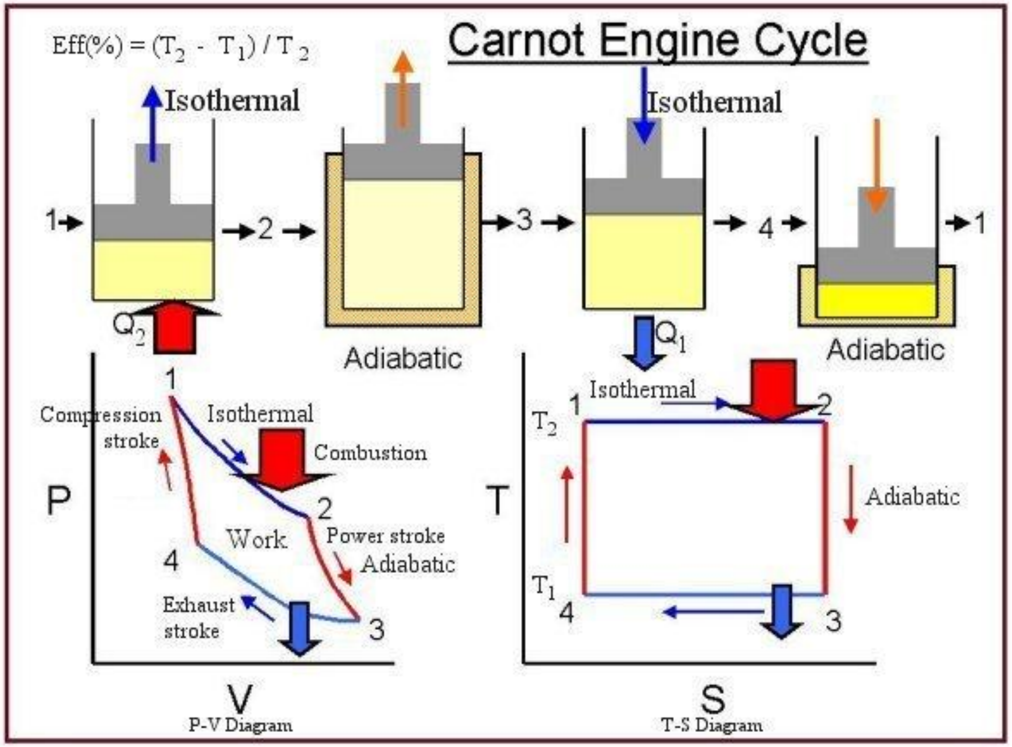
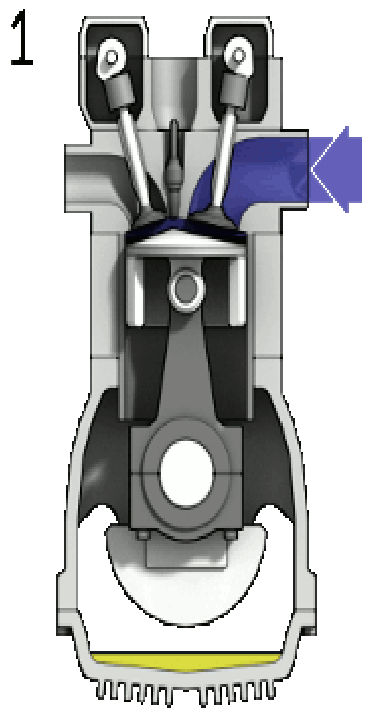


Image source: Wikipedia

Entropy - Heat Engines

- The "Otto" cycle 4 stroke engine (**your Diesel back-up generator!**) obeys the 2^{nd} Law by generating heat, then "losing" it as waste heat.



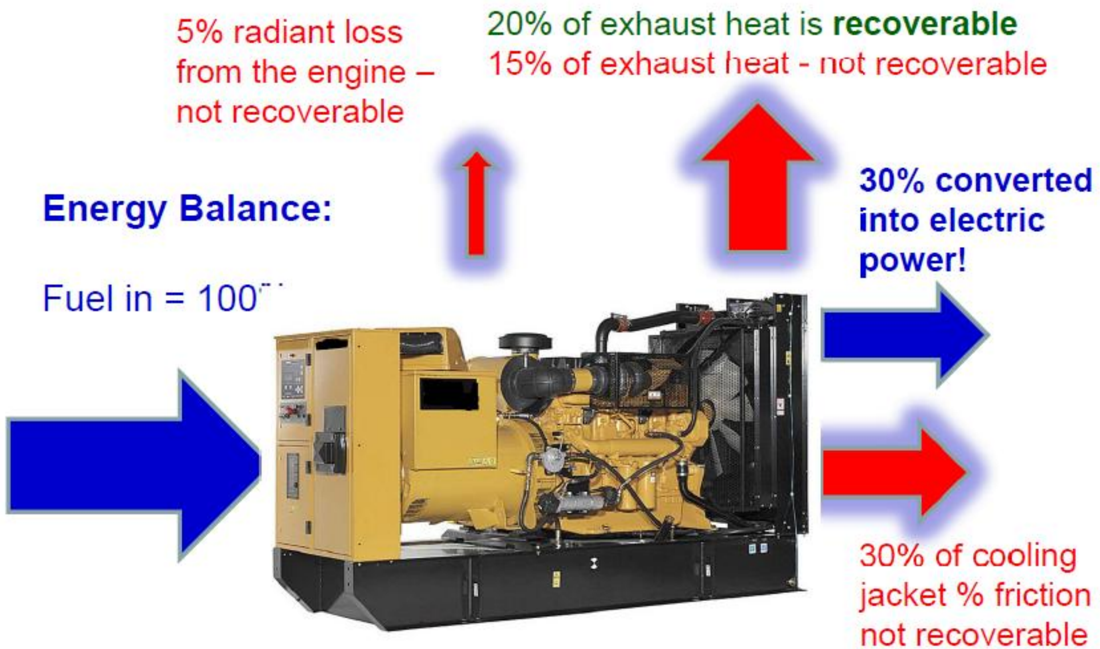


Image sources: Wikipedia, author Gill, http://www.eng.warwick.ac.uk/OEL/courses/engine/ic018.htm

Energy Efficiency

- Energy conversion efficiency is not defined only one way – and instead depends on what is "useful" for people versus what we have "available" to put into an "energy conversion machine."

$$E_{HP} = \frac{|Q_H|}{|W|}$$

Thermal efficiency is usually a dimensionless performance measure of a thermal device. Examples: A boiler, a furnace.

Since "useful" work is a human valued thing, and we need to furnish fuel to the system, you could say:

$$\eta_{th} \equiv \frac{\text{What you get}}{\text{What you pay for}}.$$

Equation Images from Wikipedia commons

General points on the 1st & 2nd Laws & Energy Efficiency

- Virtually all energy ultimately comes from the Earth and sky!

- Energy conversion always follows a path of least resistance, from higher potential to lower potential, until there is equilibrium between "before" and "after."

- No energy conversion is 100% efficient.

- The more conversions or transformations made between source and point of use, the less efficient the system.

- Local conversion – for example: Collected on site! – is typically more energy efficient than remote, centralized conversion due to conversion & transmission losses.

Some Wind Energy Physics

Image source; John Harris - Radley College – UK - http://atschool.eduweb.co.uk/radgeog/

Power in the Wind: The Power Equation

Wind is obviously powerful, or at least it can be very powerful.

Some of that power can be captured to generate energy.

- Key equation to understand the power available from the wind is . . .
  The wind turbine power equation:

$$\mathbf{P = \tfrac{1}{2}\,\rho\, v^3\, A\, C_P}$$

P = Power (Watts)

ρ = Density of Air (kg/m^3)

V = Wind Velocity (meters / second)

A = "Swept" Area (m^2)

C_P = Maximum power coefficient

C_P ranges from 0.25 to 0.45 with theoretical maximum = 0.59 (unit-less)

- **Example:** A 2.5 m diameter turbine with a 25% efficient rotor in 8.0 m/s wind will have _______ watts power available to generate electricity.

$$P = \tfrac{1}{2} \times (1.0\ kg/m^3) \times (8.0\ m/s)^3 \times [\pi\ (2.5\ m/2)^2] \times (0.35)$$

= 440 Watts

Power in the Wind: The Power Equation

FACT: The wind has relatively low "Power Density" when compared to other energy resources.

FACT: The big challenge in harvesting wind energy is maximizing harvestable power from the power available.

- Key ideas to understand about the Wind Power Equation:

$$P = \tfrac{1}{2}\, \rho\, v^3\, A\, C_P$$

P = Power

ρ = Density of Air

V = Wind Velocity

A = "Swept" Area

C_P = Power Co-efficient

Denser air increases Power

Higher air velocity increases Power

A larger swept area increases Power

Higher overall machine efficiency increases Power

Power in the Wind: The Power Equation

Of course, only some of these factors can be readily controlled, while others rely on not so controllable factors like careful site selection.

Generally:

1) The air *cannot be made denser (yet there are strategies!)*;
2) Choosing a good site is essential for finding higher air velocity;
3) Blades and turbines can be made with larger swept areas, and;
4) Manufacturers can seek to "design-in" higher overall efficiency

In the context of installing small wind turbines in urbanized areas:

2) Finding or reaching higher air velocity - *can be challenging;*

3) Building larger turbines with larger swept area is possible - *to a point;*

4) Building equipment with higher mechanical efficiency is theoretically feasible - *but hundreds of millions of dollars have already been invested in R&D on this, and even more will be, but this factor has a theoretical maximum of 0.59! This is the Betz Limit!*

Power in the Wind

- A very controllable parameter is a wind turbine rotor's ***swept area.***

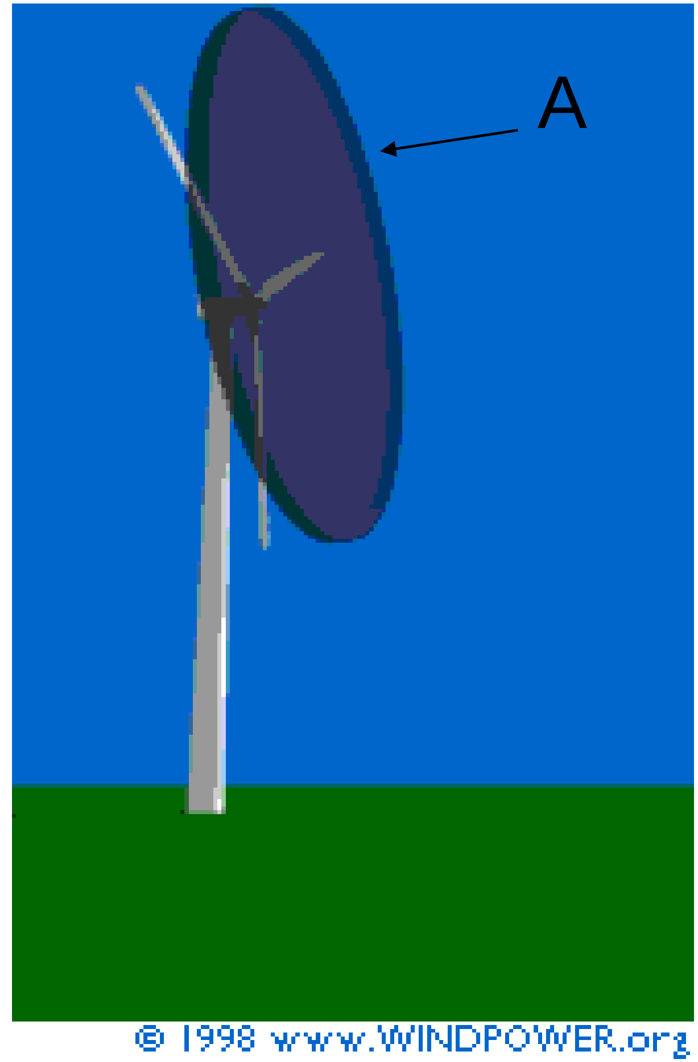
- For horizontal axis wind turbines, ***swept area*** is equal to a circle, and we know that

$$\mathbf{A_{circle} = (Radius)^2 \times \pi}$$

- Since the Radius is squared, **Doubling** the Radius increases the power available by a factor of **Four**!

$$\textit{Swept area} = (2 \times R)^2 \times \pi$$

$$\textit{Swept area} = 4 \times (R)^2 \times \pi$$



Power in the Wind

- Increasing **Wind Speed** also offers more power, since:

Power ~ V^3

- Since the **Wind Speed** is cubed, **Doubling** the **Wind Speed** increases the power available by a factor of **Eight**!

Power ~ $(2V)^3$

Power ~ $8 \times (V)^3$

- **Example:** A turbine once placed in an average **10 mph** wind is raised to a height with an average wind speed of **12 mph.** How much more power is available in the higher average wind speed?

$$P_{(increase)} = \frac{12^3 - 10^3}{10^3} = \frac{1,728 - 1,000}{1,000} = 0.728 =$$ **73% Increase!**

Image courtesy of: www.capecodwindandweather.com

Wind Speed

- Laminar versus Turbulent Flow is among the most important factors in the physics of wind energy.

- Surface Friction causes Laminar Flow to change to Turbulent Flow.

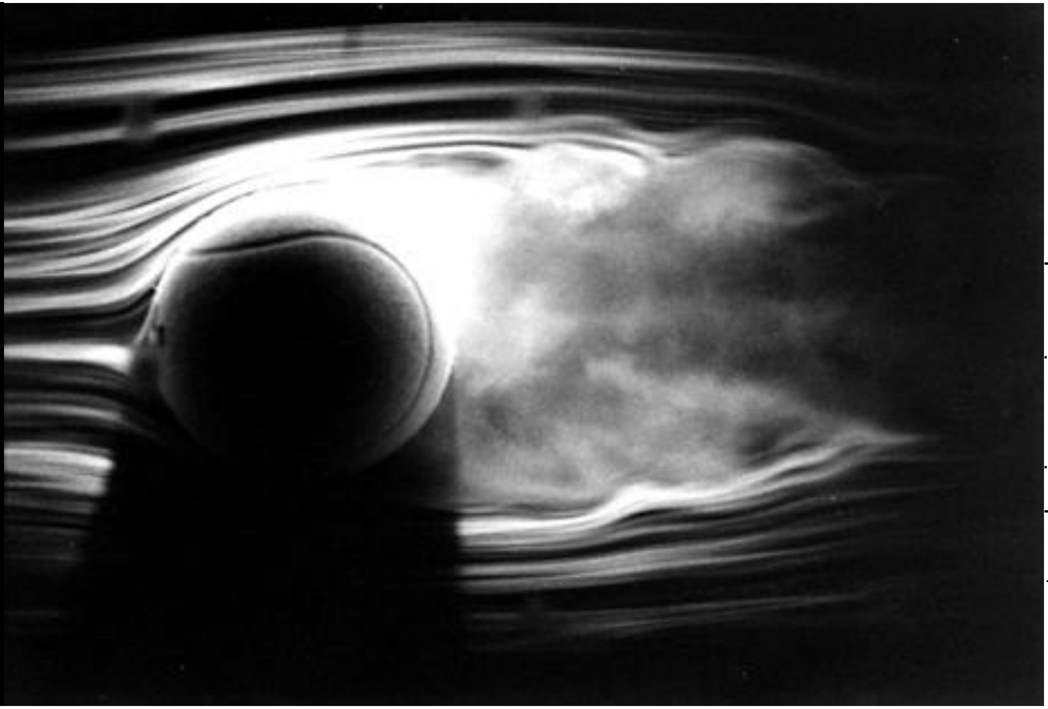


Image courtesy: boojum.as.arizona.edu

Wind Speed

- Laminar versus Turbulent Flow is among the most important factors in the physics of wind energy.

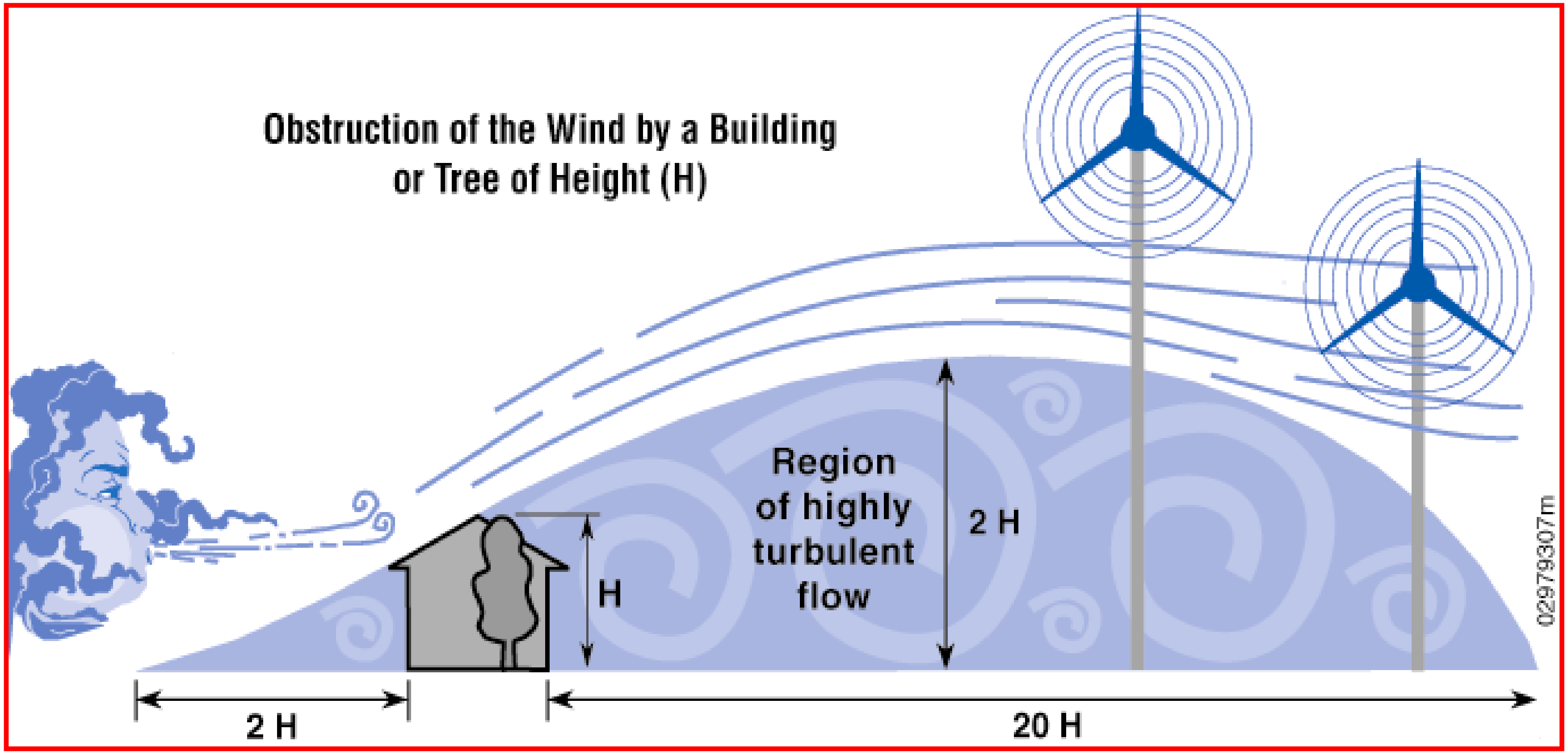
- From the wind's perspective, hills, trees, buildings and . . . .

  Wind Turbines cause surface friction.

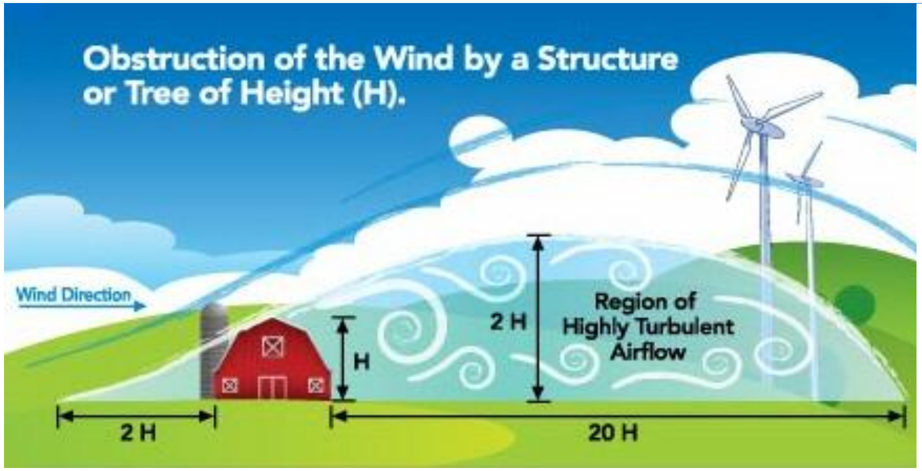
http://cires.colorado.edu/news/archives/2009/pichuginaTurbulence.html

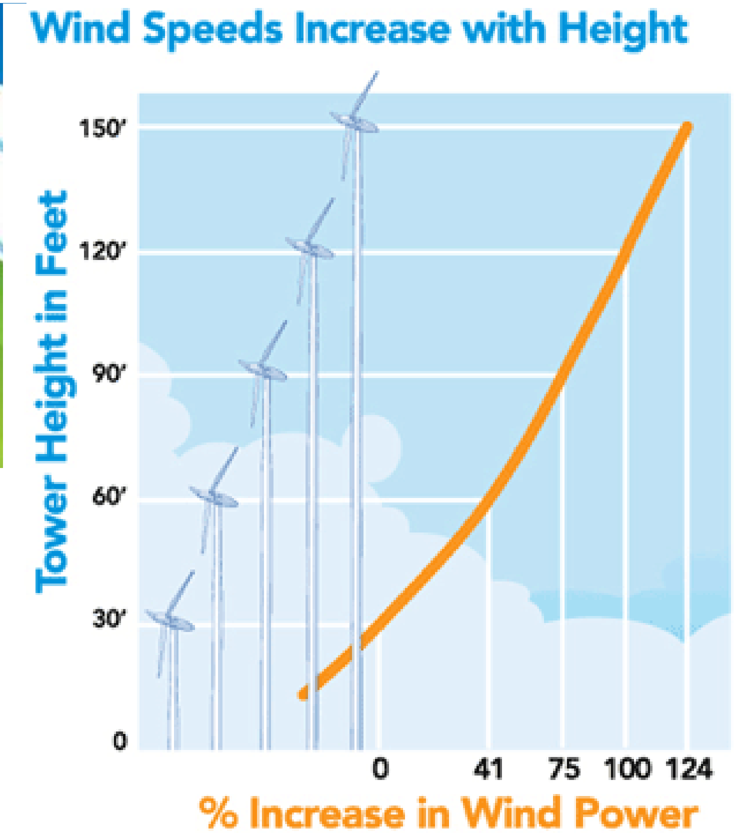
The turbines' wake effect is clearly seen at the Horns Rev offshore wind farm in the North Sea west of Denmark.

Wind Speed: Surface Friction



Wind Speed: Surface Friction





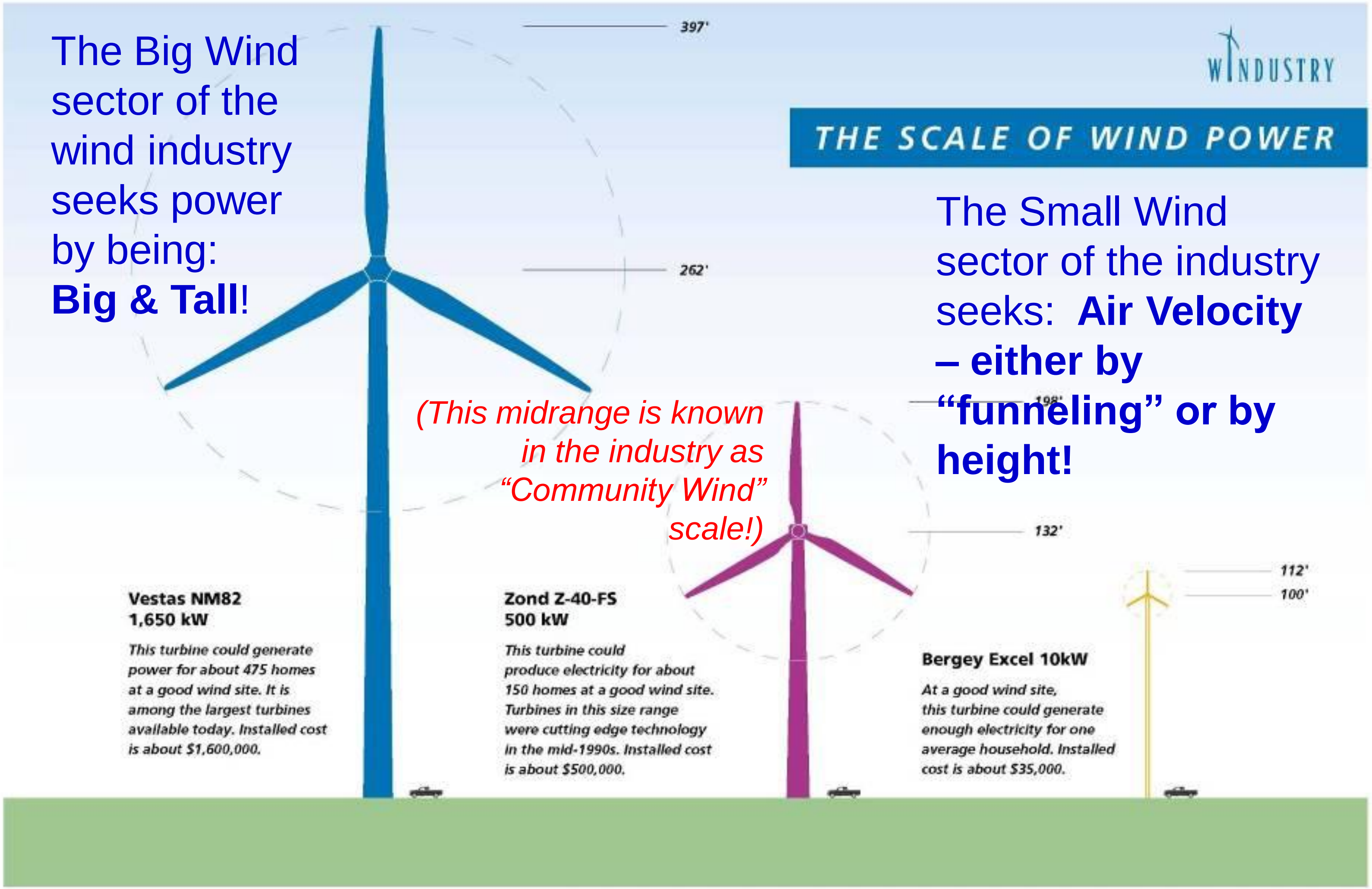
Best = at least 30' above wind obstacles

Great locations?
- Wide open spaces
- Shorelines or off-shore
- Crests of hills
- Above buildings

Taller is better!

Big Wind versus Small Wind

The Big Wind sector of the wind industry seeks power by being: **Big & Tall**!



(This midrange is known in the industry as "Community Wind" scale!)

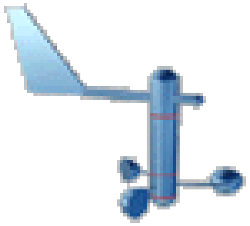
The Small Wind sector of the industry seeks: **Air Velocity – either by "funneling" or by height!**

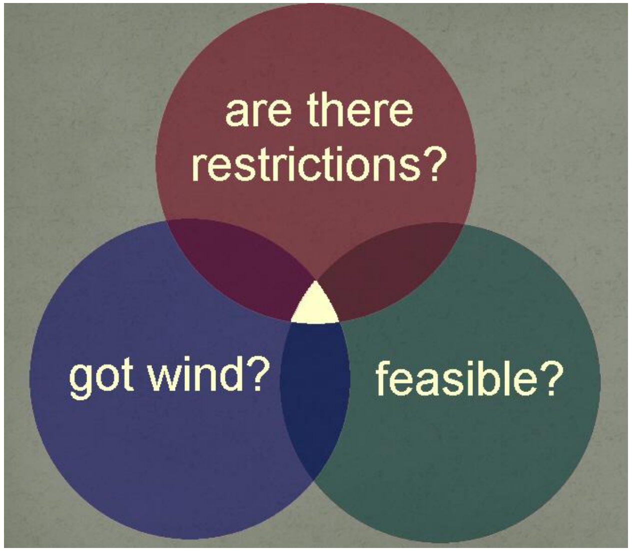
Resource Assessment

Average annual wind speed at the proposed hub height is critical!

Steps, Tools & Methods for Assessing **Average Annual Wind Speed**

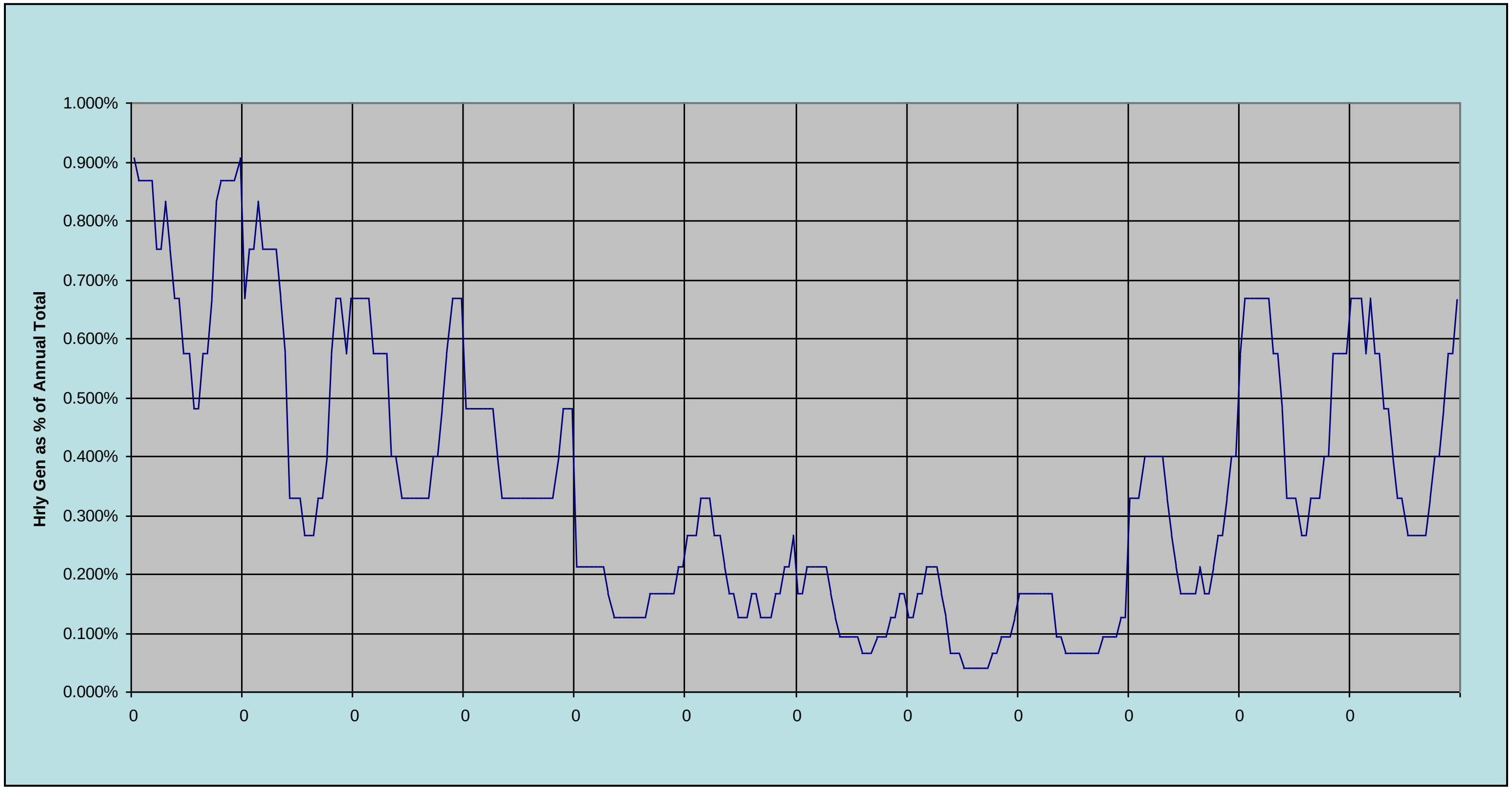
- Evaluate Legal or other Restrictions
- Review Existing Data
  - Wind maps
  - Wind roses
  - Wind distribution curves





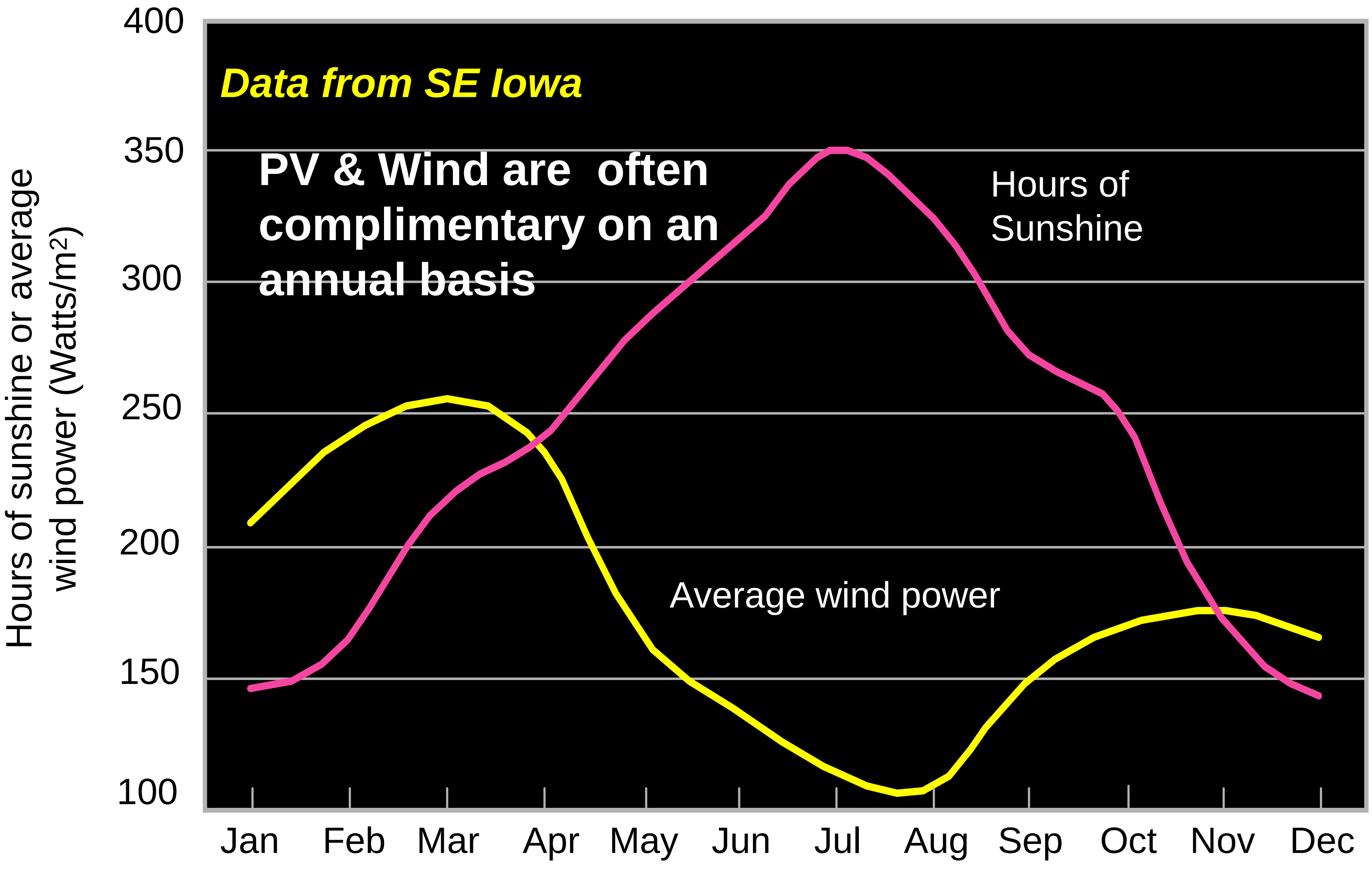
- Use direct measurement tools
  - Anemometer
  - Wind vane, Thermometer
  - Data-logger
- Hire a meteorologist experienced in wind site analysis.

Resource Assessment: Time Of Day Variances



- Higher winds are usually found late in the evening and early morning
- Higher winds are usually seen during the winter

Assessment: A Complimentary Relationship!



General points on Wind Energy Physics

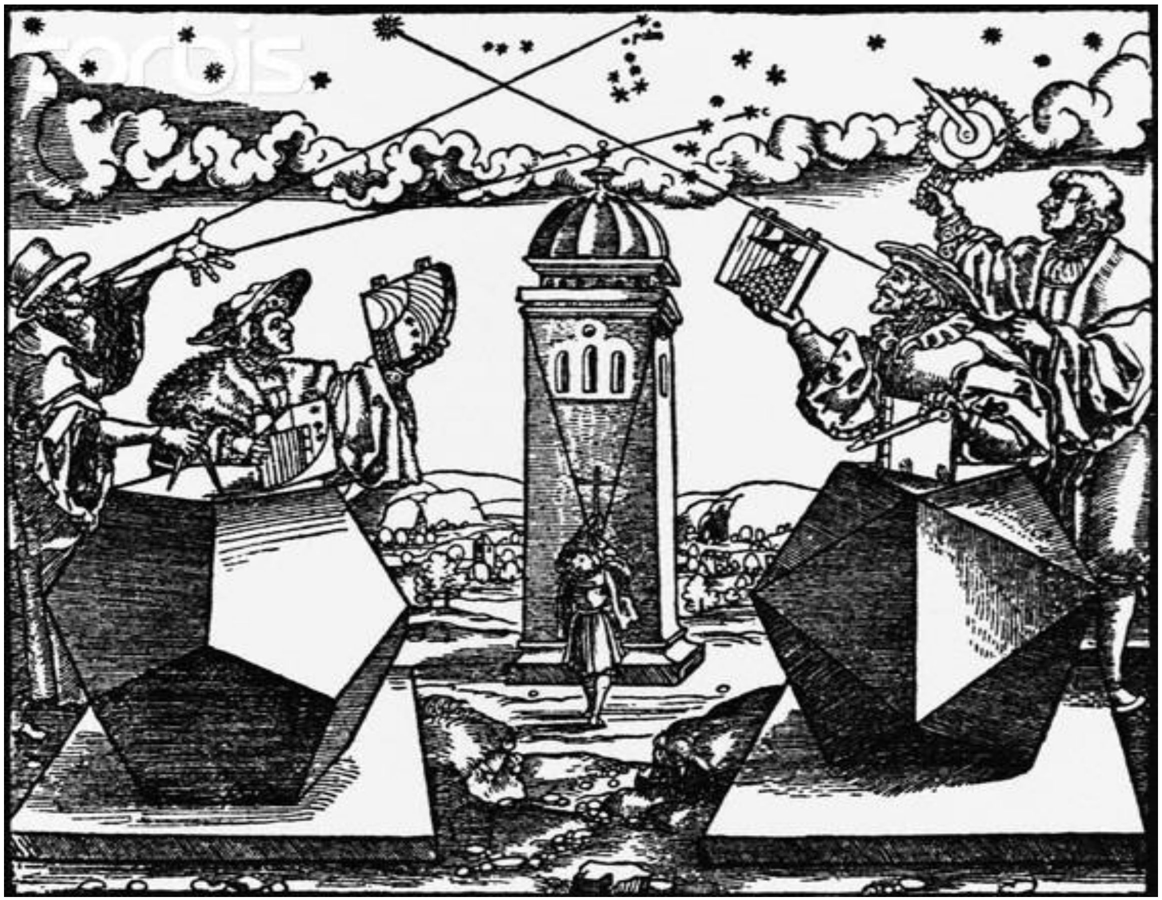
- Cost effectiveness for tapping the wind for energy relies **very heavily on optimizing for highest available average annual wind speed with a specific location & height** for turbine!

- As powerful as wind may be at times, **any site's average annual wind speed is key** for evaluating investment in the resource!

- Optimizing for wind = max. height & swept area: *(Size matters*!)

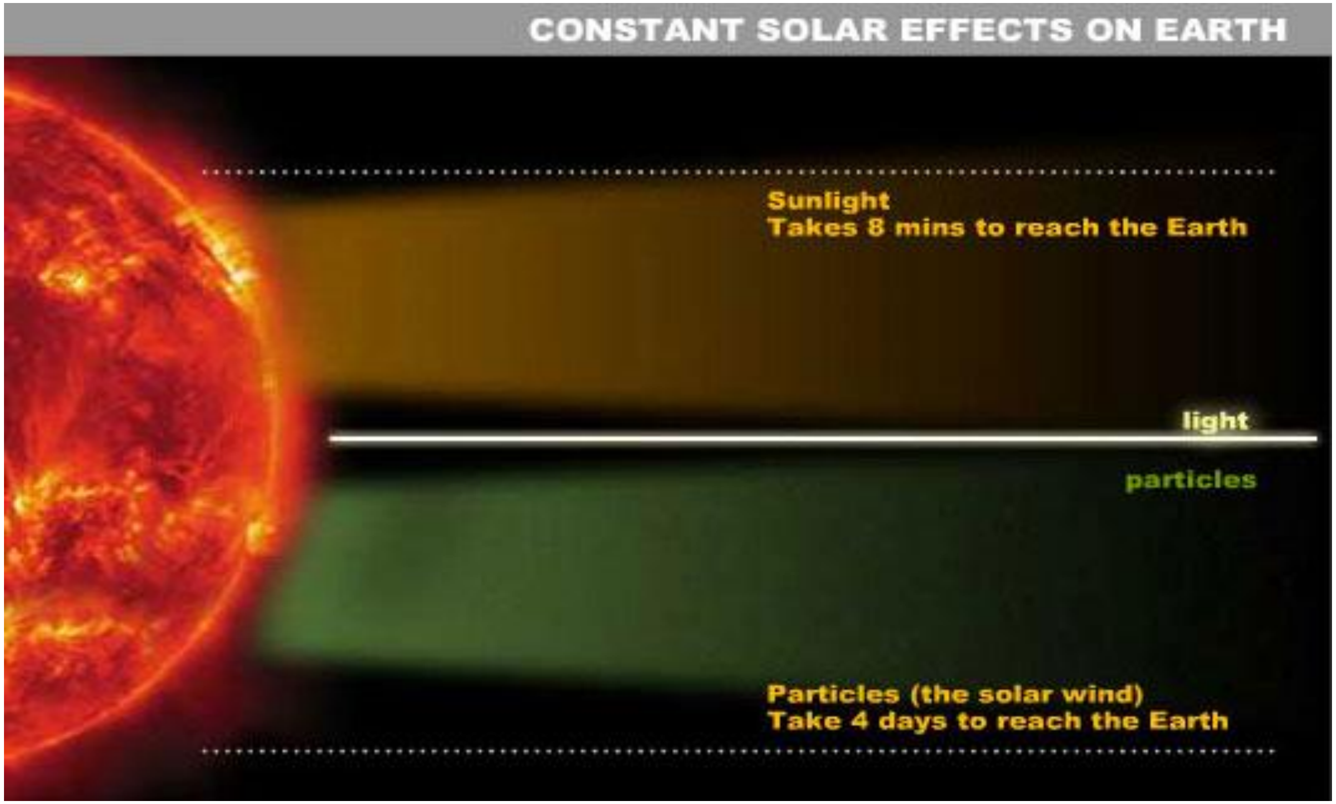
- Many "**Urban Turbines**" have given rise to two new terms in the world of alternative energy: "**Green Bling**" and "**Conspicuous Conservation**!"

Some Solar Energy Physics



The Solar Constant

Is the average amount of solar **power** received by a fixed area of the Earth – but above or at the “top” of the atmosphere *and perpendicular to the sun…*



Graphic courtesy Univ. of California, Berkeley

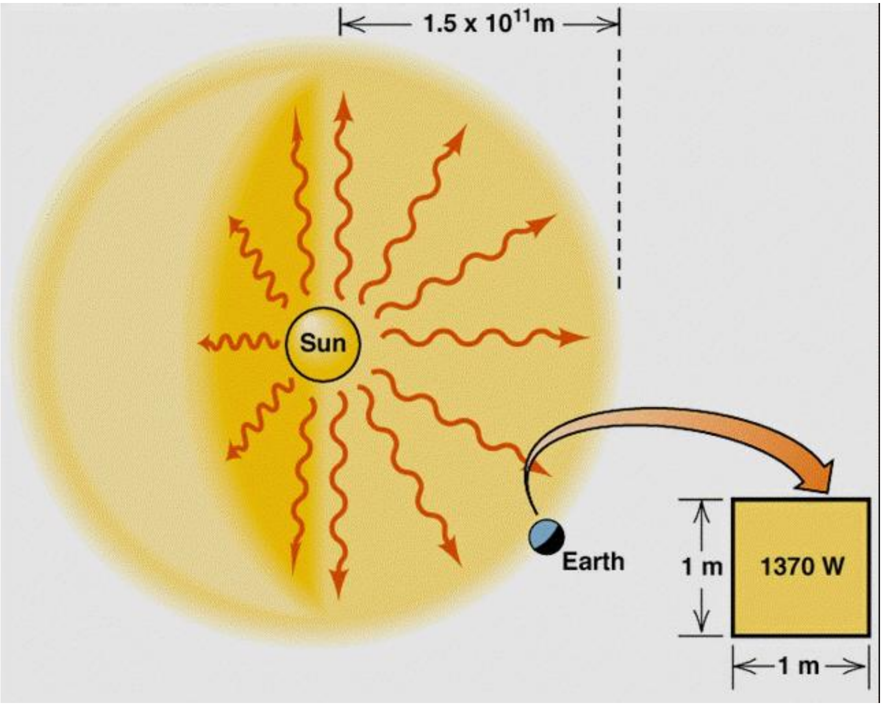
The Solar Constant

The **SOLAR CONSTANT** is the ***AVERAGED*** amount of solar **POWER** received by a fixed area of the Earth – but above or at the "top" of the atmosphere *and perpendicular to the sun…*

Above atmosphere =
1,366 w/m2 or
1.366 kW/m2

At the Earth's surface =
0.8 to 1.1 kW/m2

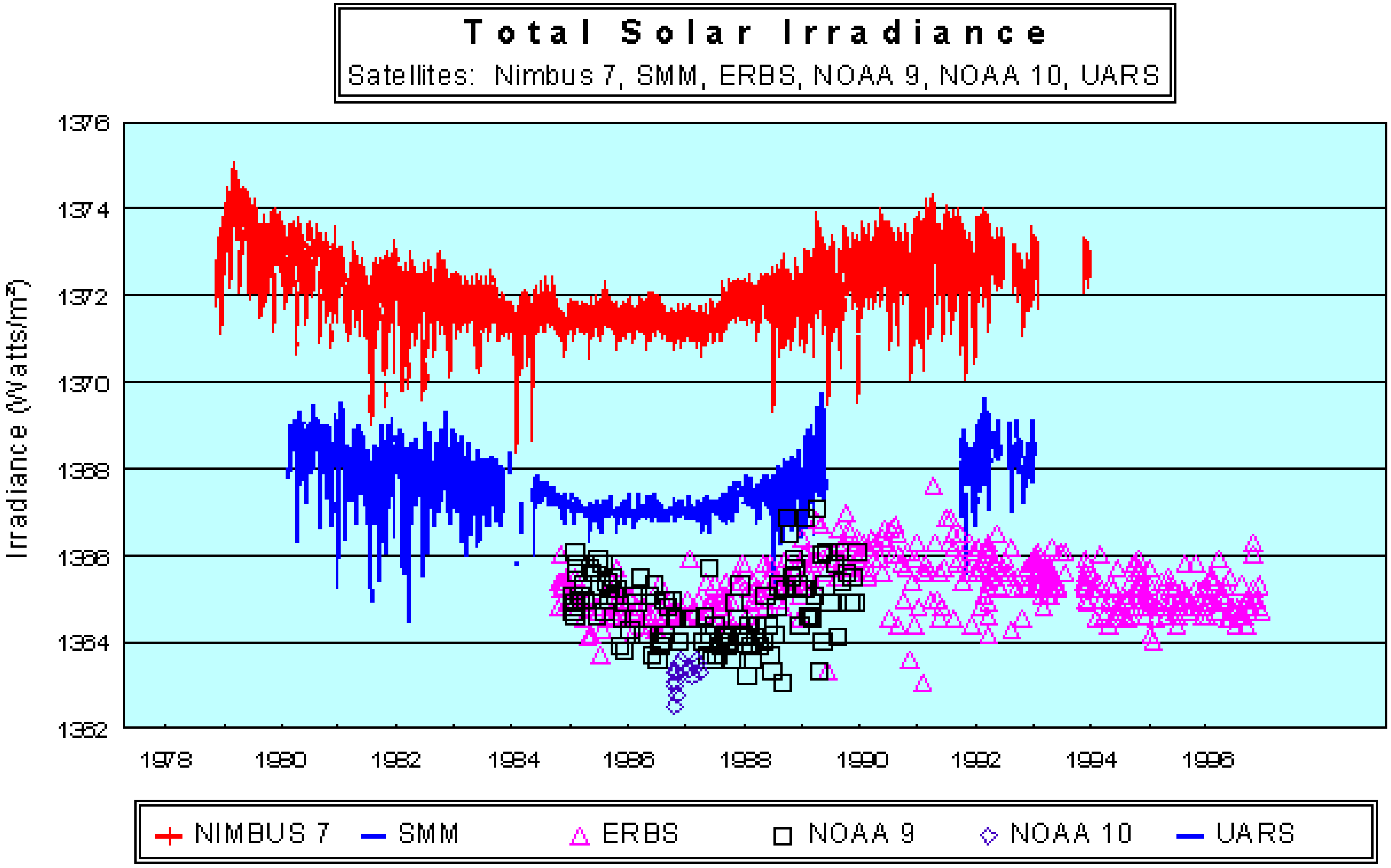
Solar design standard =
1 kW/m2



Graphic courtesy Univ. of Florida`

The Solar Not-So-Constant

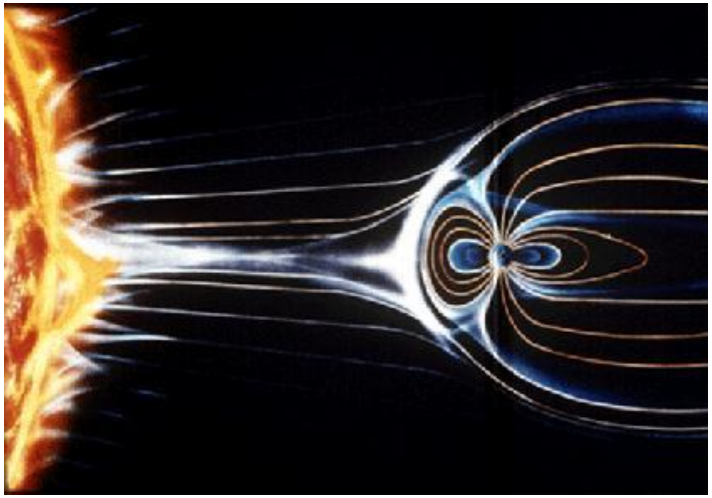
As constant and regular as the sun is, its output varies over time!



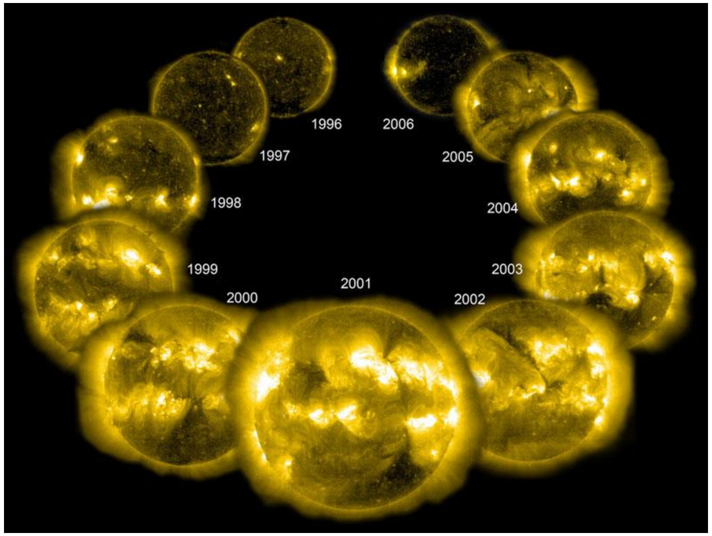
Graphic courtesy Univ. of Florida

The Solar Not-So-Constant

- *Global Warming Skeptics*
  - *Point out that the Solar Wind has been increasing steadily over the last 200 years, and claim this is causing global warming, and not human activity.*

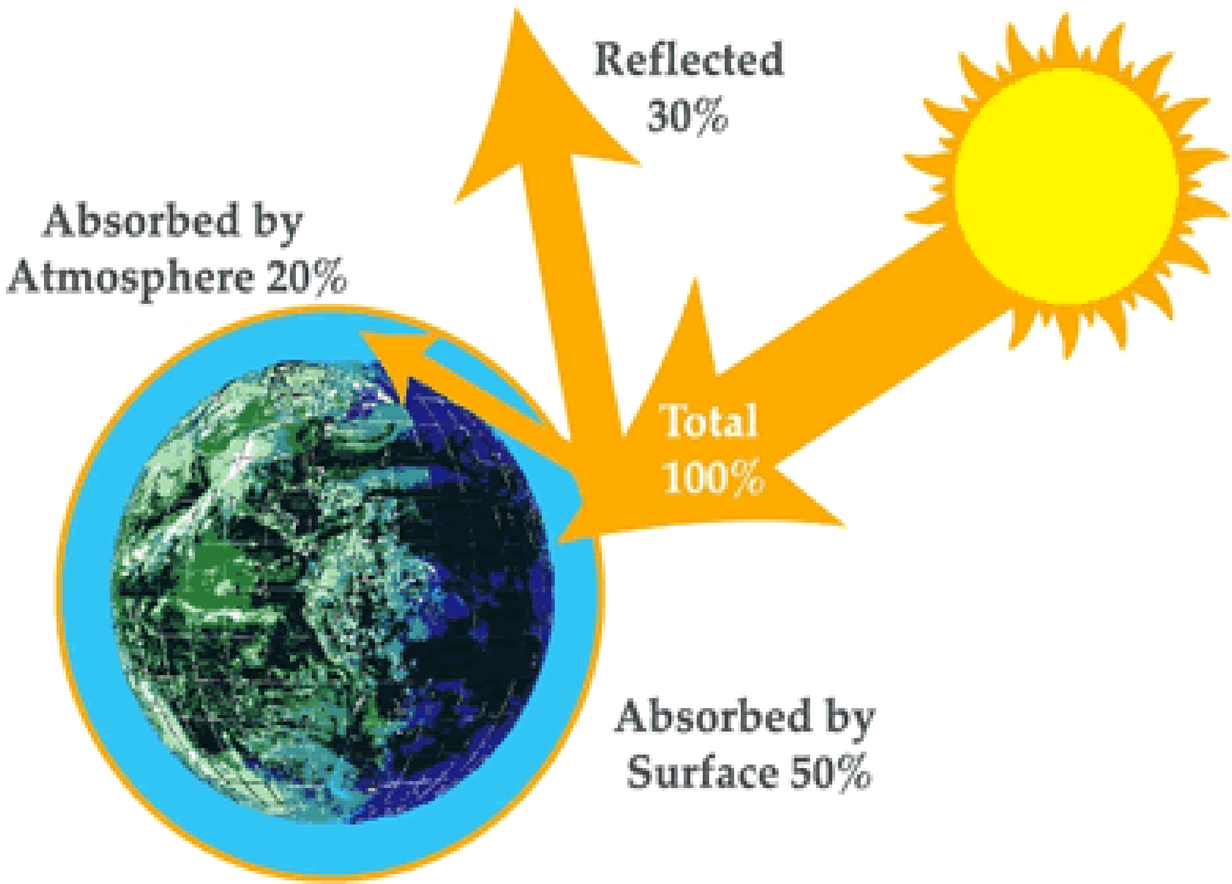


- *Global Warming Skeptics*
  - *Claim the sun's natural 11 year intensity cycle is another factor in why the Earth is warming,*
  - *Yet have not been able to convince any "scientists" besides many TV Weather announcers.*



Graphics courtesy NASA

Incoming Solar Radiation

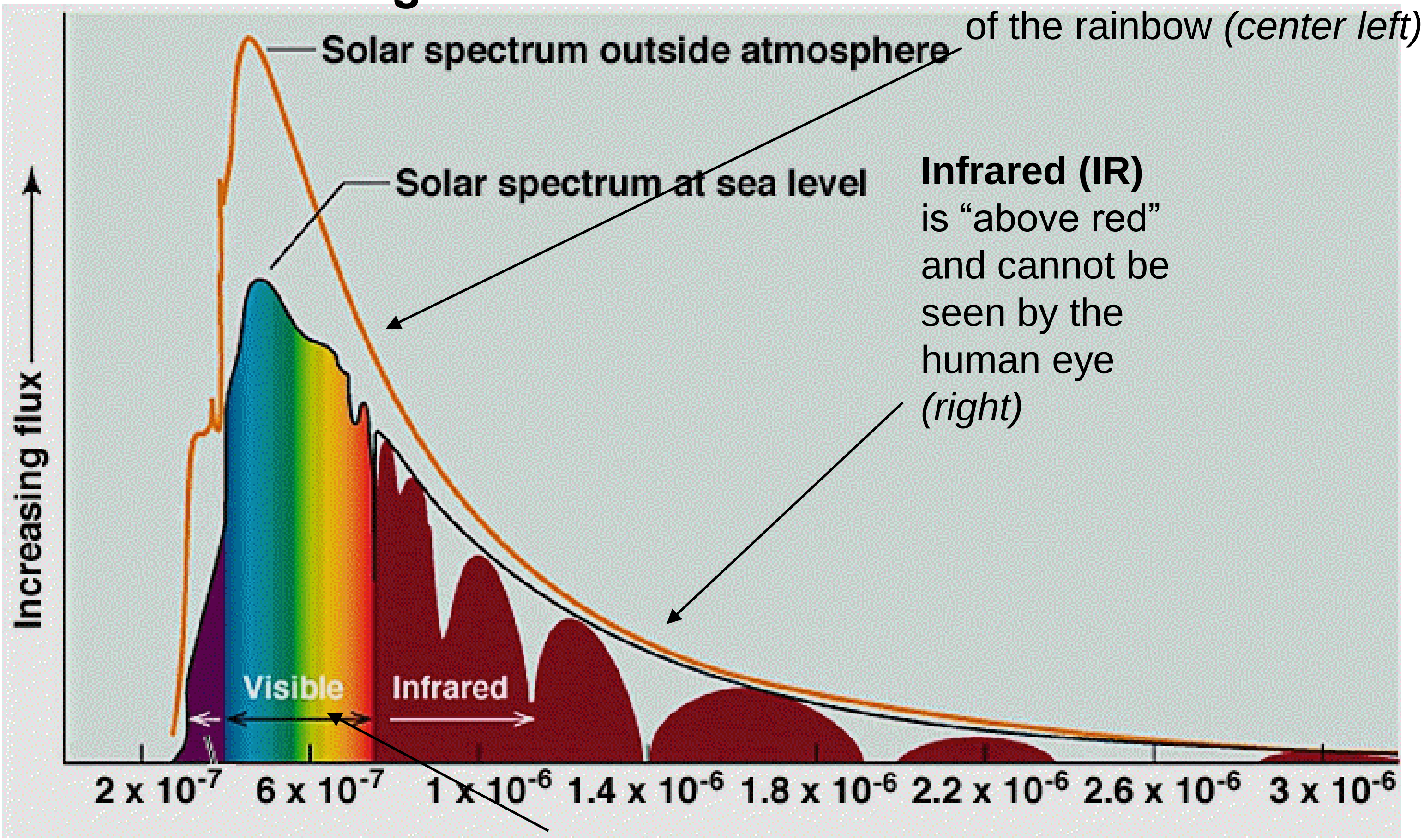


Peuser, Felix A., Remmers, Karl-Heinz, and Schnauss, Martin. 2002. Solar Thermal Systems: Successful Planning and Construction. Earthscan: Germany.

The Solar Spectrum

How we "see the light" . . .

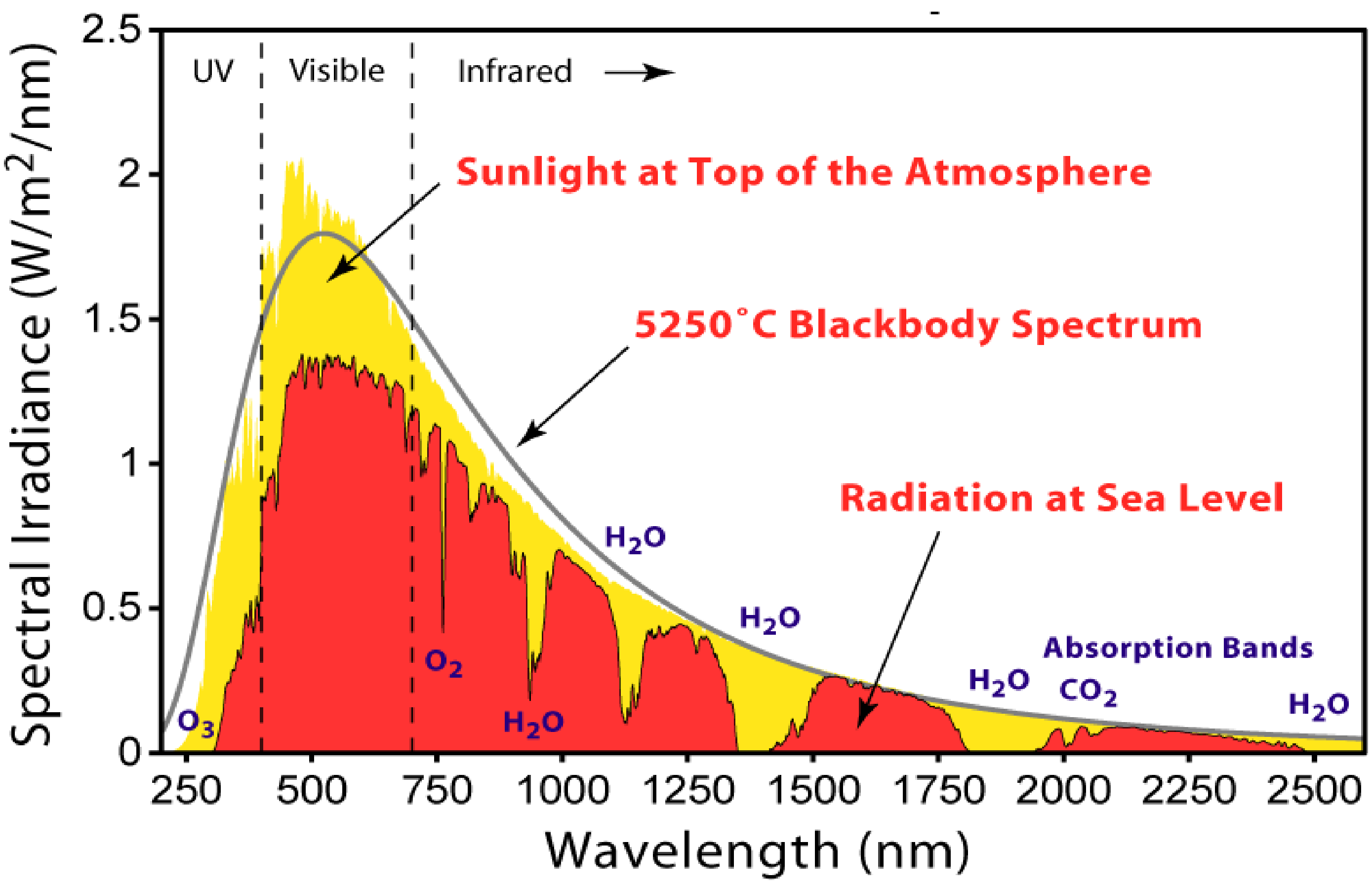
Visible light has all the colors of the rainbow *(center left)*



Infrared (IR) is "above red" and cannot be seen by the human eye *(right)*

Ultra-violet (UV) is "beyond violet" and its frequencies are also too high for the human eye to detect *(left)*

The Solar Spectrum



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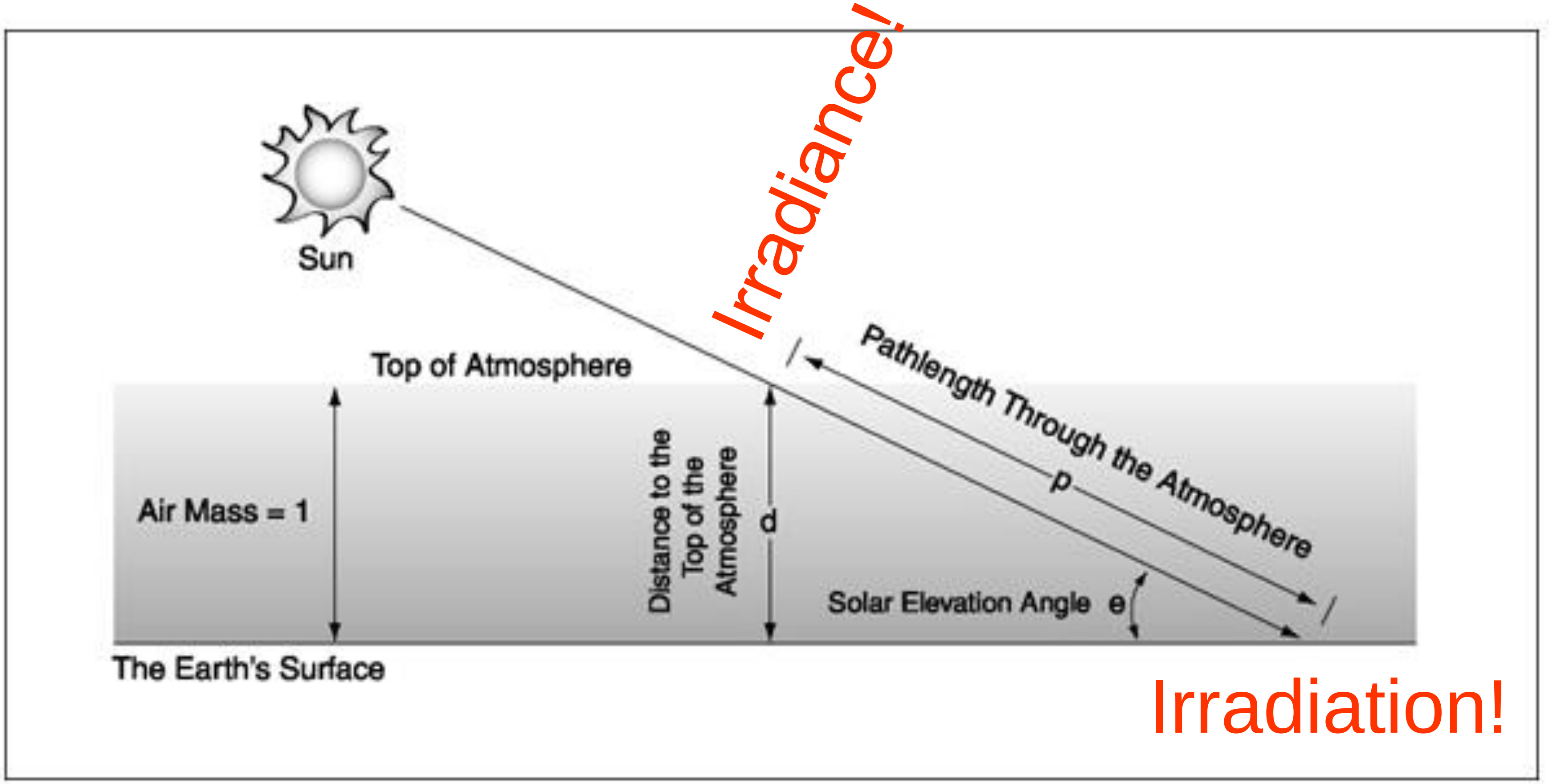
Irradiance and Irradiation



Irradiance vs. Irradiation vs. Radiation

- Solar Irradiance…
  - Varies over time due to sun's irradiative variability
  - Units are **Power** per unit perpendicular area, ***typically kW/m2***
  - Also varies due to upper atmospheric clarity and density
- Solar Irradiation…
  - Varies with **incident angle** of receiving-surface
  - Units are **Energy** per unit area, ***kWh/m2***
  - Its value = Irradiance x time x cos θ
- Solar Radiation...
  - Varies due to reflectance from surrounding surfaces
  - Units are same as Solar Irradiation
  - Its value = Solar Irradiance *plus solar reflectance*

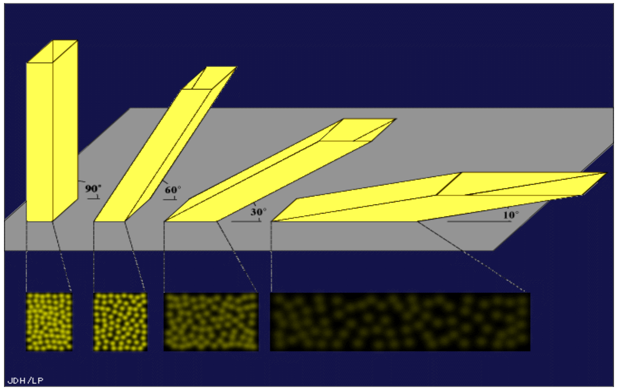


Image Courtesy Univ. of Florida

Solar Radiation is also known as **INSOLATION – *INcoming SOLar RadiATION***

Irradiance vs. Irradiation & Insolation

What factors reduce how much sunlight energy can be harvested?

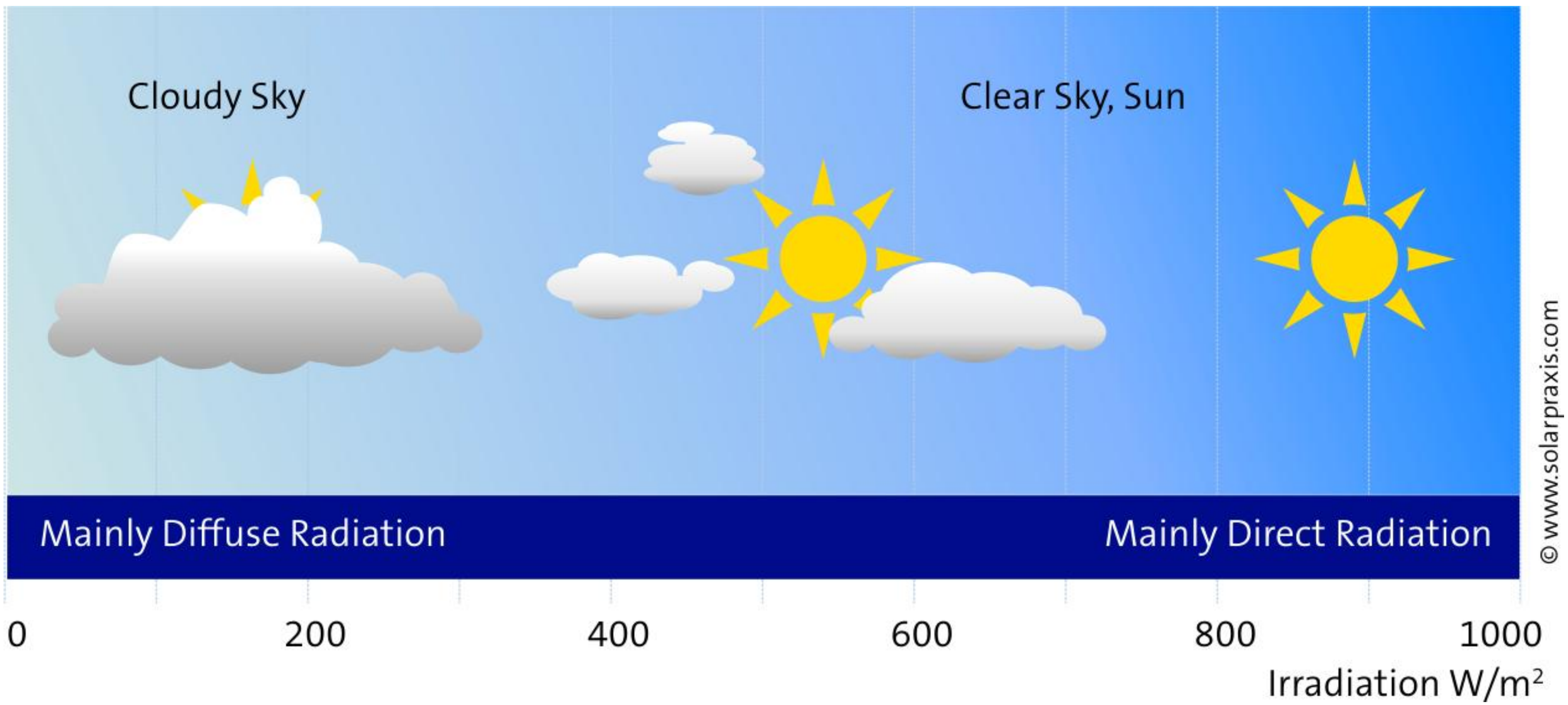
Solar Irradiance is affected by:

- Sun's variation in cyclic, seasonal & daily output
- Upper strata atmospheric changes

Solar Irradiation *and* Insolation at a solar collector are affected by:

- Time of day
- Latitude
- Altitude
- Weather
- Season
- Climate
- Shading –
  - Roofline
  - Trees
  - Other buildings
  - Roof appurtenances (chimneys, antenna, equipment, etc.)
- Dust/soiling on surface of the collectors
- Snow and ice on the collectors
- *Reflection ONTO an array –*
  from other buildings, snow, standing water on roofs

Insolation



Insolation as a Function of Weather

Example of Weather affecting Insolation on a plane perpendicular to the sun

Clear days = high levels ranging **800 to 1000 W/square meter**

Heavy overcast days = low levels ranging **200 W/square meter or less**

Peuser, Felix A., Remmers, Karl-Heinz, and Schnauss, Martin. 2002. Solar Thermal Systems: Successful Planning and Construction. Earthscan: Germany.

Measuring Insolation

Pyranometer – a device for measuring Insolation

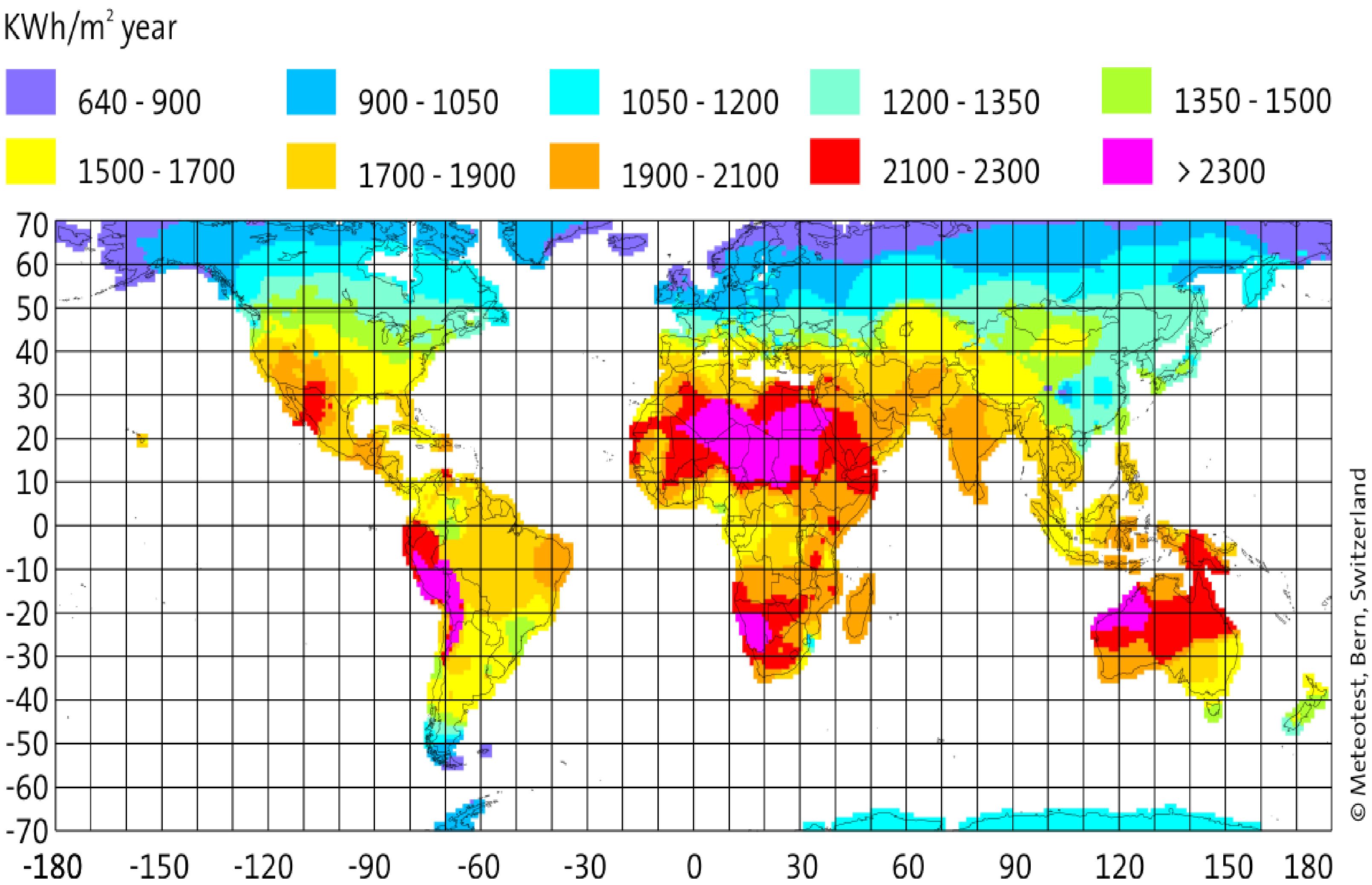
It is a thermo-electrical pile which produces an electromotive force (emf) when exposed to light.

Gage reads emf to determine "irradiance" (instantaneous value of Insolation) in W/square meter

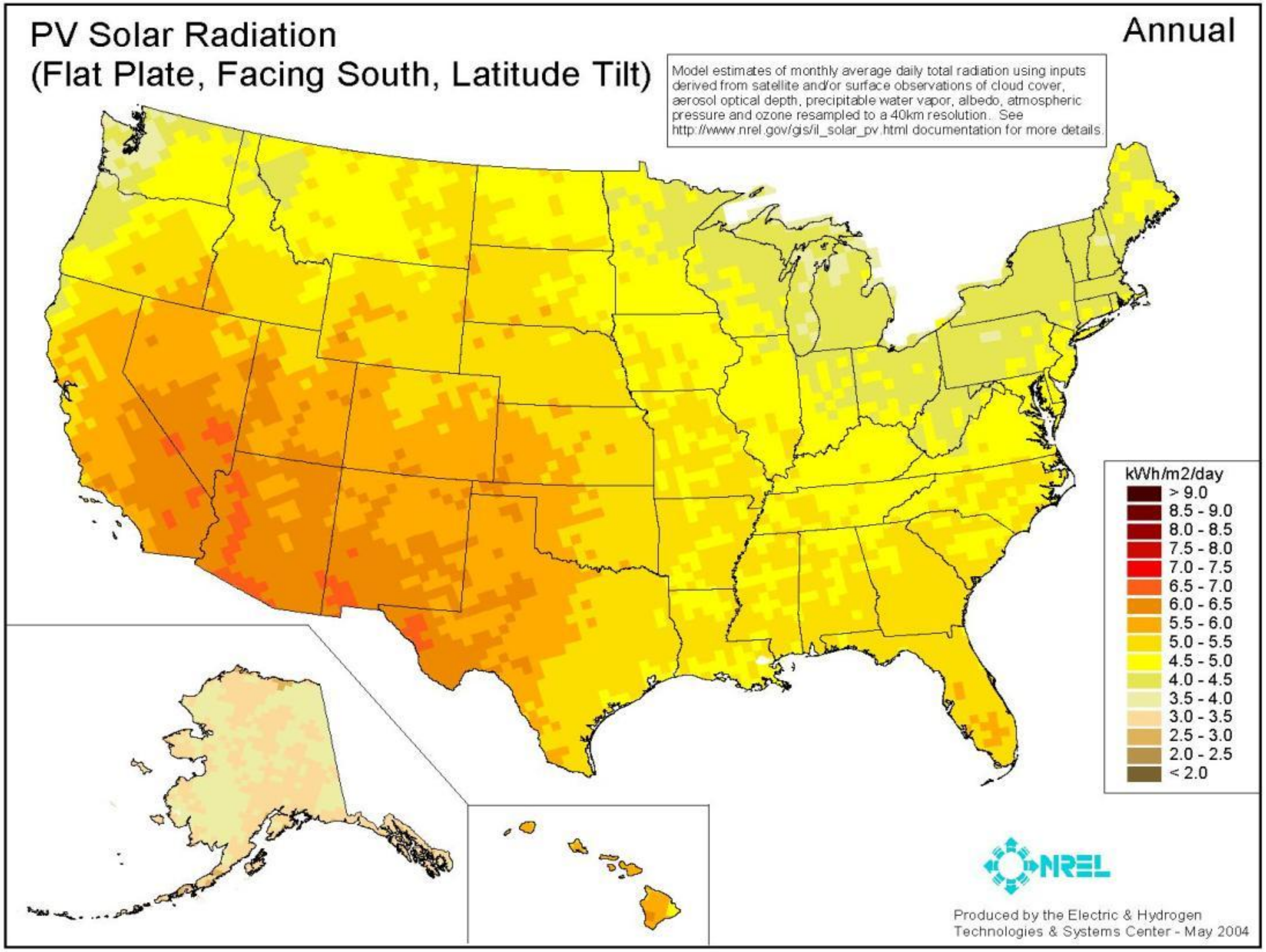
These are typically installed horizontally, often positioned at an array or collector assembly

Peuser, Felix A., Remmers, Karl-Heinz, and Schnauss, Martin. 2002. Solar Thermal Systems: Successful Planning and Construction. Earthscan: Germany.

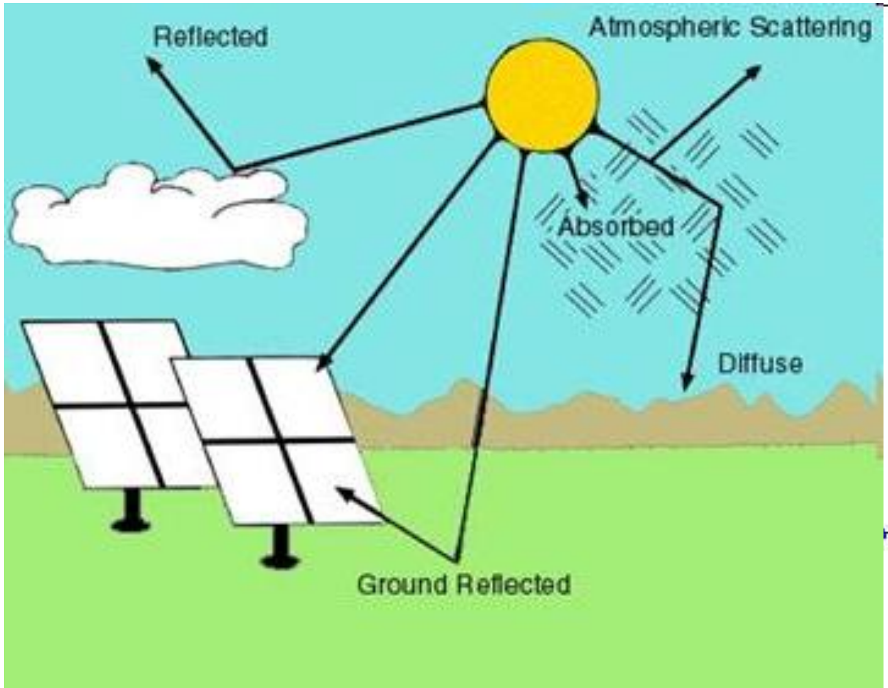
Average Insolation: Earth

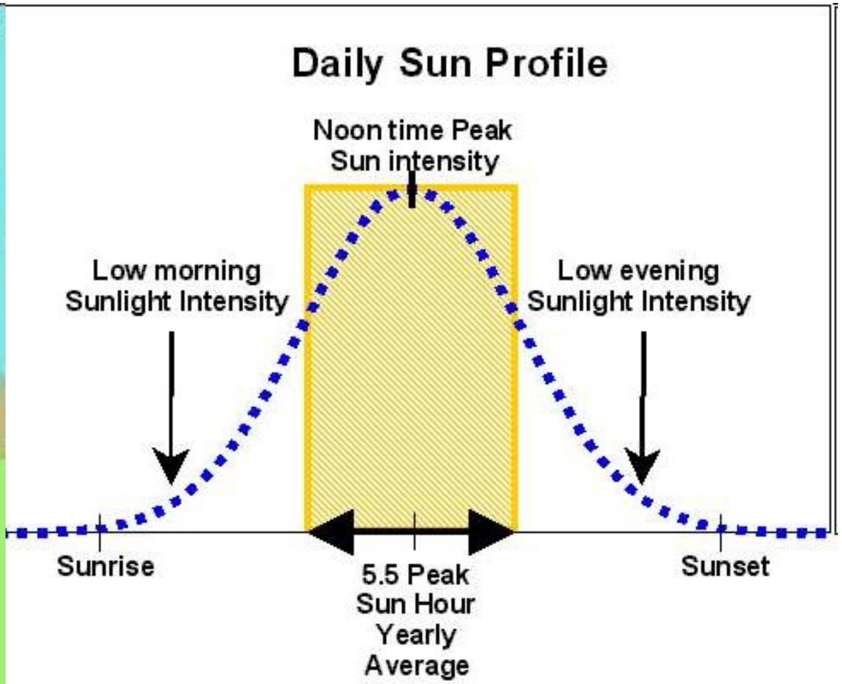


Average Insolation: US



Peak Sun Hours





Actual Insolation varies moment to moment.

Solar design data uses “average” peak sun hours

Peak Sun Hours

Peak Sun Hours is the ANNUAL BASIS average hours per day of peak sun experienced at a specific location

- **Peak Sun Hours** varies by **latitude** and **local climactic conditions**.
- Total daily Irradiance (watt-hours/m^2) ÷ Peak Sun irradiance (watts/m^2) =

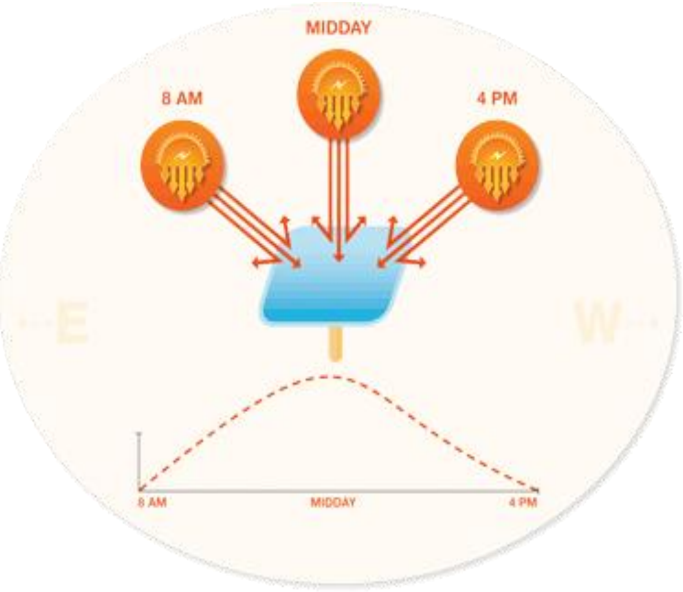
Peak Sun Hours

- **Peak Sun Hours** is used for sizing

PV arrays

and to a lesser degree,

Thermal Collector arrays



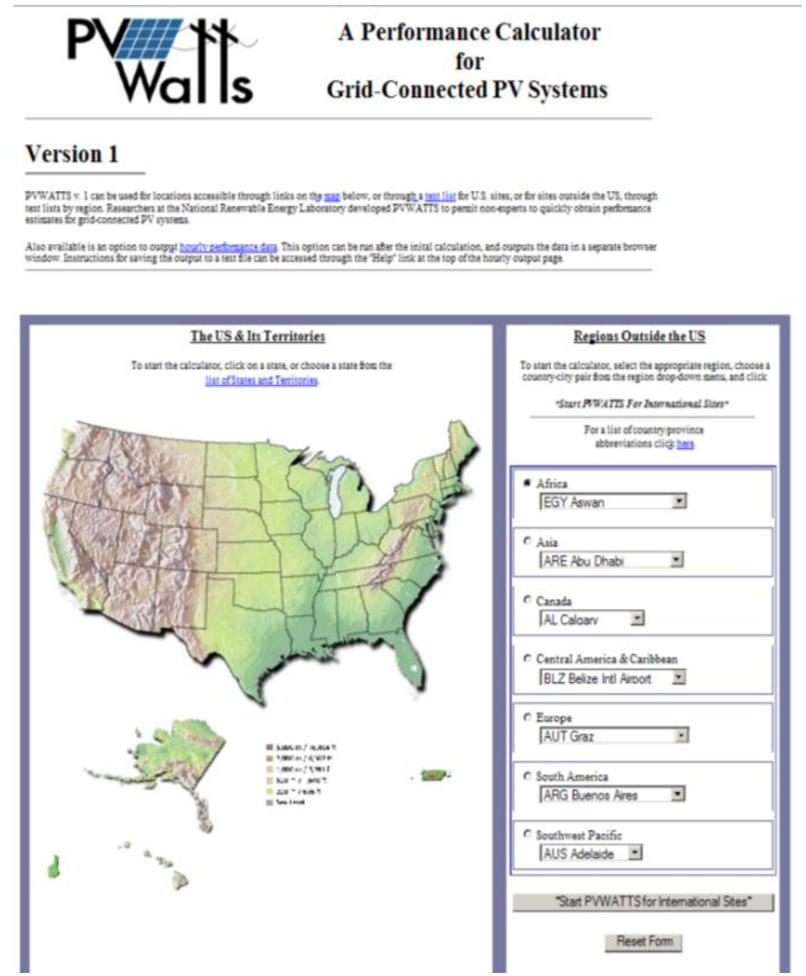
Obtaining Peak Sun Hours

It's a free on-line tool maintained by the National Renewable Energy Laboratory (NREL).

Results are location specific, **based on Zip Code**, and incorporate decades of weather/climate data collected by NOAA **(US agency runs the National Weather Service).**

One valuable piece of information it furnishes is "Peak Sun Hours."

URL / Link is below!



About the Hourly Performance Data

Saving Text from a Browser

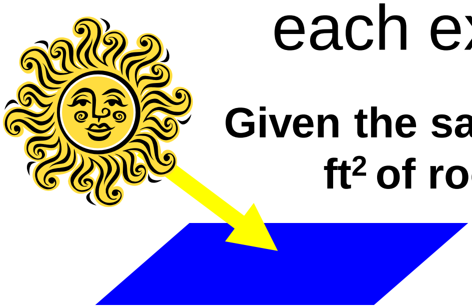
http://rredc.nrel.gov/solar/calculators/PVWATTS/version1/

Differences between PV and ST

There is a difference in how much energy can be harvested with each existing technology:

__About 8 TIMES as much ENERGY__ with ST as PV from the same area of solar panel

How Come?



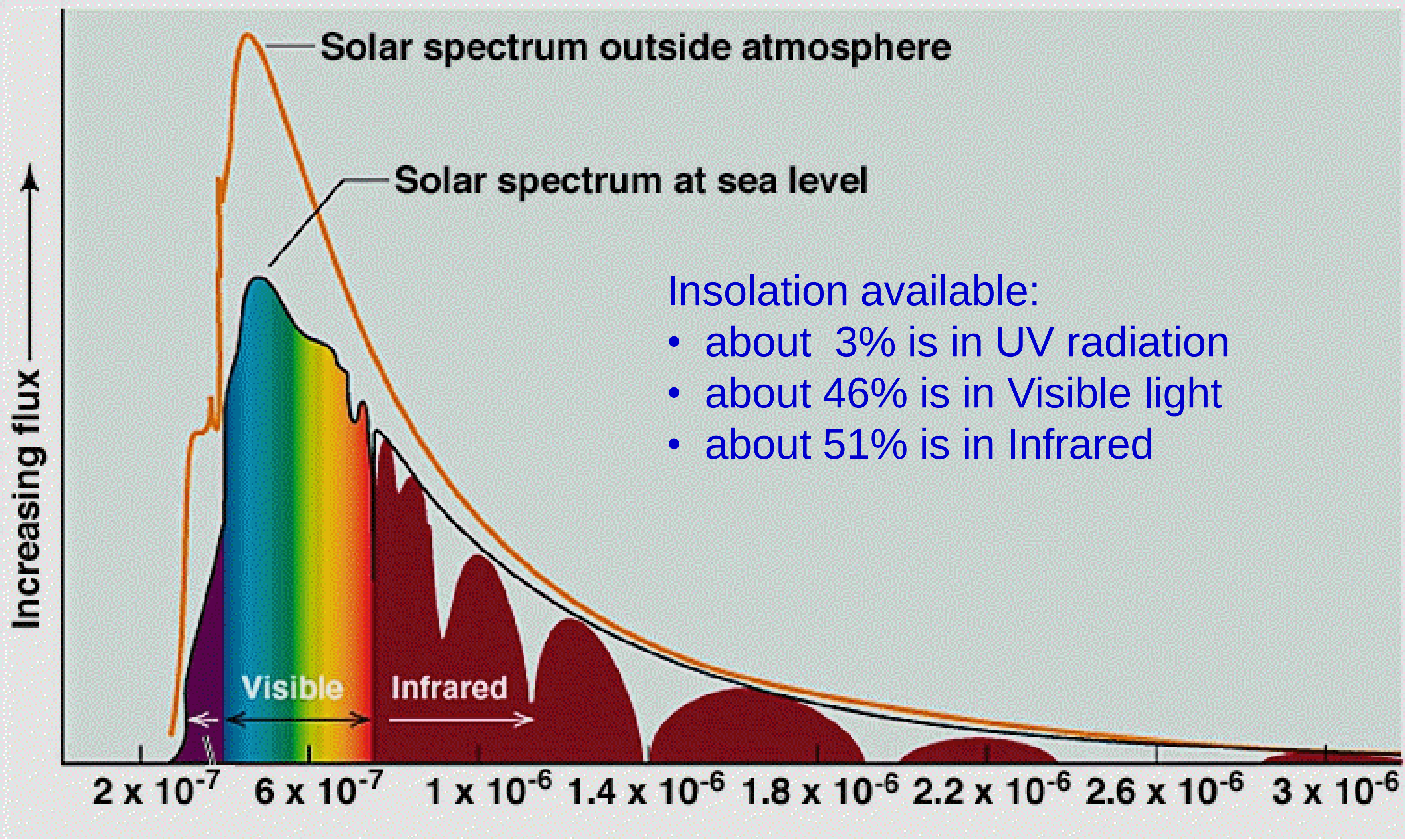
Given the same 100 ft^2 of roof area, one can expect to collect about:

200 Therms/yr = **20,000,000 Btu/yr**

750 kWh/yr = **2,500,000 Btu/yr**

Solar Heat Efficiency	Solar Heat	Solar Electricity	PV Efficiency
40%	200 Therms/yr	750 kWh/yr	5%
50%	250 Therms/yr	1,500 kWh/yr	10%
60%	300 Therms/yr	2,250 kWh/yr	15%
70%	350 Therms/yr	3,000 kWh/yr	20%

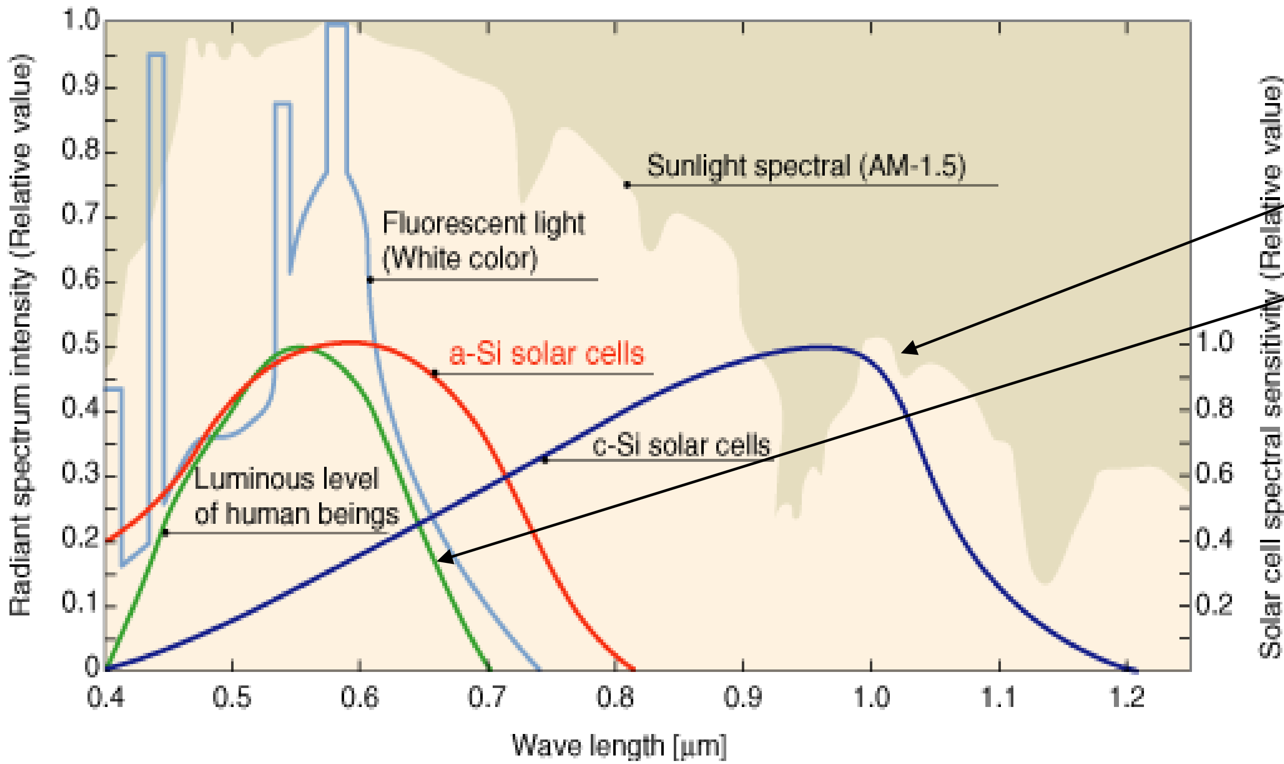
Solar Spectrum Physics



Insolation available:

- about 3% is in UV radiation
- about 46% is in Visible light
- about 51% is in Infrared

Solar Spectrum Physics



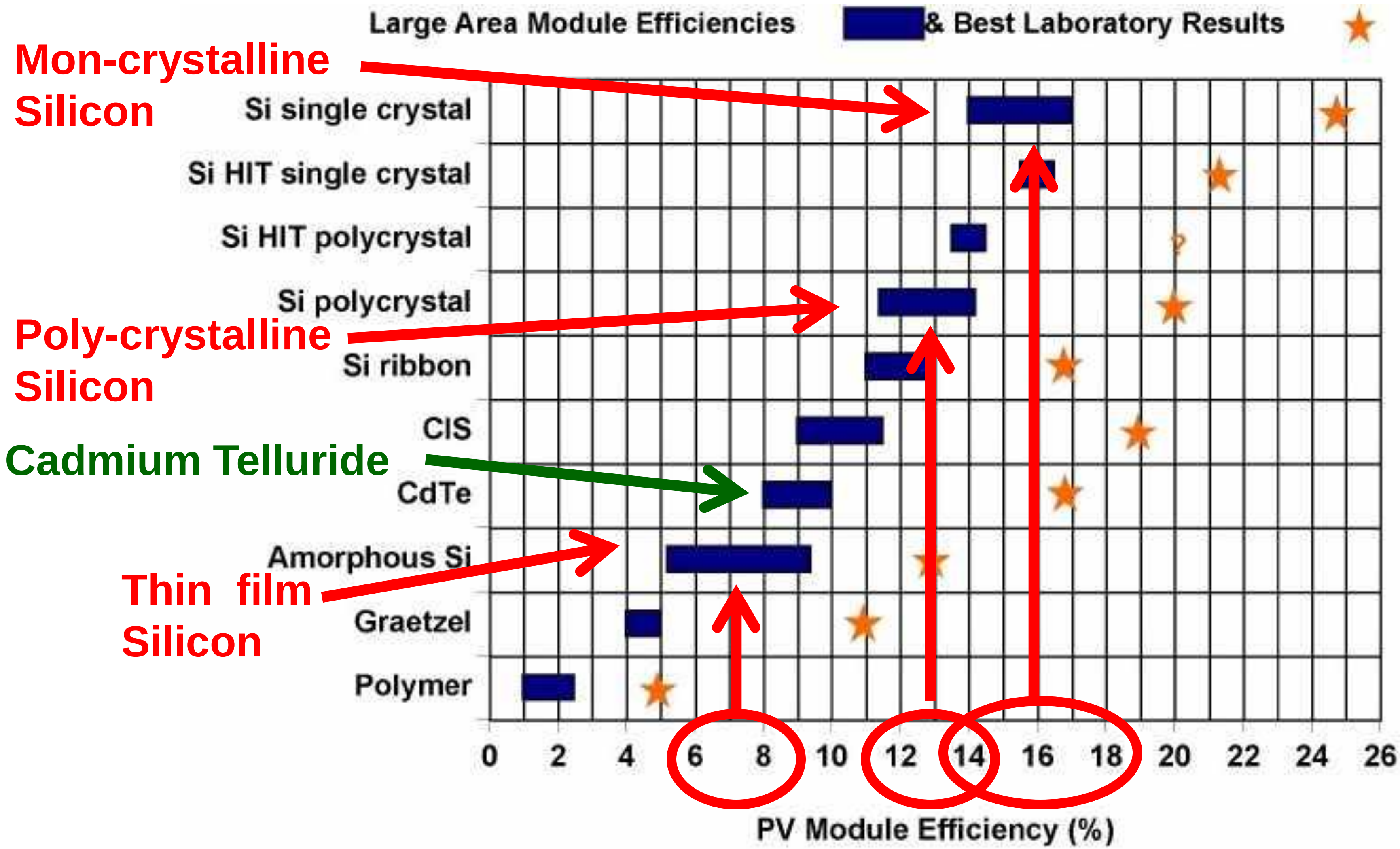
http://semicon.sanyo.com/en/amorton/feature/index.php

Poly-crystalline & mono-crystalline **Silicon**

Some of the crystalline Silicon *sun light responsive frequencies* are within the **visible** part of the solar spectrum, **but most are not.**

- Semi-conductors used in PV respond to different frequencies of light. PV generates from only a fraction of the full solar spectrum.

Semiconductor Efficiency Ranges



General points on Solar Energy Physics

- As constant and reliable as sunshine may seem, the energy available from this resource actually varies!

- “Peak Sun Hours” is a key value to know about any specific location for further evaluation of that site’s solar resource!

- Much more **Thermal Energy** (ST) is available from conversion of sunlight at any given location than **Solar Electricity** (PV)!

- Understanding the physics of solar is key to prioritizing among and evaluating between which alternative energy systems are worth investment in time and money on any path toward sustainability!

Some Geo-Thermal Energy Physics

Electricity Generation in Iceland
Photo by Gretar Ivarsson

Geothermal: Earth Heat vs. Solar Heat

Geothermal power is extremely sustainable, theoretically

Two sources of energy:

1. Earth's core has been hot since its formation and it is still cooling down & solidifying.

   The heat is both latent AND due to radioactive material decay.

   Heat continually trickles up through the mantle and crust from the core.

2. Also, the sun daily – and continuously - warms Earth, reducing overall heat loss radiating from Earth into space.

Earth temperature rises by depth:

- About 3° C each 1,000 ft down
- The base of the mantel is estimated at 4,000° C

The Earth is cooling as it ages:

- It radiates its heat, thus loses energy, into space
- Mantel temperatures are estimated to have dropped by only 350° C over the last 3,000,000,000 years!
- The sun's continuous glow keeps Earth's surface warmer than it would be if the Earth were alone in deep space. So the sun slows the overall Earth cooling rate.

Geothermal: Earth Heat vs. Solar Heat

Geothermal power is extremely sustainable, theoretically

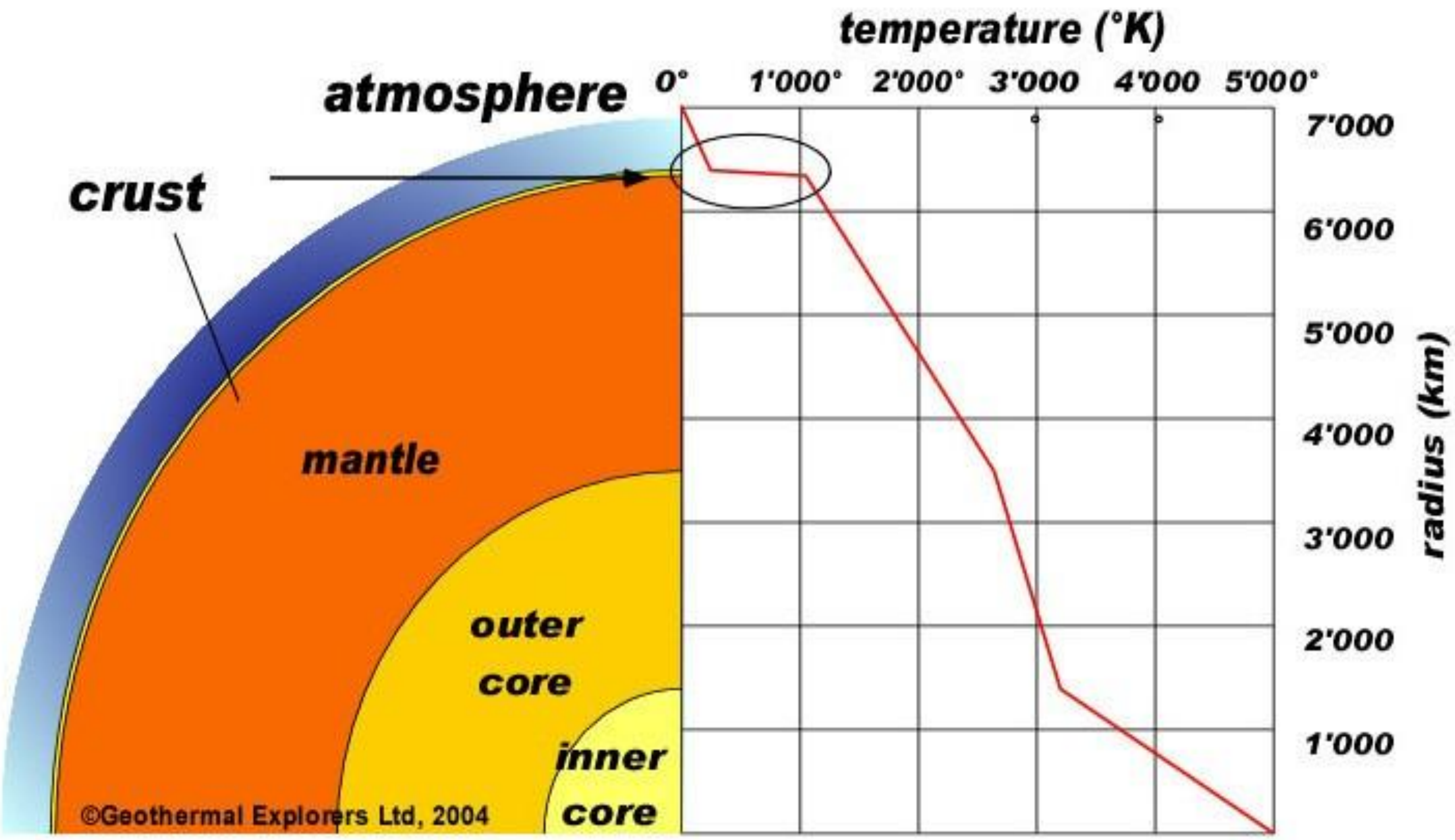


Image Source: http://www.geothermal.ch/eng/vision.html

Geothermal: Earth Heat vs. Solar Heat

How much geothermal energy is available?

one milliwatt (1 mW) is 0.001 W.

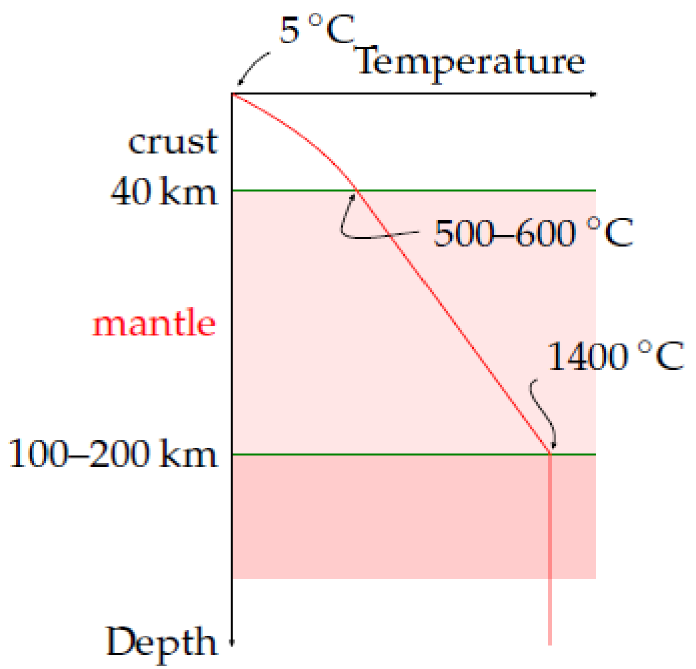


Figure 16.4. Temperature profile in a typical continent.

Latent core heat flows from the center of the Earth through the mantle at about 10 mW/m^2

(1 milli-Watt = 1/100 Watt).

Heat flow rates off the Earth's surface are about 50 mW/m^2 = 0.05 W/m^2

(compare to solar radiation of 1000 W / m2),

Therefore, radioactive decay adds an extra 40 mW/m^2 to the heat flow rates at the surface of the planet.

But 50 mW/m2 per year, in the end, is low-grade heat trickling through.

C

Geothermal: Earth Heat vs. Solar Heat

How much geothermal energy is available?

- Earth Temperature of the first 25 feet of the crust:
    - Varies a few degrees between Summer and Winter in temperate zones
- Earth Temperature of the first 500 feet of the crust:
    - Remains stable over the course of a year in all climates
    - But it varies by latitude! (in continental or tectonic plate core areas) by about 6 degrees each 1,000 miles further from the equator.

Image is an excerpt from a geothermal atlas of North America
6 F degrees cooler at 50 feet below James Bay than 50 feet below northern Alabama

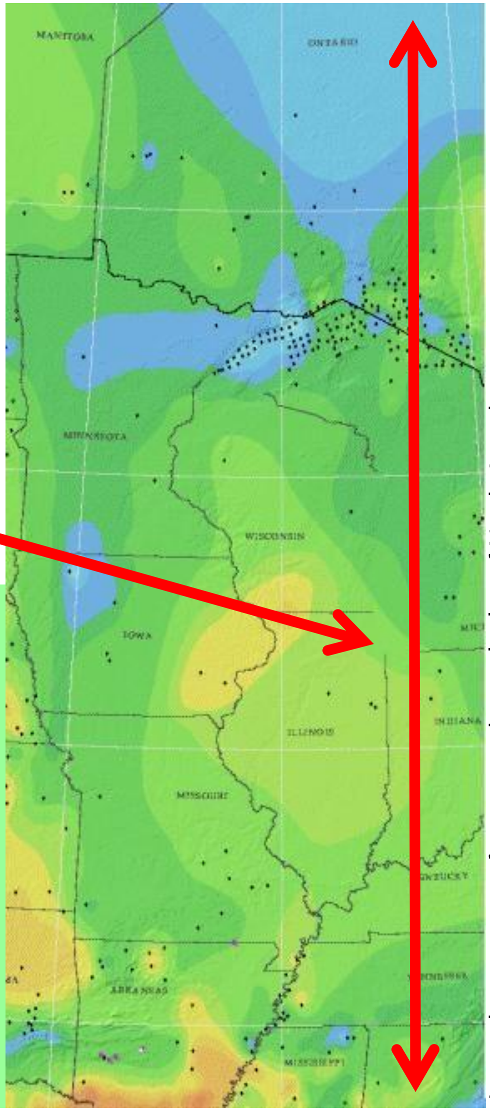
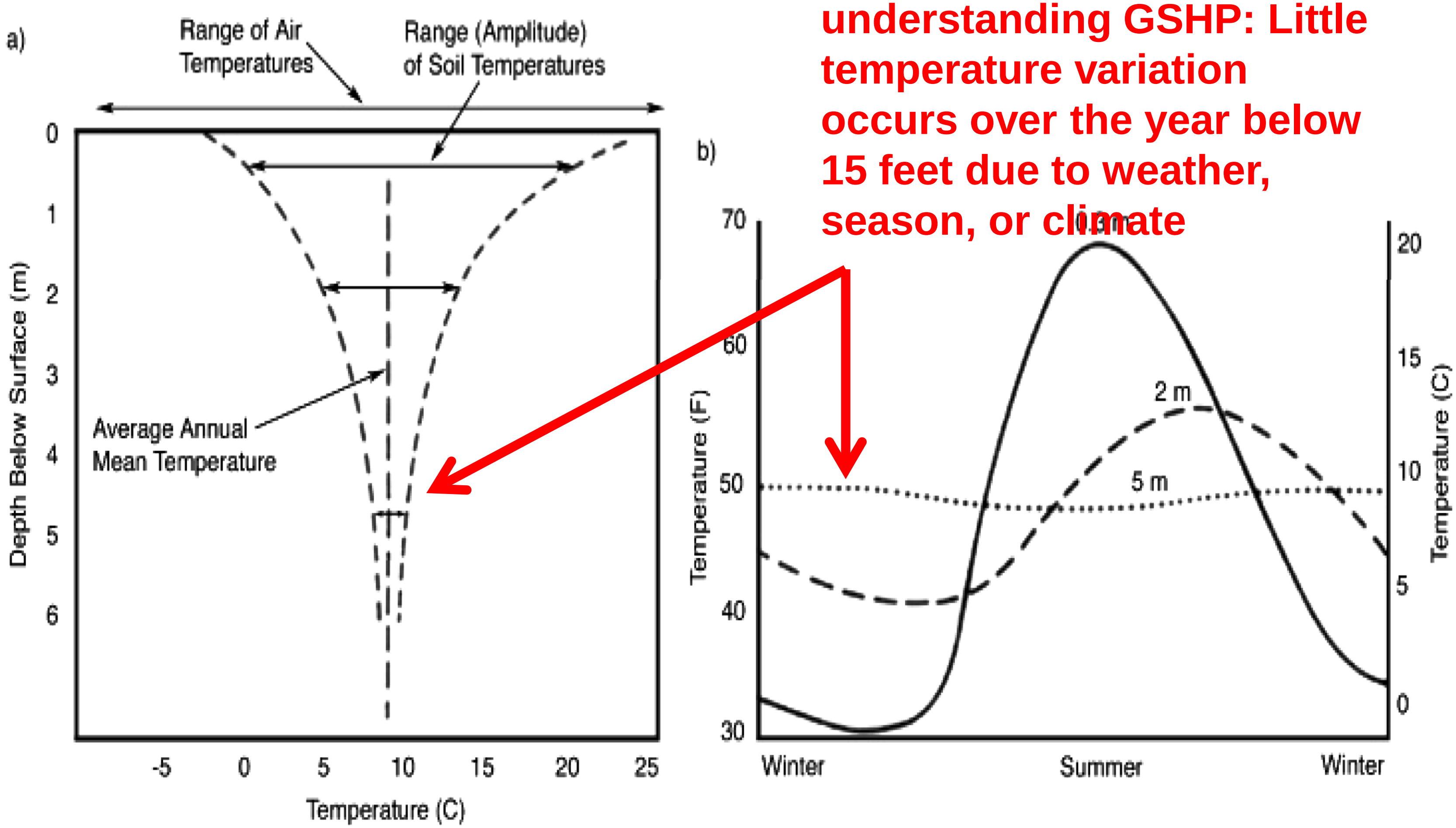


Image is an excerpt from a geothermal atlas of North America

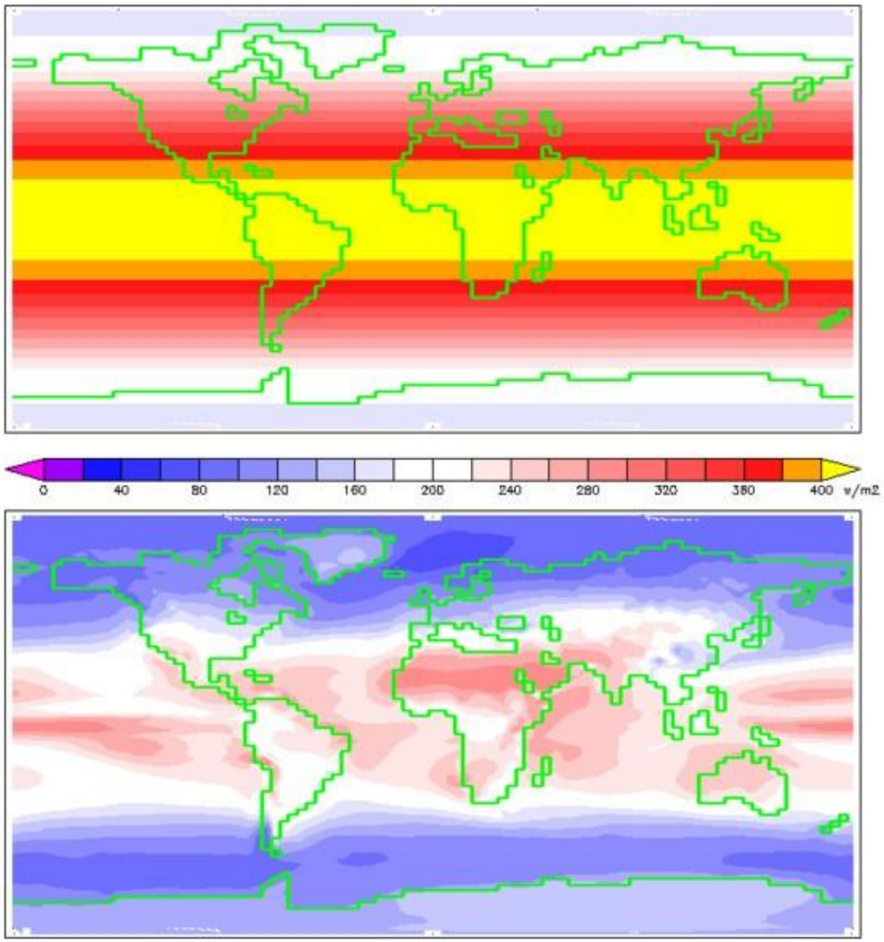
Geothermal: Earth Heat vs. Solar Heat

More useful for understanding GSHP: Little temperature variation occurs over the year below 15 feet due to weather, season, or climate



Hanova, J., and Dowlatabadi, H., 2007

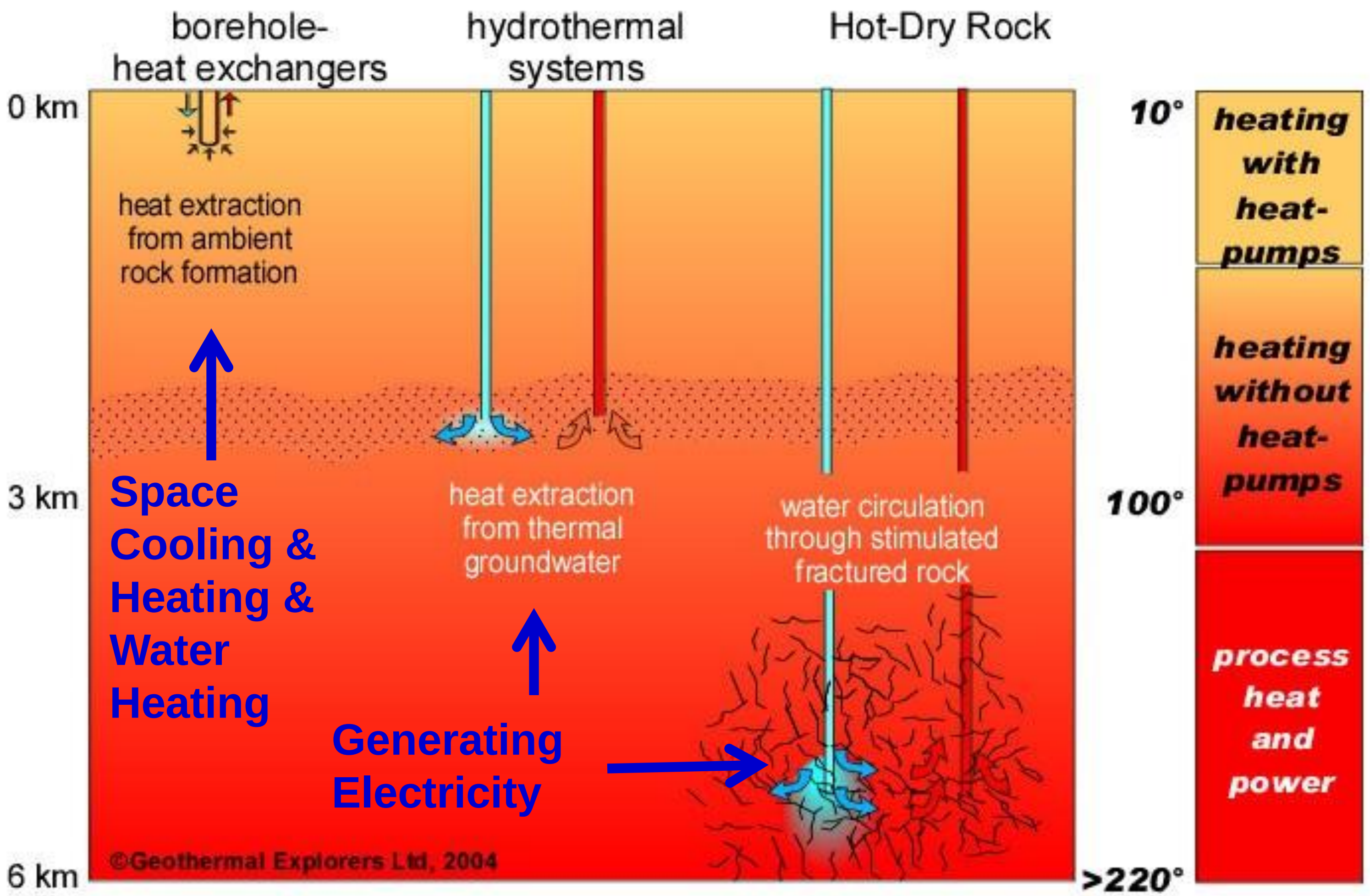
Geothermal: Earth Heat vs. Solar Heat



Therefore:
Shallow Earth Geothermal Power is stable and reliable, and is due as much to <u>Solar</u> energy gain as it is Earth interior sourced energy!

And:
For practical purposes here in much of the continental US, geothermal power means using the heat banking properties of the Earth’s crust to depths of up to a few hundred feet.

Geothermal: Methods of Heat Extraction



http://www.geothermal.ch/eng/vision.html

General points: Geothermal Energy Physics

- Geothermal systems using the HIGH heat from within the Earth can generate electricity.

- Shallow Geothermal systems – perhaps more familiar here - are known as GeoExchange® or more accurately referred to as Ground Source Heat Pump (GSHP) Systems.

- In GSHP Systems, the pump cannot by itself raise temperatures in the space to where they pump heat *higher than their heat source temperature (which is often around* 55° F).

- However, a GSHP can easily LOWER interior temperatures in summer since it is pumping heat into a large 55° F heat sink!

Energy Auditing (an endorsement)

Energy "audits" are not all alike

Energy Audits are much like Financial Audits: They vary by the degree of attention needed to find problems & opportunities.

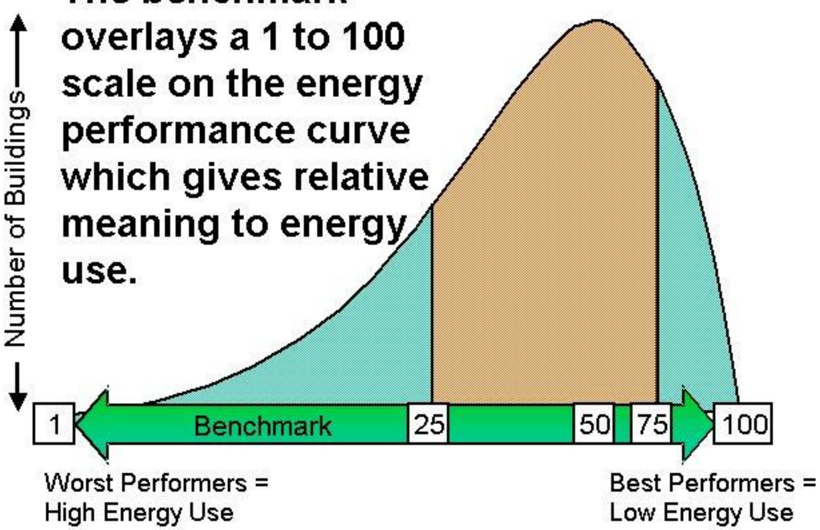
This level of Financial Audit:		***This level of Energy Audit:***
– Balancing your check book or reviewing a credit card statement.	***is like*** →	– A Benchmarking study using a data base like Energy Star Portfolio Manager. (ASHRAE Level 1)
– Asking your nephew to advise you on your accounts - because he is "good with numbers."	***is like*** →	– A *walk through audit* by a utility company or consultant. (Level 2)
– Hiring a service to do your taxes or your bookkeeping.	***is like*** →	– A professional *diagnostic assessment* of your facility using instruments and preparing a prioritized ECM report. (Level 3)
– Retaining a financial planner to study your circumstances & prepare a customized savings & investment plan.	***is like*** →	– An investment grade audit, often using building modeling software for sake of a B/C or ROI analysis. (ASHRAE Level 4)

Benchmark Assessments

ENERGY STAR

1 to 100 Benchmark Scale

The benchmark overlays a 1 to 100 scale on the energy performance curve which gives relative meaning to energy use.



Use Portfolio Manager to find out where you are

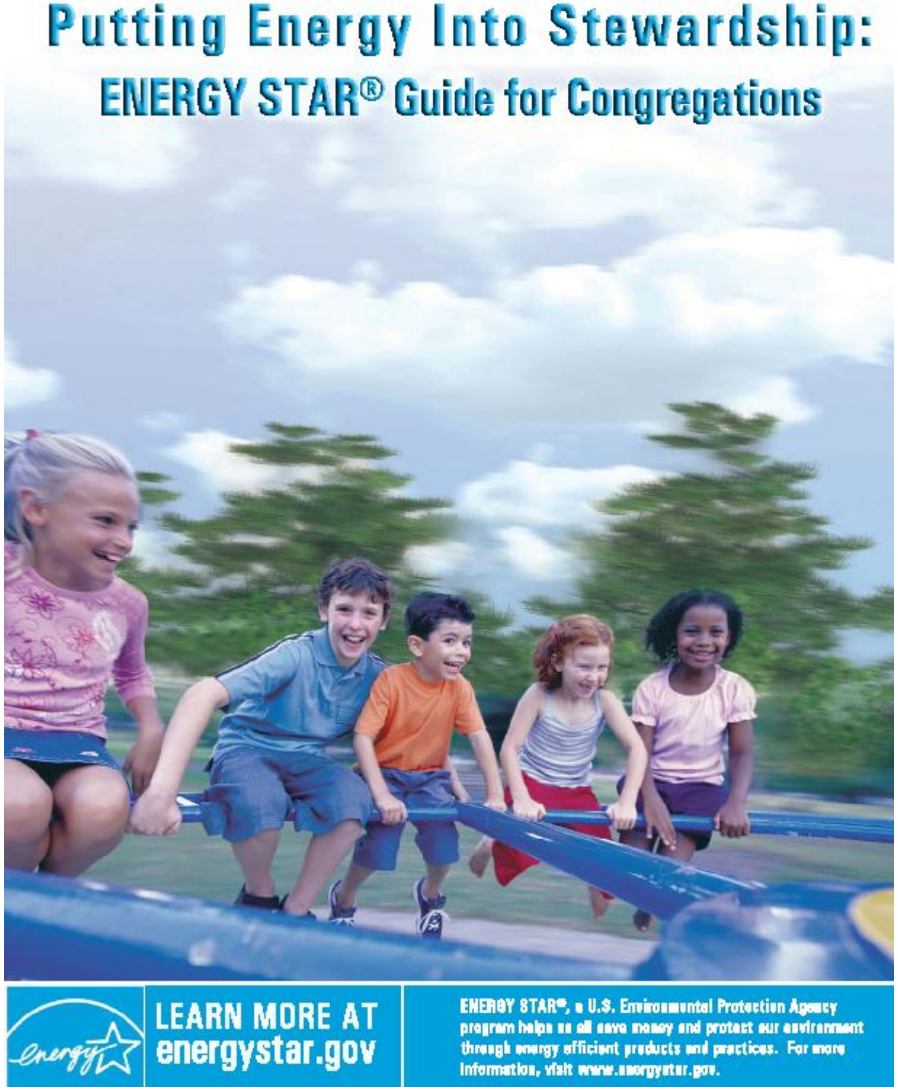
10 steps to Energy Efficiency

Many Federal and state funded programs offer guidance, advice, and sometimes free or low cost consulting services to building owners on energy efficiency and renewables.

Together, the priority on what to do first, second, etc., tends to all agree with the sequence offered here!

1. Benchmark your building
2. Retrofit old lighting
3. Install occupancy sensors
4. Upgrade inefficient mechanical systems
5. Install demand control ventilation
6. Install a controls system
7. Upgrade envelope
8. Control Plug Loads
9. Develop an energy program
10. Consider Renewables

ENERGY STAR Guides



Please avail yourself of the free resources at DOE's Energy Star website.

Use "Portfolio Manager" to establish a baseline for each facility, then use it to compare each building or campus to similar buildings in the same climate (a Benchmark study).

Continue to use these resources as you work toward a more sustainable future.

Part 2: Four Alternative Energy Technologies

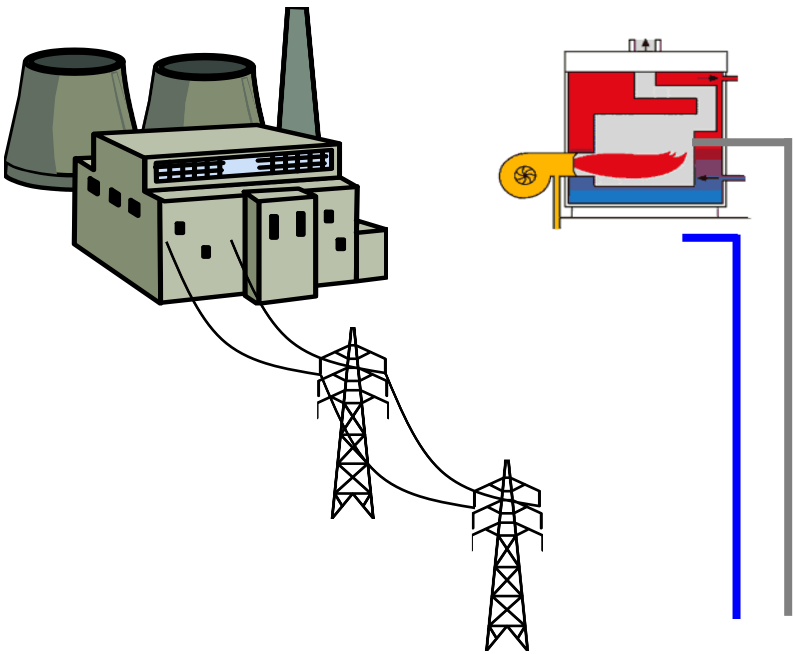
A Primer on a leading EE strategy: CHP

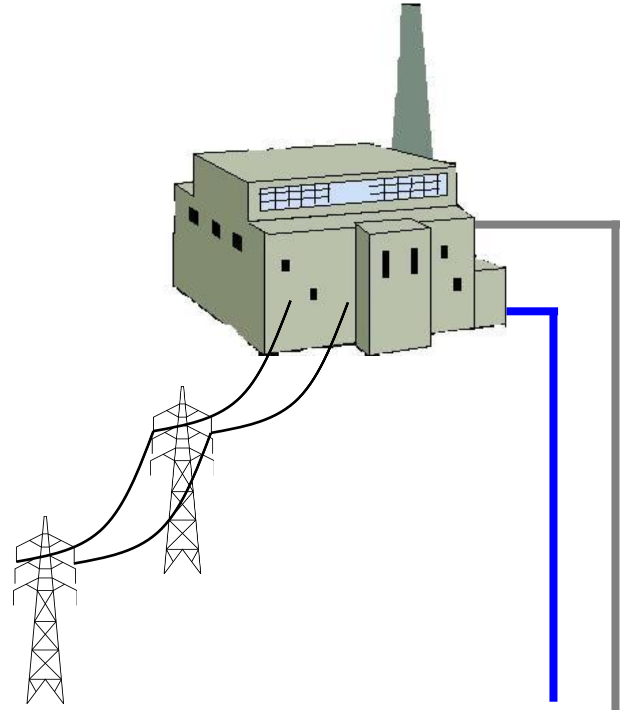
A Photo Album of Building Mounted Photovoltaic Systems

Basics to know for Urban Turbines

An Introduction to Ground Source Heat Pump Systems

Combined Heat and Power





<u>Convention</u>: Separate power and heat

<u>Alternative</u>: Combined power and heat

CHP – Definition & Clarifications

CHP is an energy efficiency "strategy"
or an "approach" toward greater energy efficiency.
*It is not by itself an alternative energy **generating** technology*

- CHP = Generating electricity or useful heat from one integrated system.
  It uses what would otherwise be "Waste Heat" after doing other work.

- "Waste Heat" is *a waste by-product* from some other process.
- CHP strategies use otherwise "waste" heat to:
  - generate electrical power, or
  - accomplish other heat based processes or purposes.
- Examples:
  - Run a **Micro-Turbine** to generate electrical power and use the heat for space heating!
  - Use excess heat to run an **absorption chiller** for Air Conditioning!
- Efficiency:
  - A coal fired power plant "efficiency" = 45% (55% of coal's energy is "lost" as heat)
  - *CHP can use this otherwise "lost" heat to drive turbines!*
  - ***CHP can raise overall efficiency from 45% to as much as 80%!***

CHP – Nomenclature Clarifications

Heat & Power Synonyms or related other terms in use:

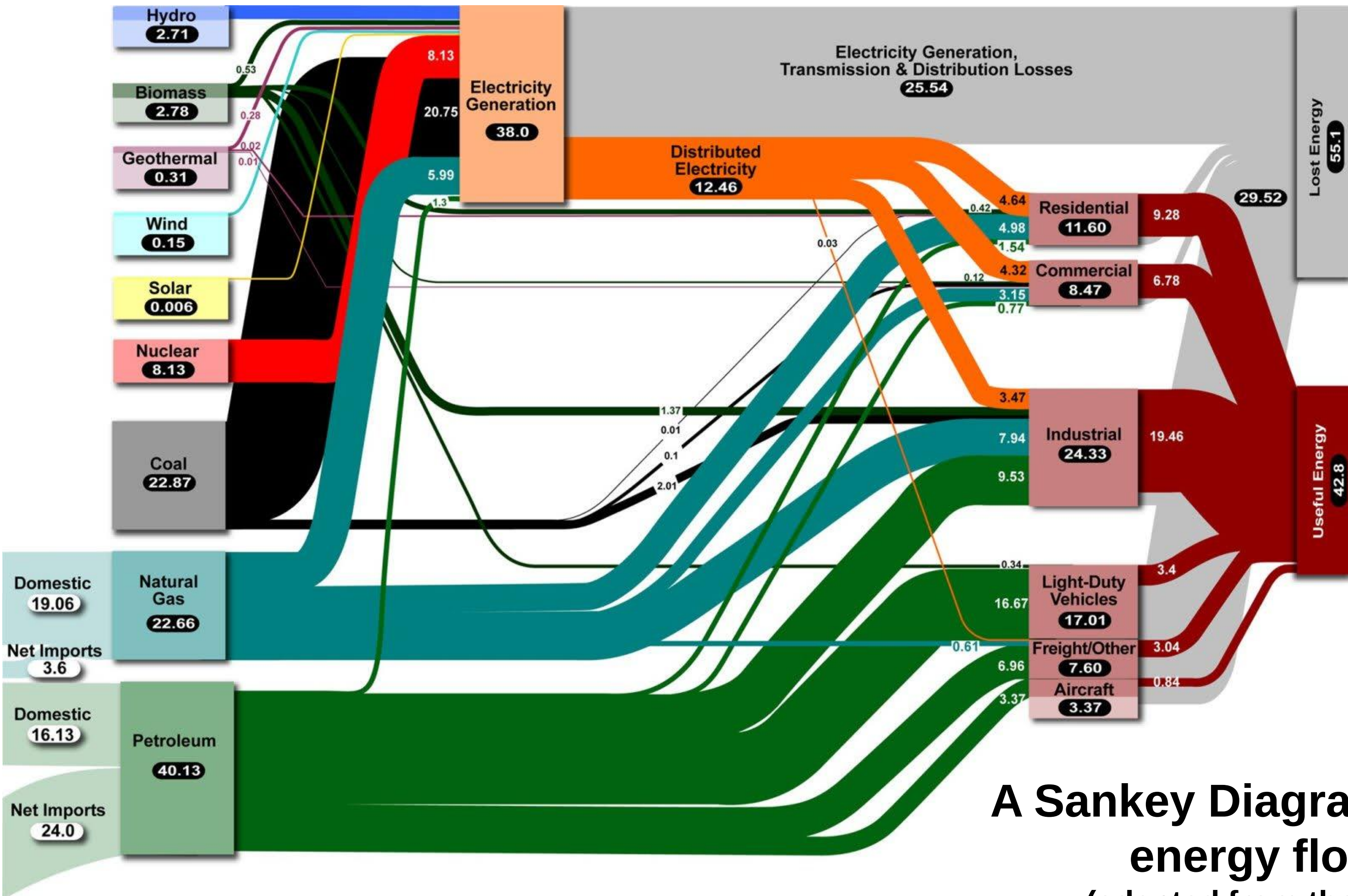
- **Combined Heat & Power -** (CHP of course)
- **Cogeneration -** Often in conjunction with NG "Peaker" Turbines
- **"Cogen" -** Usually specific only to electricity generation.
- **Combined Heat And Power -** (CHAP)
- **Combined Heat and Energy -** (CHE)
- **Combined Heat Power -** (also CHP)

Heat, Power, and Cooling Synonyms

- **Trigeneration** and
- **"Trigen" -** Simultaneous production of ***electricity, heat and cooling*** in a single plant!

  *Uses EXCESS heat for Air Conditioning or Refrigeration or other Cooling by **absorption cooling**.*
- **Building Cooling Heating & Power -** (BCHP)
- **Integrated Energy System -** (IES used by USDOE)
- **Combined Cooling Heating & Power** - (CCHP)

The Nation's Energy Flow Accounts



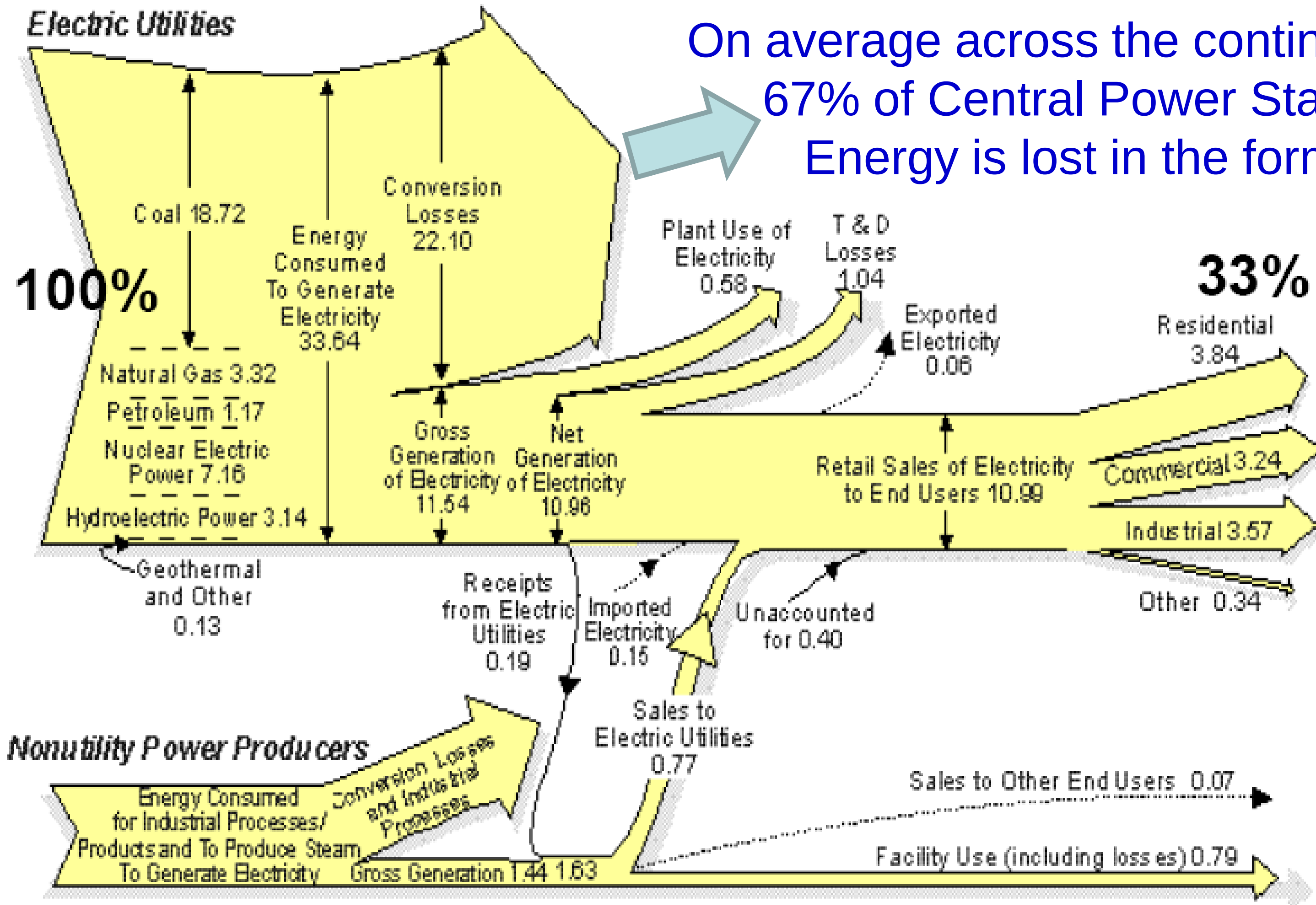
The bulk of this "lost" energy is lost as "waste" heat.

A Sankey Diagram of US energy flow

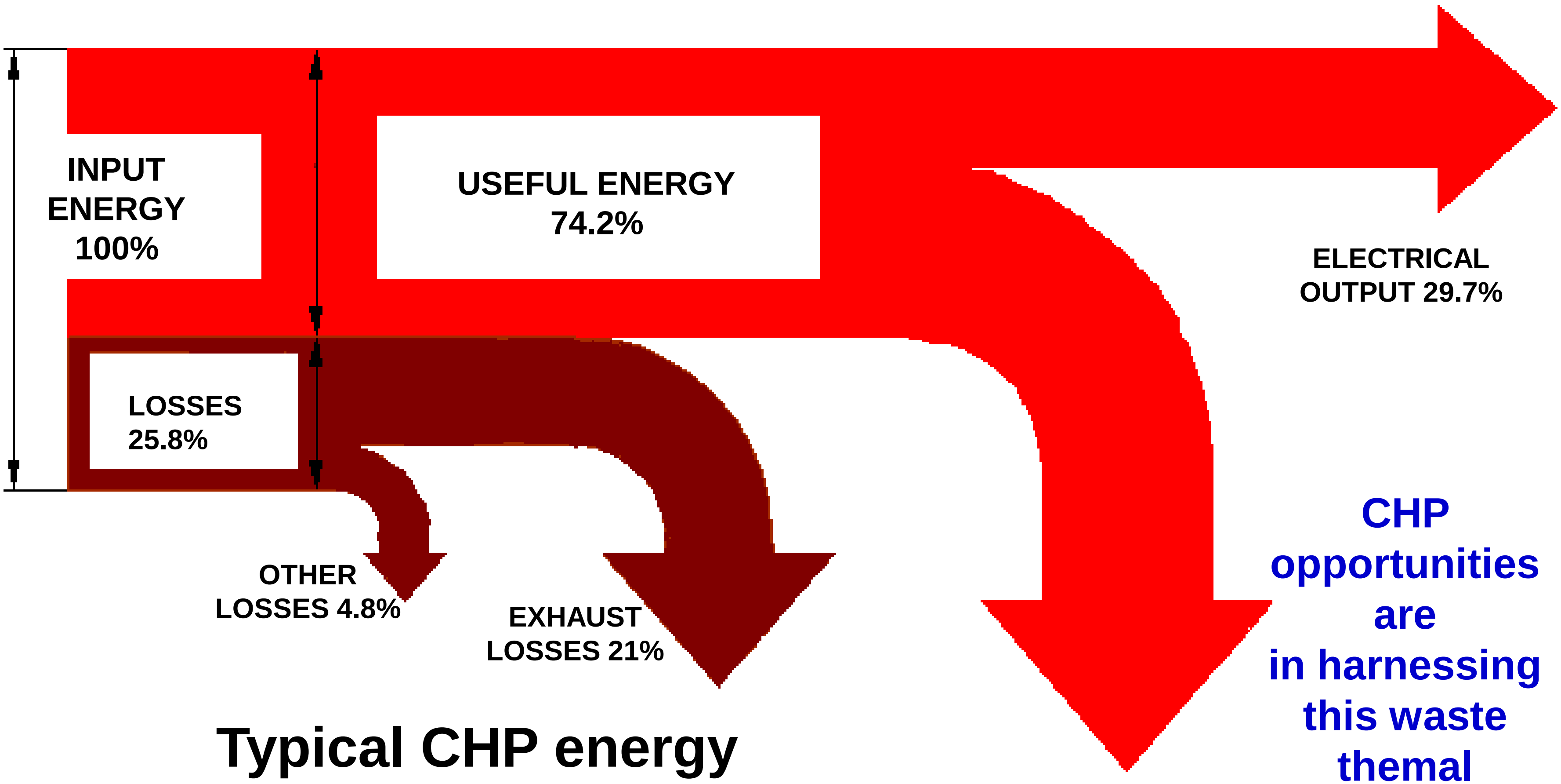
(adapted from the EIA)

The Nation's Power Grid Energy Flow

On average across the continental US, 67% of Central Power Station Input Energy is lost in the form of Heat.



CHP – The Key Concept



Typical CHP energy balance / flow / assessment

CHP opportunities are in harnessing this waste themal energy stream!

Slide Source: Presentation by Nitin Pathakji of Broad USA Inc.

CHP Benefits

Benefits for the operator

- Increased comparative advantage due to lower specific energy costs
- Price stability (with long term contract for fuel, no dependency on utility)
- Independent generation → security of supply
- Secure investment, if heat and power demand can be forecasted
- Independent generation → increase quality of electricity: stable frequency
- With more generation than consumption → Selling electricity can be a new source of income or opportunity

Benefits for the regulator

- Distributed generation:
  - reduced transmission losses
  - reduced need for grid investment
- Increased energy security
- Reduced prime energy consumption:
  - Lower dependency on imported fuels
  - Reduced overall emissions
  - Possibly lower Carbon Dioxide emissions

CHP – Typical Components

- **Prime Mover** generates mechanical energy
  - Turbine (Steam, Gas, micro)
  - Reciprocating Engine
  - Fuel Cell, etc.
- **Generator** converts mechanical energy to electrical energy
- **Waste Heat Recovery** is one or more heat exchangers that capture and use heat given off from the prime mover
- **Thermal Utilization** equipment converts the recycled heat into useful heating, cooling, and/or perhaps dehumidification
- **Operating Control Systems** ensure the CHP components function properly together

Slide Source: Presentation by John Cuttica, UIC – for Wilbur Wright College 2008

CHP – The Prime Movers

- **Steam Turbines:** Large Industrials with Waste Streams, Large Pressure Drop Requirements
  Up to 500 MW Capacity

- **Industrial Gas Turbines:** Provides High Pressure, Usually over
  3 to 4 MW in Capacity
  10s of MW with CHP Applications

- **Reciprocating Engine:** Provides Hot Water / Low Pressure Steam
  5 kW to 10 MW in Capacity

- **Micro-Turbines:** Provides Hot Water (≈ 500^{o} F Exhaust), Fuel Flexibility, Compact Size
  25 kW to 400 kW in Capacity

- **Fuel Cells:** Extremely Clean, Very Expensive
  250 kW modules integrated into systems delivering 10s of MW

Slide Source: Presentation by John Cuttica, UIC – for Wilbur Wright College 2008

CHP – System Size Terminology

- **Micro:** Typically below 60 kW - applicable to small residential & small commercial buildings.
- **Mid:** Up to several Mega-Watts - suitable for commercial buildings, multi-family housing, light industrial property. Pre-engineered package units may make sense.
- **Large:** 10+ Mega-Watts - suitable for industrial and large commercial buildings. Often multiple package units are used. Almost always a custom engineered system is needed.
- **Mega:** 50 to 100+ Mega-Watts – Very large systems, perhaps district scale with a mix of a central large CHP facility and satellite installations with multiple package units. Always a custom engineered solution.
- **District Scale:** Varies, with key aspect being multiple buildings being served by one system.

Slide Source: Presentation by John Cuttica, UIC – for Wilbur Wright College 2008

Types of Electrical Generators for CHP

Induction

- Requires External Power Source to Operate (Grid)
- When Grid Goes Down, CHP System Goes Down
- Less Complicated & Less Costly to Interconnect
- Preferred by Utilities

Synchronous

- Self Excited (Does Not Need Grid to Operate)
- CHP System can Continue to Operate thru Grid Outages
- More Complicated & Costly to Interconnect (Safety)
- Preferred by CHP Customers

CHP with a Fuel Cell?

- Power from a Fuel Cell is DC, so it requires an Inverter!

Slide Source: Presentation by John Cuttica, UIC – for Wilbur Wright College 2008

CHP – Classifications

CHP Systems are usually classified by their "prime movers:"

- Steam turbines
- Combustion turbines
- Reciprocating engines
- Microturbines
- Fuel cells

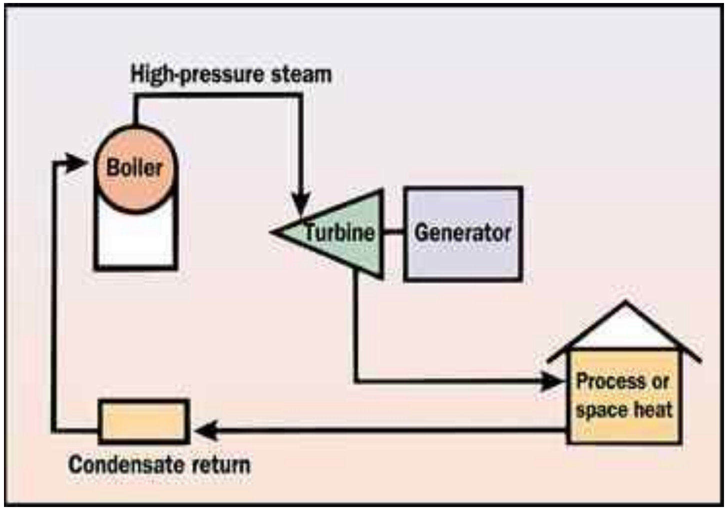
CHP Turbines are also referred to as being:

- Topping cycle
- Bottoming cycle

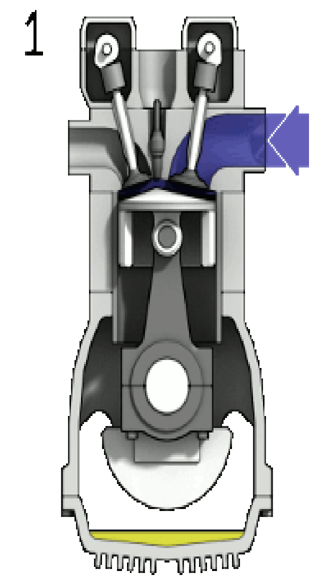
CHP power plants can also be referred to as:

- Serving base load
- Load following
- Peaking power

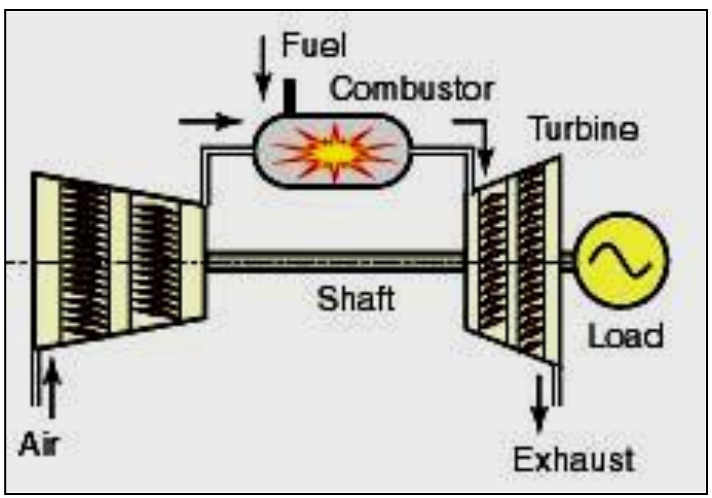
CHP – Prime Movers



Steam Turbines



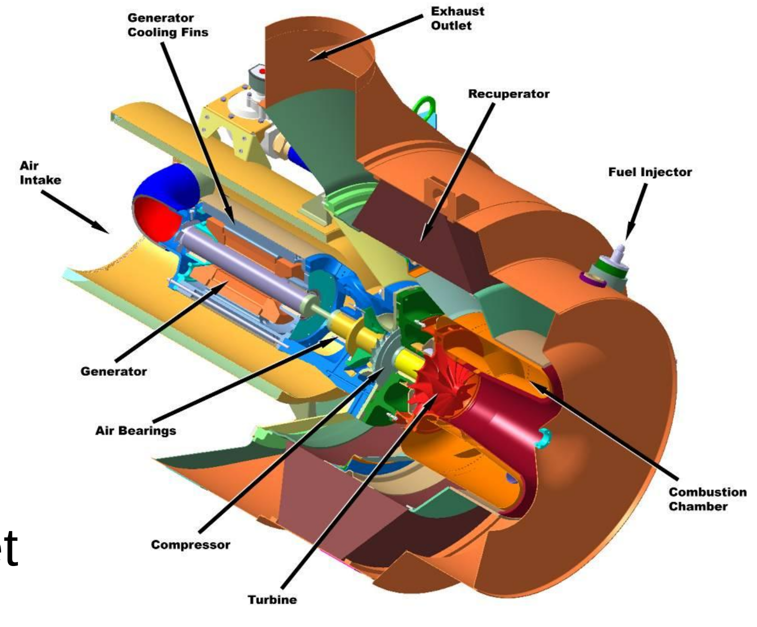
Reciprocating Internal Combustion Engines (RICE)



Gas Turbines

CHP – Micro-Turbine Prime Movers

- Consists of compressor, combustor, and turbine



C200 Capstone MicroTurbine Engine

In the Commercial / Industrial market

- Capstone Turbine Corporation
- Elliott Energy systems
- Bowman Power Systems
- Ingersoll-Rand Company
- Turbec AB

Microturbine Advantages / Disadvantages

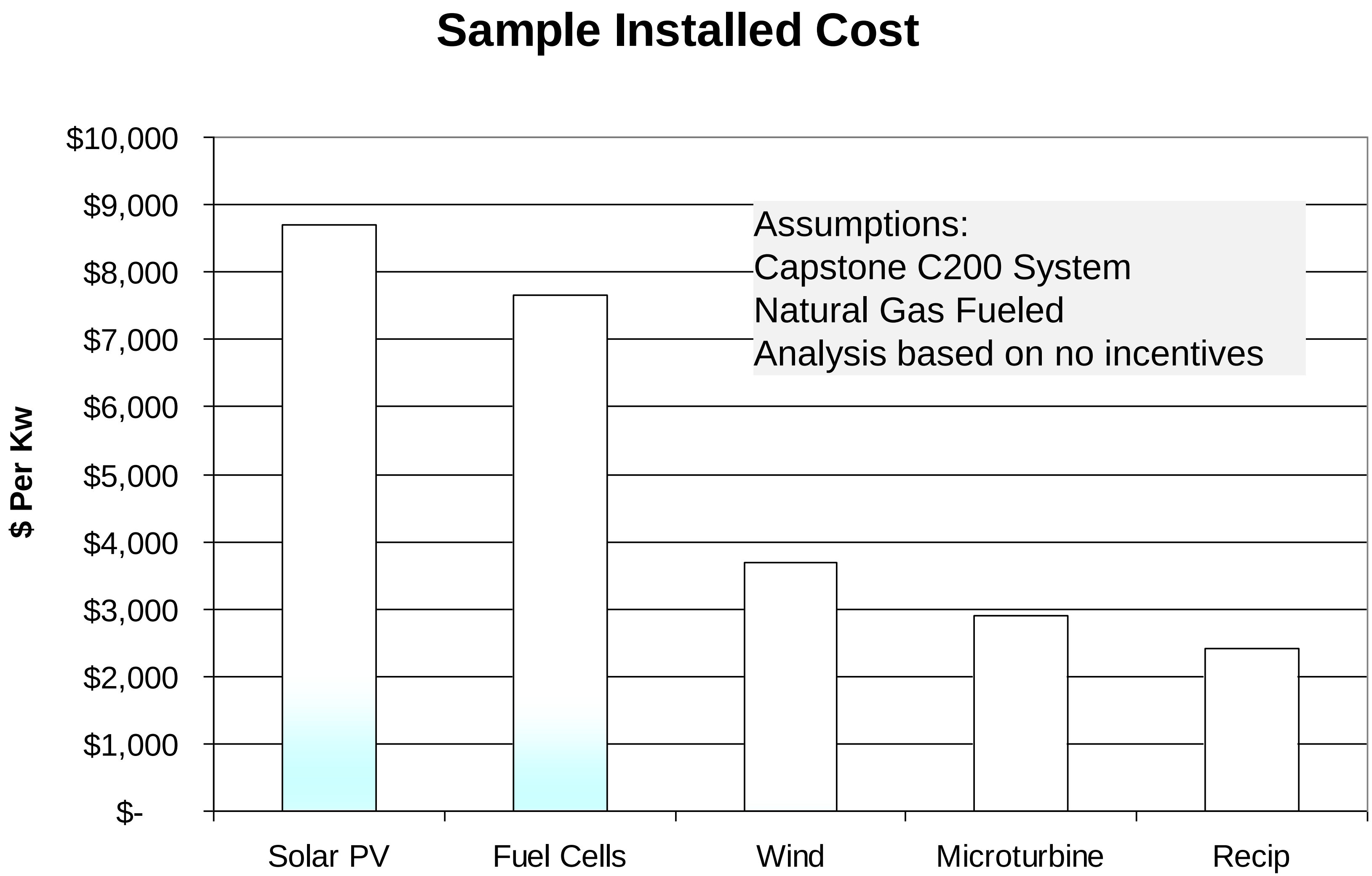
Benefits & Advantages:

- Scalable!
- Compact with small footprints
- Lightweight – for upper floors!
- Good total efficiencies with CHP (>80%)
- Low emission (NOx < 7 ppm w/ NG)
- Can use what might otherwise be waste fuels
- Reliability & Durability (11,000+ hrs MDT)
- Long maintenance intervals (5,000 to 8,000 hrs)
- No vibration & much less noise than RICE
- Often can be adapted into existing systems
- DG: Power produced on site where needed, as needed
- DG: Can serve as stand-by power or to shave peak power demand

Disadvantages:

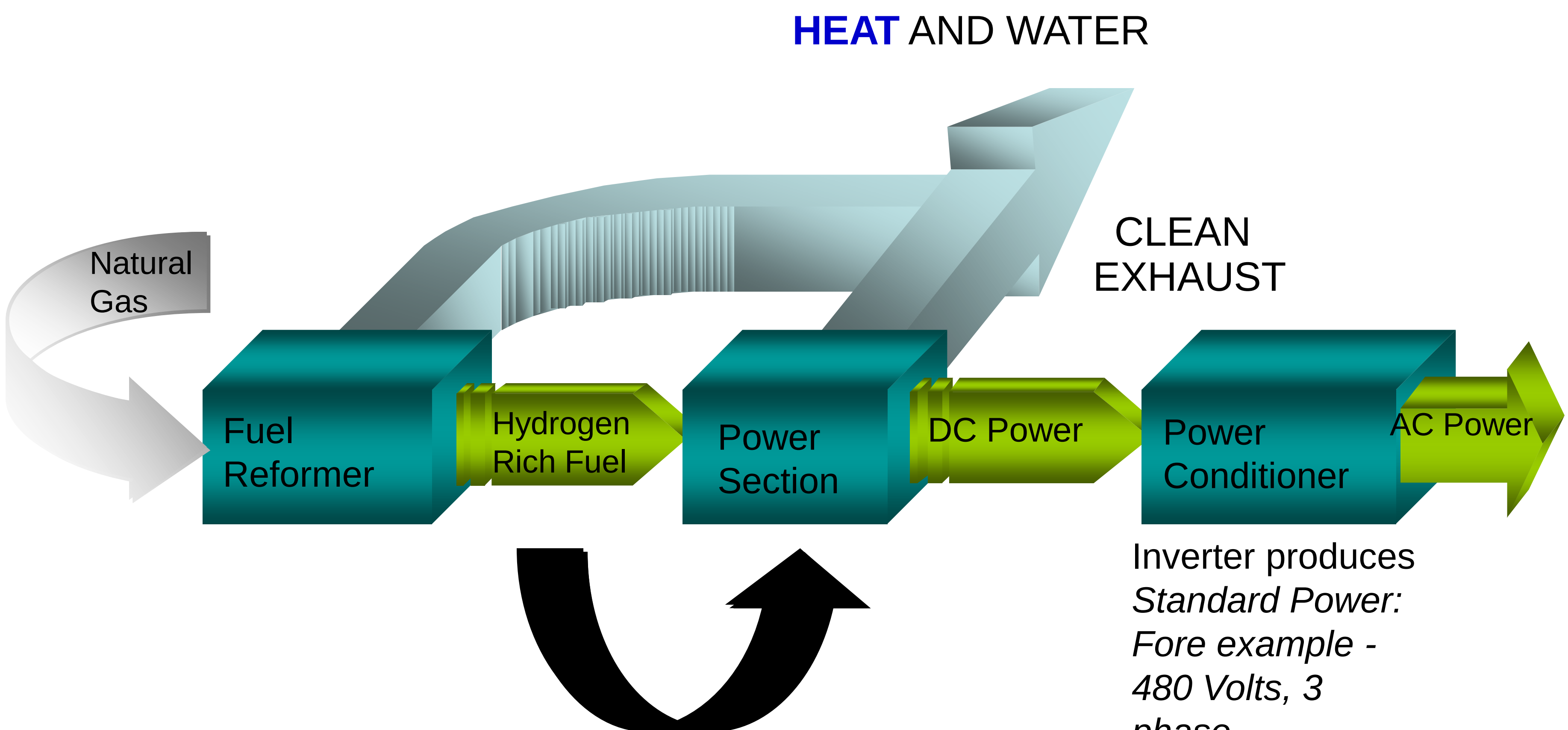
- High initial investment
- Low fuel-to-electricity only efficiencies (therefore, CHP)
- Loss of power output and efficiency with higher ambient temperature and higher elevation
- Installations for temporary “off-grid” operation require islanding electrical isolation and control

Microturbines – A Comparison



Slide source: Darren Jamison Capstone Presentation PowerGen June 2008

CHP – Fuel Cells as "Prime Mover"



Inverter produces
Standard Power:
Fore example -
480 Volts, 3 phase,
3 wire, 60Hertz

Source: Midwest CHP Application Center

Slide Source: Presentation by John Cuttica, UIC – for Wilbur Wright College 2008

Fuel Cells – Types

Alkali (AFC)

Solid Oxide (SOFC)

Phosphoric Acid (PAFC)

Proton Exchange Membrane (PEM)

Molten Carbonate (MCFC)

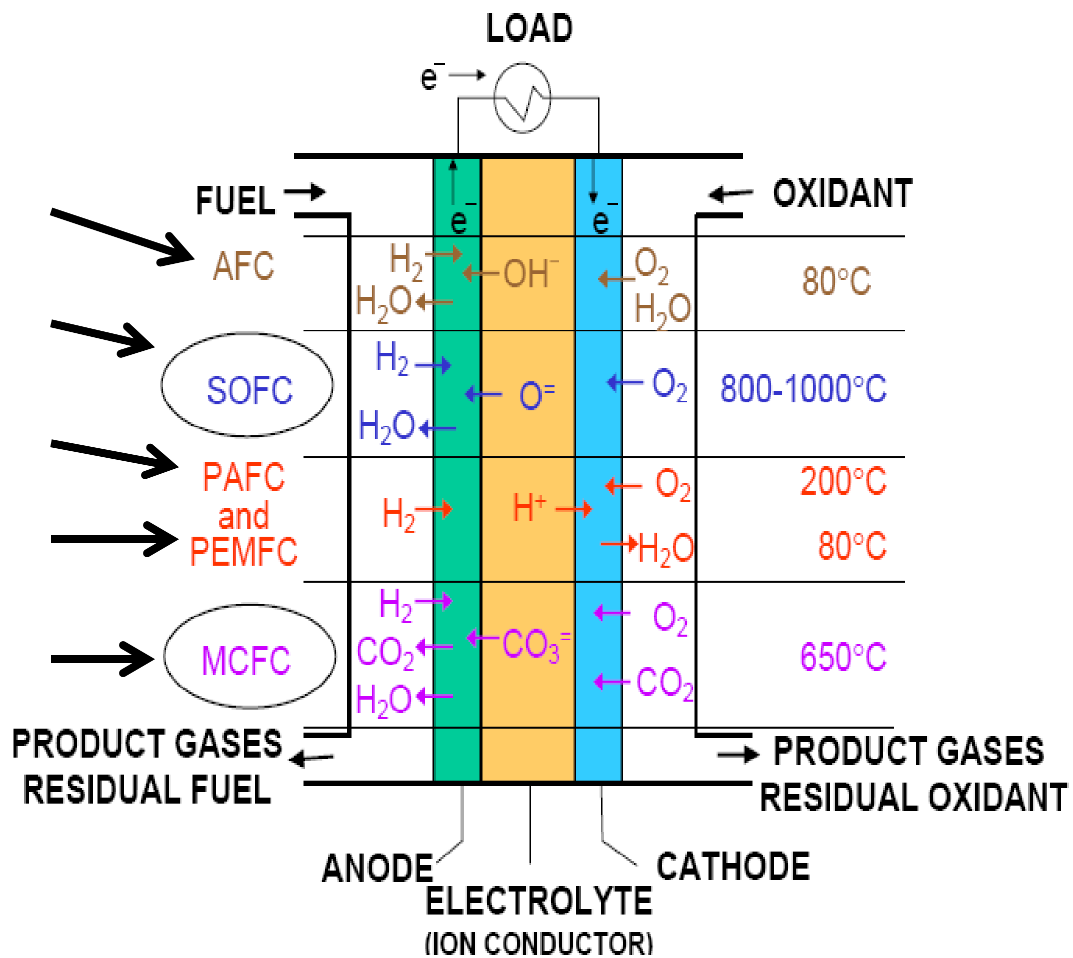
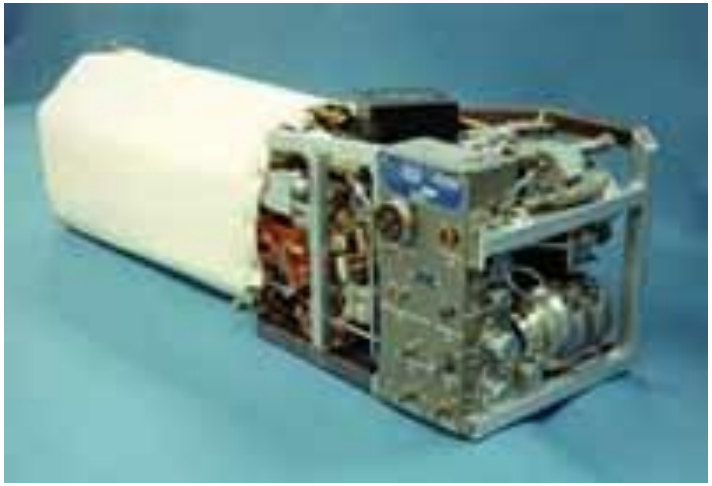


Image source: http://americanhistory.si.edu/fuelcells/origins/origins.htm

Fuel Cells – Low Temperature Systems

Proton Exchange Membrane (PEM)
50 kW
Ballard

Phosphoric Acid (PAFC)
250 kW
United Technologies



Alkaline Fuel Cell (AFC)
Space Shuttle 12 kW
United Technologies

Fuel Cells – High Temperature Systems

Molten Carbonate (MCFC)
250 kW
Fuel Cell Energy

Solid Oxide (SOFC)
100 kW
Siemens-Westinghouse

CHP Priority: Power or Heat? Topping Cycle or Bottoming Cycle?

Power First – or Topping Cycle:

- Most CHP plants are designed to produce free heat that reduces the effective cost of electricity, and waste-heat is recycled to generate useful steam/hot water

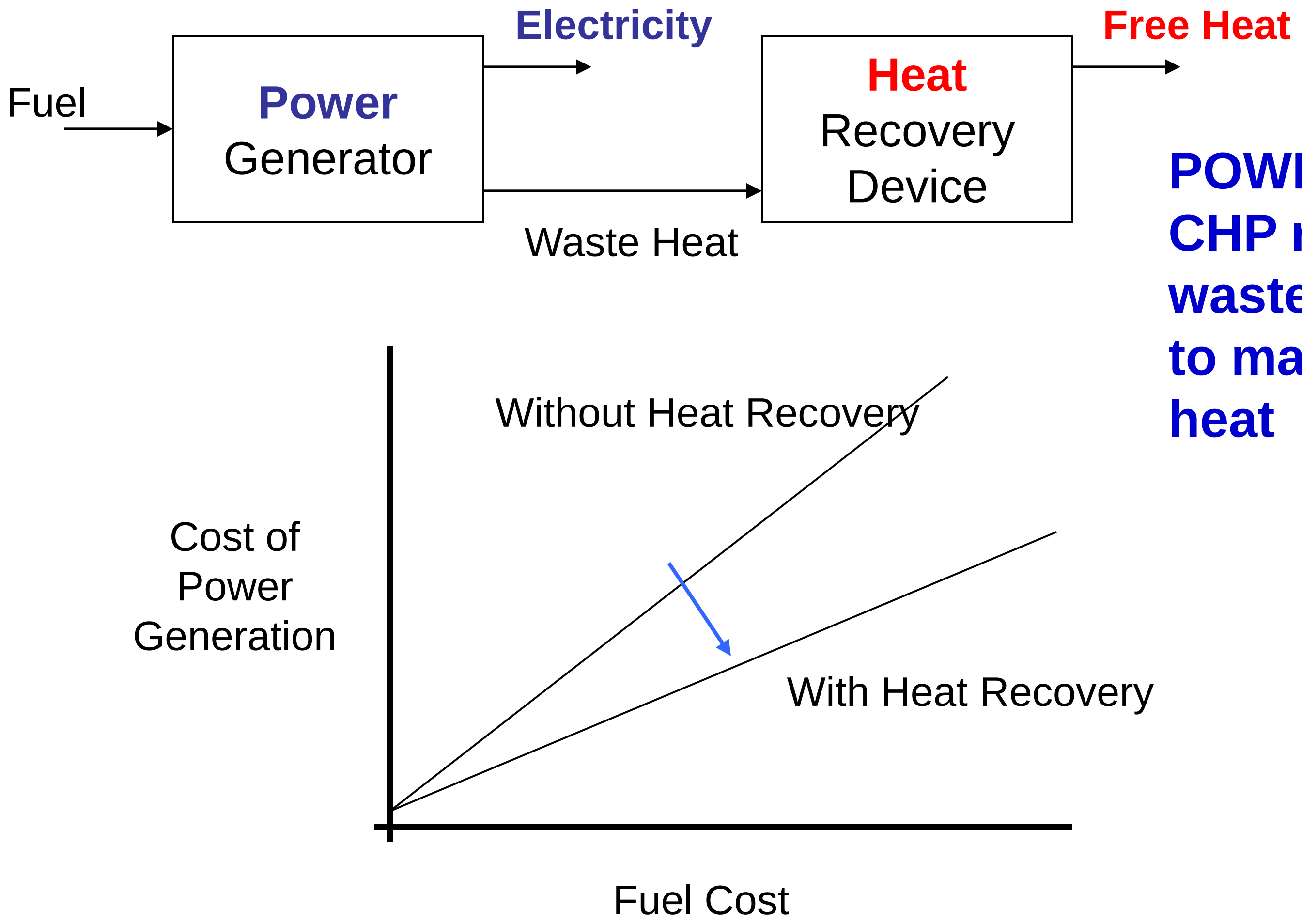
- *Examples abound.*

Heat First – or Bottoming Cycle:

- Some CHP is designed for "heat-first" to produce free electricity to reduce the effective cost of heat where waste heat *and/or pressure* is used to generate useful electricity.

- *Residential scale microturbine installations are examples of "Heat-first" CHP.*

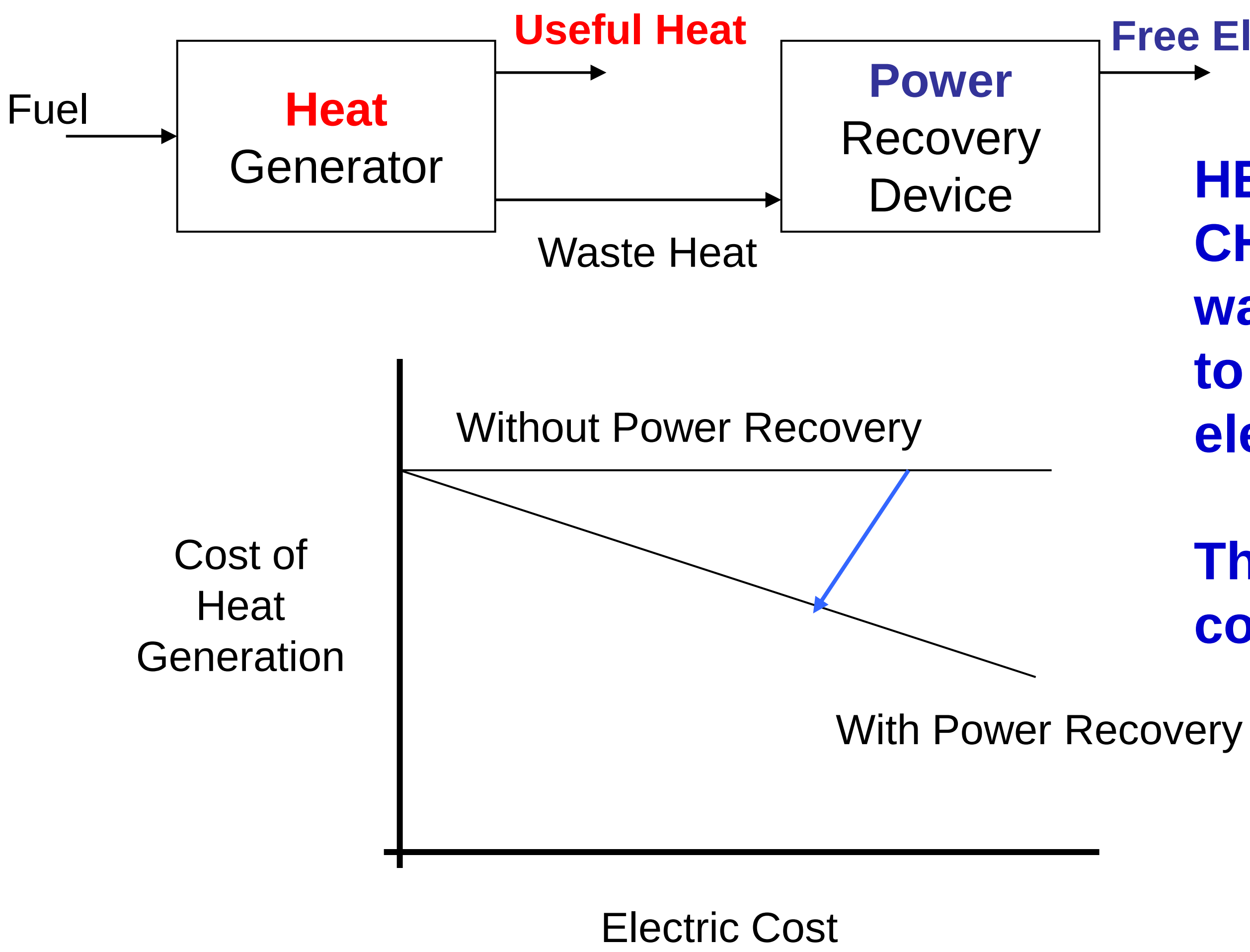
CHP – Priority: Power First (Topping Cycle)



POWER FIRST CHP recycles waste energy to make useful heat

Slide Source: Sean Casten, CEO www.turbosteam.com

CHP – Priority: Heat First (Bottoming Cycle)



HEAT FIRST CHP recycles waste energy to make electricity

These are less common.

Slide Source: Sean Casten, CEO www.turbosteam.com

CHP – Candidate Applications for CHP

CHP Configurations

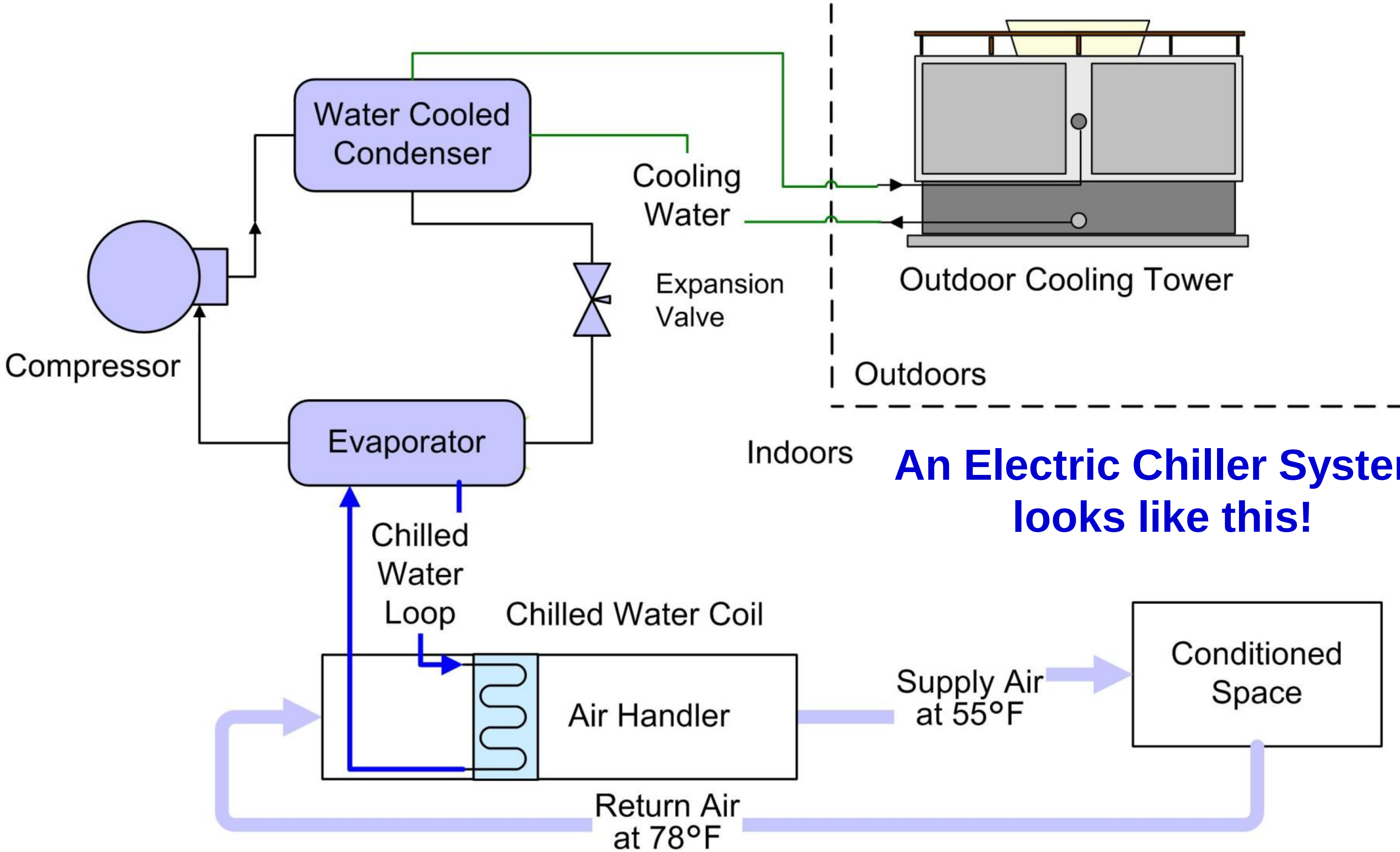
- Space heating (either Steam or Hot Water)
- Hot water heating (example: Swimming pool)
- Space Cooling (absorption cooling)

What Makes for Good CHP?

- Good coincidence between thermal & electric loads
- High cost difference between electricity and CHP fuel
- Fair / Favorable regulatory environment
- High value of Power Reliability – operations that must not lose power
- Long operating hours

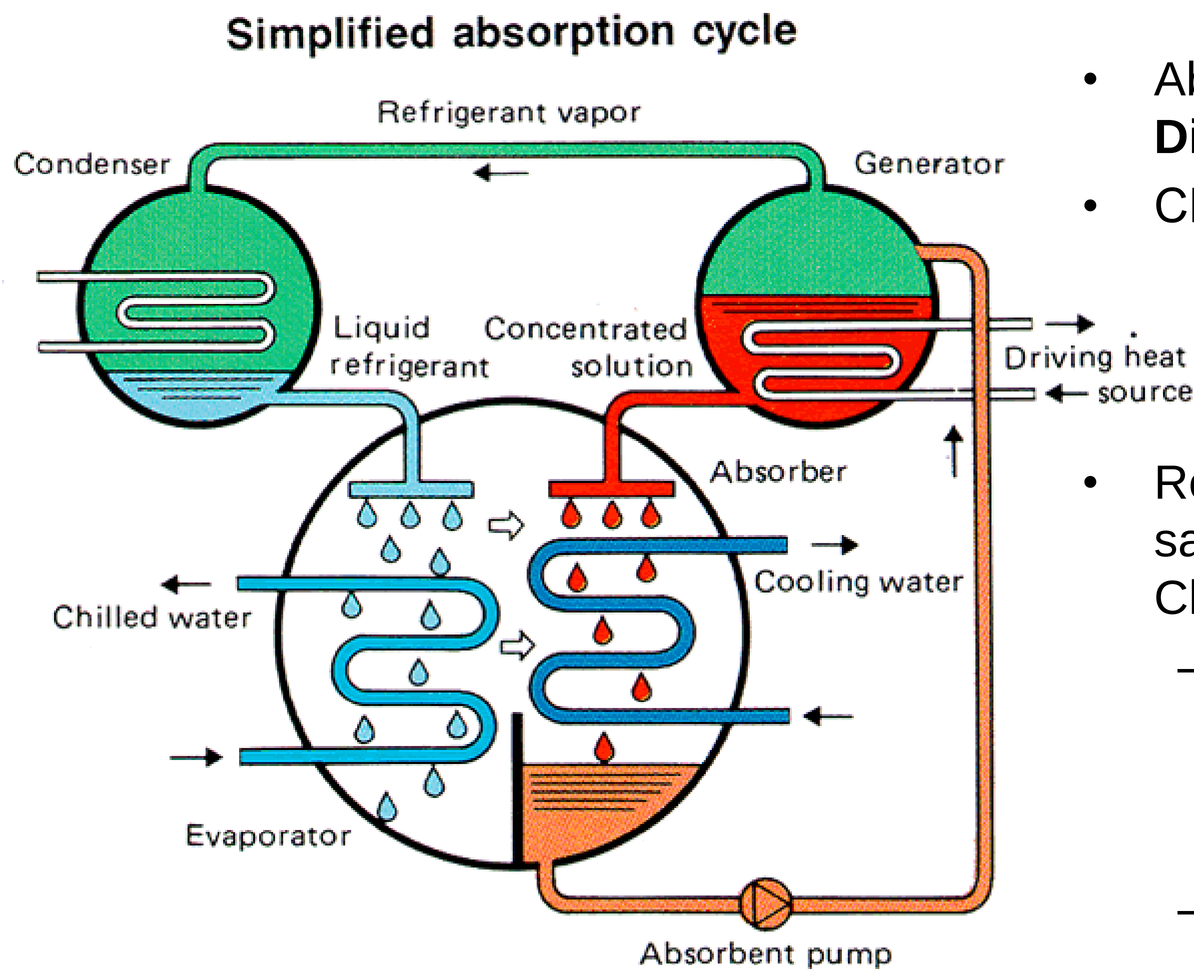
Slide Source: Presentation by John Cuttica, UIC – for Wilbur Wright College 2008

CHP Heat – Absorption Chillers!



An Electric Chiller System looks like this!

CHP Heat Uses – Absorption Chillers



- Absorption Chillers can be **Direct Fired** or **Indirect Fired**
- CHP is "Indirect Fired" type

- Refrigeration Cycle is the same as with an Electric Chiller with these differences :
  - Electric/Mechanical Compressor Replaced with an Absorber/ Generator
  - Refrigerants are Different

E

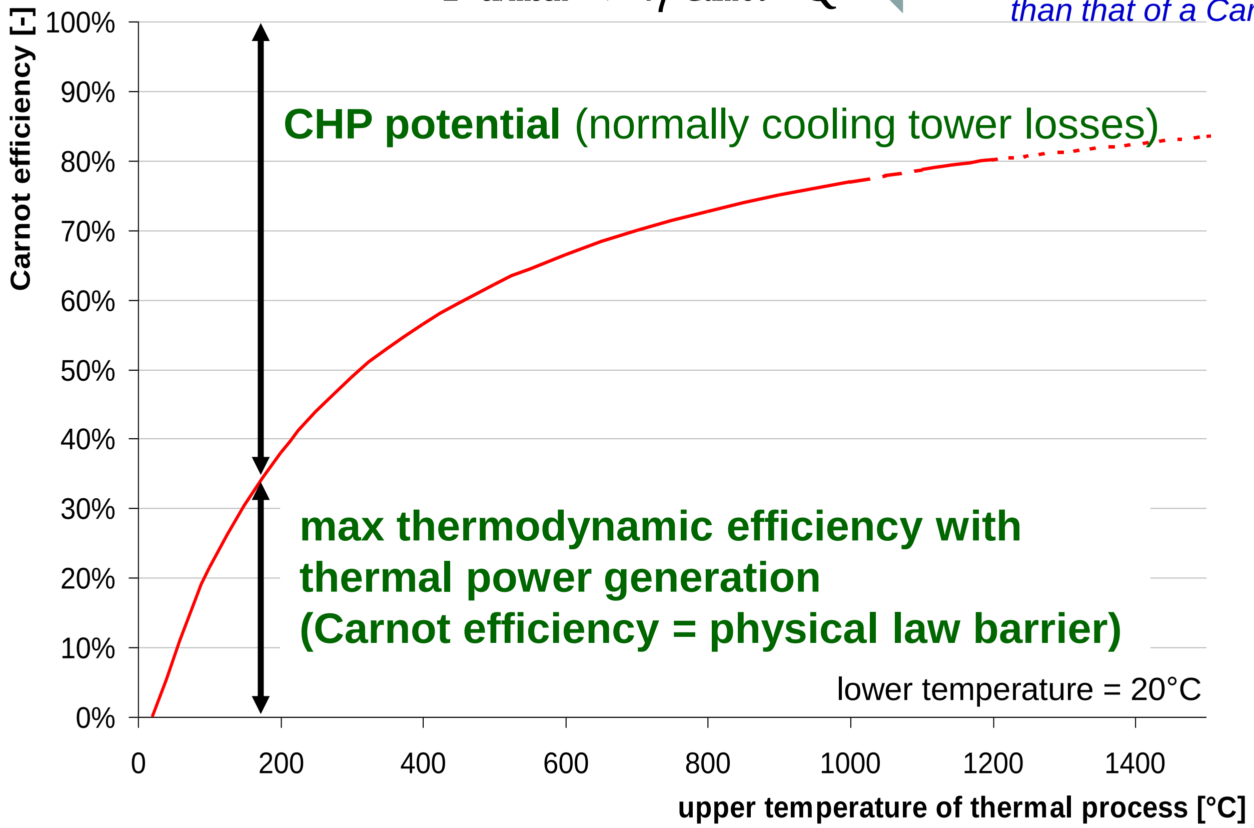
CHP - Where do the savings comes from?

$$\eta_{Carnot} = \frac{T_{upper} - T_{lower}}{T_{upper}}$$

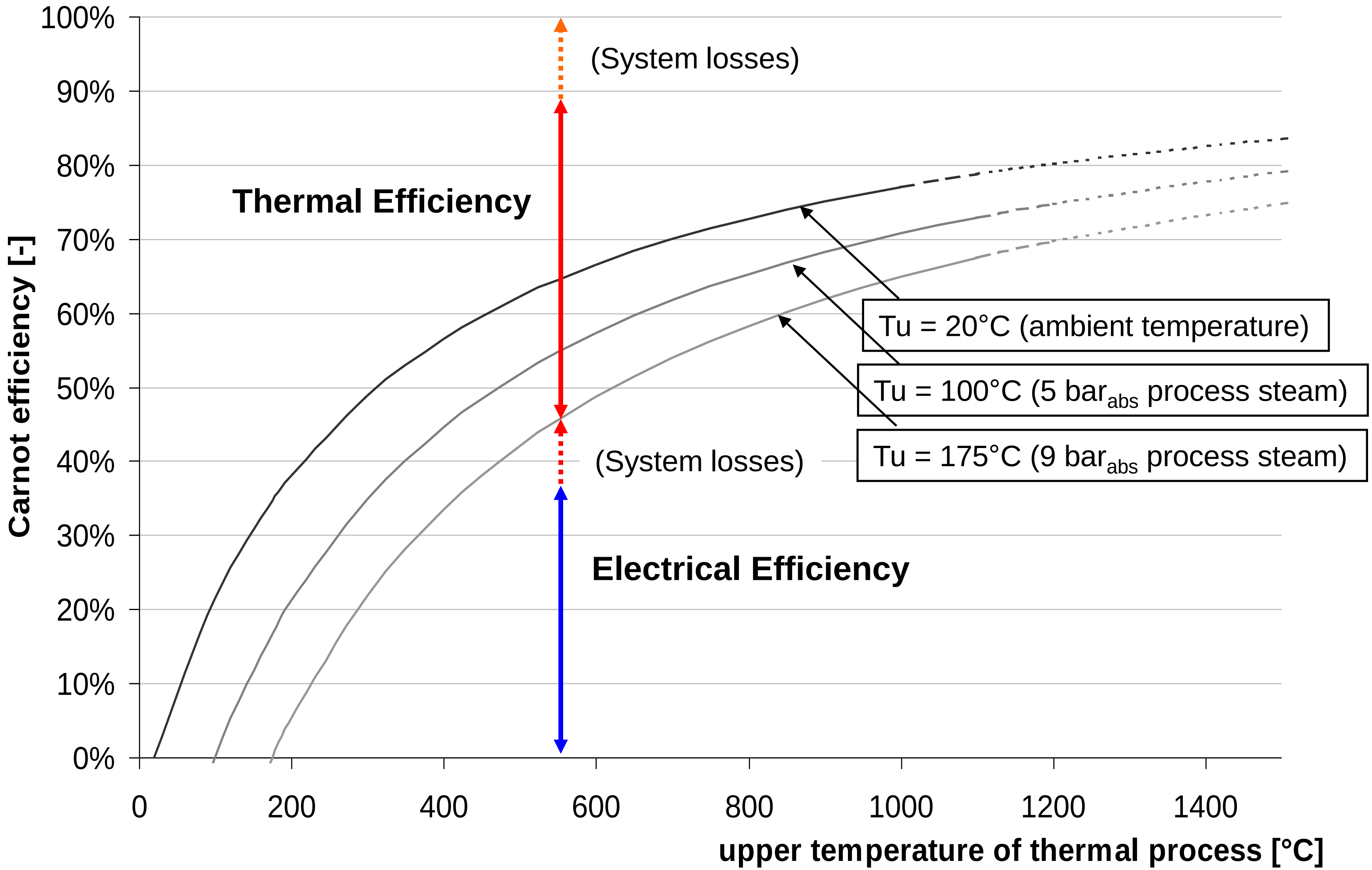
$$P_{el/mech} <= \eta_{Carnot} * Q$$

Of course, Electrical Power from any heat engine prime mover will be less than that of a Carnot heat engine!

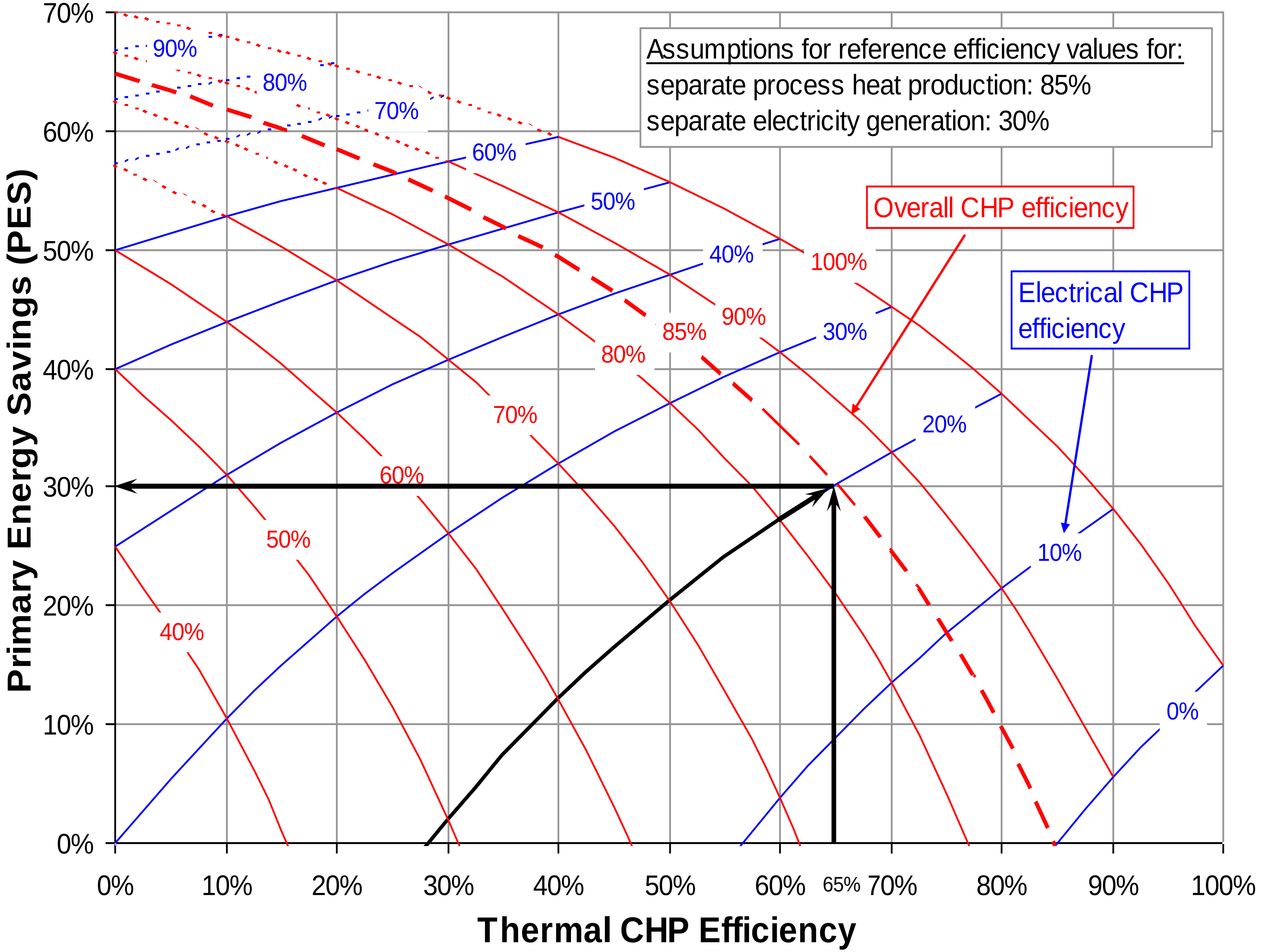
Carnot Efficiency:



CHP - Where do the savings comes from?



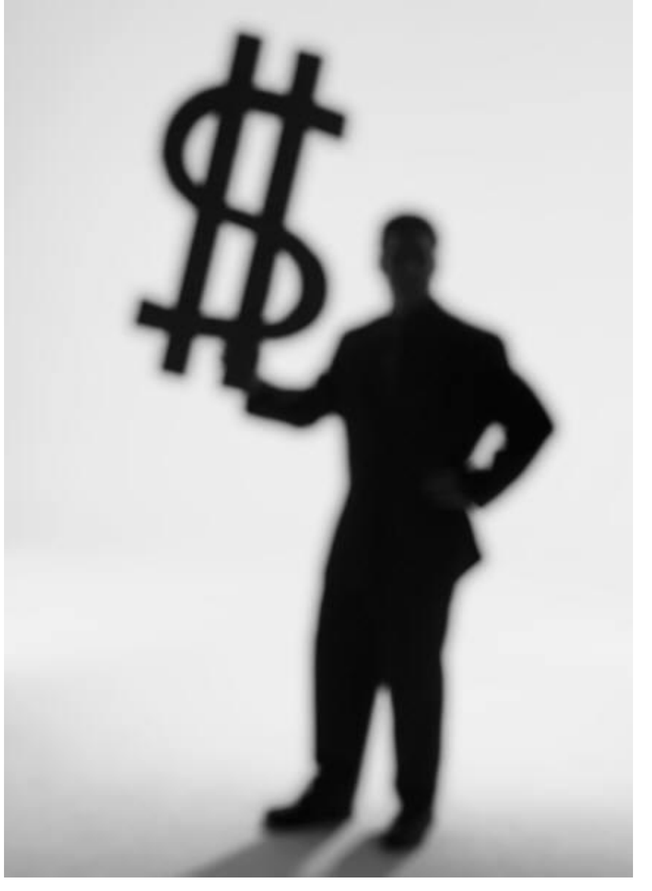
CHP - Where do the savings comes from?



Spark Spread

Definition: Cost differential between electricity and natural gas

Purpose: Offers a first cut, very rough screening of the viability of CHP at a facility <u>**based solely**</u> on the average prices of natural gas and electricity.



Slide Source: Presentation by John Cuttica, UIC – for Wilbur Wright College 2008

Steps to Determining Spark Spread

1. Determine the Average Annual Electric Cost in dollars per million Btu ($/MMBtu)

2. Determine the Average Gas Cost in dollars per million Btu ($/MMBtu)

3. Determine the gas/electric price difference… "Spark Spread"

4. Is the "Spark Spread" > $12/MMBtu?

Spark Spread Guide: If the Thermal to Power cost ratio is:

- 0.5 to 1.5 then consider an ICE (engine)
- 1 to 10 then consider a Gas Turbine
- 3 to 20 consider a Steam Turbine

Always use the same units for both T and P ***(use $/MMBtu)***

Slide Source: Presentation by John Cuttica, UIC – for Wilbur Wright College 2008

Spark Spread Cheat Sheet

1. Determine the Average Annual Electric Cost ($/MMBtu):				
a.	**Sum** the total cost for electricity from the last 12 months of bills:			
	Total Cost	$		
b.	**Sum** the number of kWh utilized over the last 12 months of bills:			
	Total kWh			kWh
c.	**Divide** the Total Cost by the Total kWh:			
	Average Annual Electric Cost	$		/kWh
d.	**Multiply** the **Average Annual Electric Cost** ($/kWh) by 293 to convert to $/MMBtu:			
	Average Annual Electric Cost	$		**/MMBtu**
2. Determine the Average Gas Cost ($/MMBtu):				
a.	a. **Sum** the total cost for gas from the last 12 months of bills:			
	Total Cost	$		
b.	b. **Sum** the number of Therms utilized over the last 12 months of bills:			
	Total Therms			Therms
c.	c. **Divide** the Total Cost by the Total Therms:			
	Average Annual Gas Cost	$		/Therm
d.	d. **Multiply** the **Average Annual Gas Cost** ($/Therms) by 10 (for NG) to convert to $/MMBTU:			
	Average Annual Gas Cost	$		**/MMBtu**
3. Determine the "Spark Spread":				
a.	Average Annual Electric Cost (1.d.) $ /MMBTU	$		/MMBtu
b.	Minus Average Annual Gas Cost (2.d) $ /MMBTU	$		/MMBtu
	Spark Spread	$		
4. Is the "Spark Spread" >$12/MMBtu? Yes / No			**Yes / No**	

Slide Source: Presentation by John Cuttica, UIC – for Wilbur Wright College 2008

J

Example - Determining Spark Spread

1.	**Determine the Average Annual Electric Cost ($/MMBtu):**			
a.	**Sum** the total cost for electricity from the last 12 months of bills: **Total Cost**	$	900,000	
b.	**Sum** the number of kWh utilized over the last 12 months of bills: **Total kWh**		12,000,000	kWh
c.	**Divide** the Total Cost by the Total kWh: **Average Annual Electric Cost**	$	$0.075	/kWh
d.	**Multiply** the **Average Annual Electric Cost** ($/kWh) by 293 to convert to $/MMBtu: **Average Annual Electric Cost**	$	21.98	**/MMBtu**
2.	**Determine the Average Gas Cost ($/MMBtu):**			
a.	a. **Sum** the total cost for gas from the last 12 months of bills: **Total Cost**	$	700,000	
b.	b. **Sum** the number of Therms utilized over the last 12 months of bills: **Total Therms**		1,000,000	Therms
c.	c. **Divide** the Total Cost by the Total Therms: **Average Annual Gas Cost**	$	0.70	/Therm
d.	d. **Multiply** the **Average Annual Gas Cost** ($/Therms) by 10 (for NG) to convert to $/MMBTU: **Average Annual Gas Cost**	$	7.00	**/MMBtu**
3.	**Determine the "Spark Spread":**			
a.	Average Annual Electric Cost (1.d.) $ /MMBTU	$	21.98	/MMBtu
b.	Minus Average Annual Gas Cost (2.d) $ /MMBTU	$	7.00	/MMBtu
	Spark Spread	$	14.98	
4.	**Is the "Spark Spread" >$12/MMBtu? Yes / No**		**Yes**	

Slide Source: Presentation by John Cuttica, UIC – for Wilbur Wright College 2008

General points on Combined Heat & Power

- CHP is “alternative energy” in North America, but is in such widespread use in some areas of Europe that it may be the “norm.”

- *After “Lighting” and “Shell” upgrades,* CHP may be the next most promising EE / Alternative Energy strategy for larger scale campuses and houses of worship, **particularly those with district or shared HVAC plant infrastructure.**

- “CHP” can include the emerging *and very scalable* technologies such as fuel cells and micro-turbines!

- Evaluating whether to pursue a CHP strategy may be best first assessed by using a “spark spread” analysis.

Wind Power Systems

Small Wind Systems Standards

- **The Small Wind Certification Council** (SWCC) part of Interstate Renewable Energy Council (www.irecusa.org)
  - Certify performance of small wind turbines <=65 kW or <=200 sq meters and certify that they meet or exceed the performance, durability, and safety requirements of the *American Wind Energy Assn Small Wind Turbine Performance and Safety Standard*.
  - Easy-to-understand labels for *SWCC:*
    - *Rated Annual Energy Output*
    - *Rated Power*,
    - *Rated Sound Level*
    - Currently in draft form and going through AWEA approval process. AWEA is accredited by the American National Standards Institute (ANSI) to write standards.

Small Wind: Example Cost Analysis

A Small Wind Case:

- Average residential electric use:
  7,600 kWh / year (or 7.6 MWh / year)
- A larger small wind turbine might be a 4 kW unit

4 kW in a 12% capacity factor location produces
= 4 kW x 0.12 x (365.25 x 24) hrs/year
= 5,256 kWh/yr (or 5.3 MWh/year)

- NOTE: Divide 5.3 by 7.6 yields 69% - *which means the turbine would furnish about a 70% of annual electricity use for an average home, assuming of course, there is enough wind.*

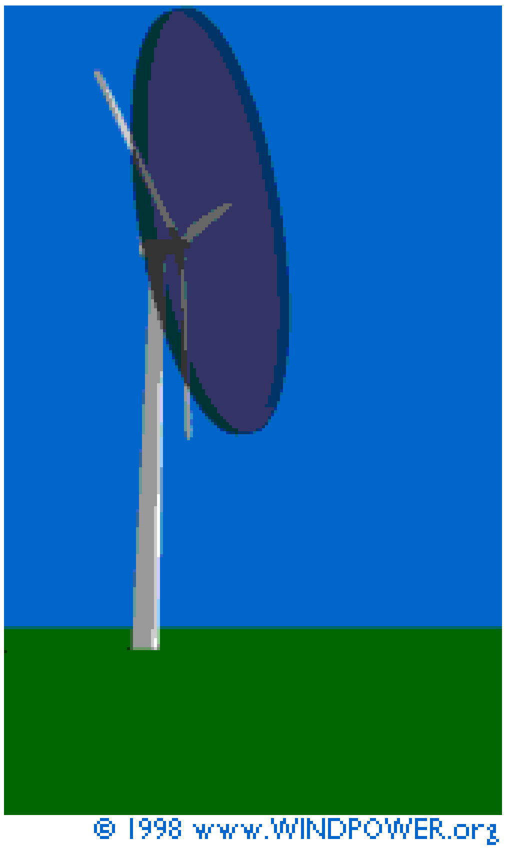
Small Wind: Wind Power Density “Classes”

Classes of wind power density at 10 and 50 meters (a)				
Wind Power Class	**10 meters (33 feet)**		**50 meters (164 ft)**	
	Wind Power Density (W/m^2)	**Average Annual Wind Speed (b) meters/ second (miles/hr)**	Wind Power Density (W/m^2)	**Average Annual Wind Speed (b) m/s (mph)**
1	**<100**	**<4.4 (9.8)**	**<200**	**<5.6 (12.5)**
2	**100<150**	**4.4<5.1 (9.8<11.5)**	**200<300**	**5.6<6.4 (12.5<14.3)**
3	**150<200**	**5.1<5.6 (11.5<12.5)**	**300<400**	**6.4<7.0 (14.3<15.7)**
4	**200<250**	**5.6<6.0 (12.5<13.4)**	**400<500**	**7.0<7.5 (15.7<16.8)**
5	250<300	6.0<6.4 (13.4<14.3)	500<600	7.5<8.0 (16.8<17.9)
6	300<400	6.4<7.0 (14.3<15.7)	600<800	8.0<8.8 (17.9<19.7)
7	400<1000	7.0<9.4 (15.7<21.1)	800<2000	8.8<11.9 (19.7<26.6)

a = Vertical extrapolation of wind speed based on 1/7 power law

b = Mean wind speed based on Rayleigh speed distribution at standard sea level conditions *www.nrel.gov/gis/wind.html*

Estimating Annual Energy Output



- Annual Energy Output = AEO

  $AEO = 0.01328 \times D^2 \times V^3$

  D = diameter in feet V = avg. speed in mph

- An Example: A turbine with 20 ft long blades mounted in a Class 3 wind (7 mph) location:

  $AEO = 0.01328 \times (2 \times 20)^2 \times 7^3$

  $AEO = 0.01328 \times 1600 \times 343$

  AEO = 7,288 kWh-year

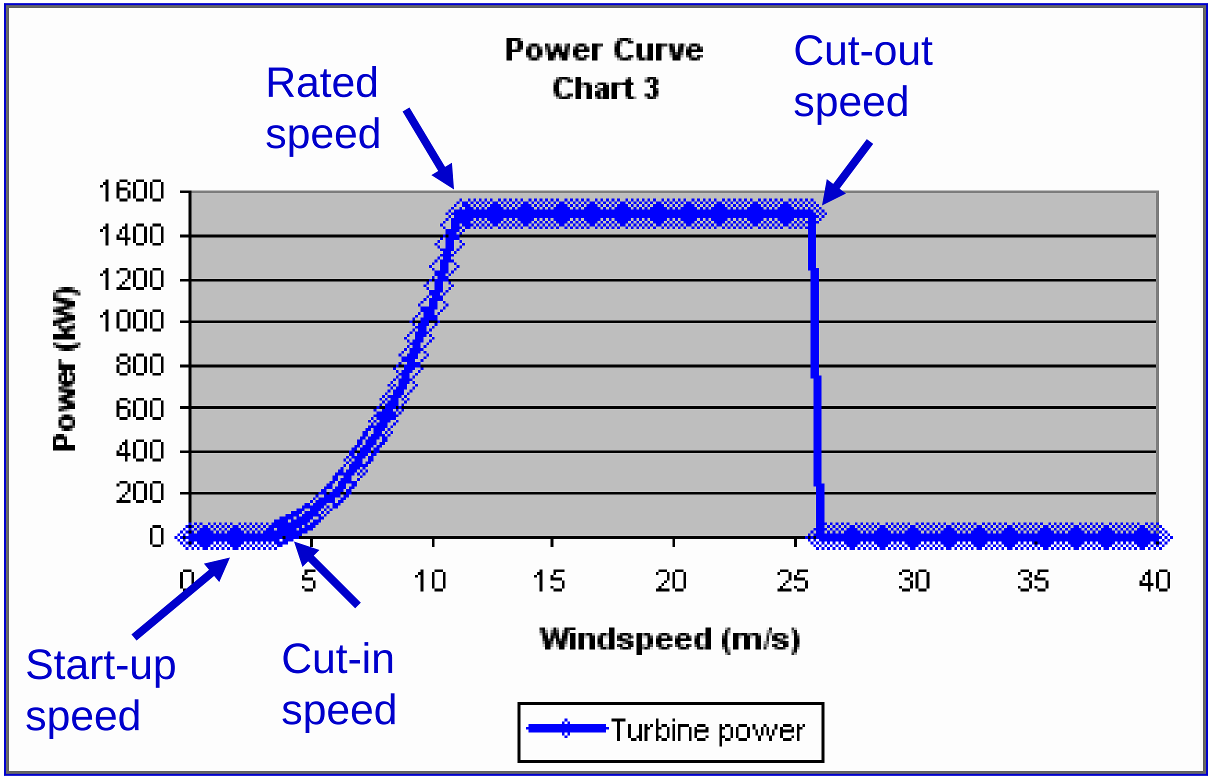
- The factor 0.01328 is derived from the wind power equation and several “constants” like air density, unit conversions, and typical power coefficients

Turbine Vocabulary for Wind Speeds

- **Start up speed** – what starts the turbine moving
- **Cut in speed** – when it begins to generate usable electricity
- **Rated speed** – when it generates the DC electricity it is rated for
- **Cut out speed** - when it begins to level off or cease generating electricity because of excessive speed

Wind power curve example

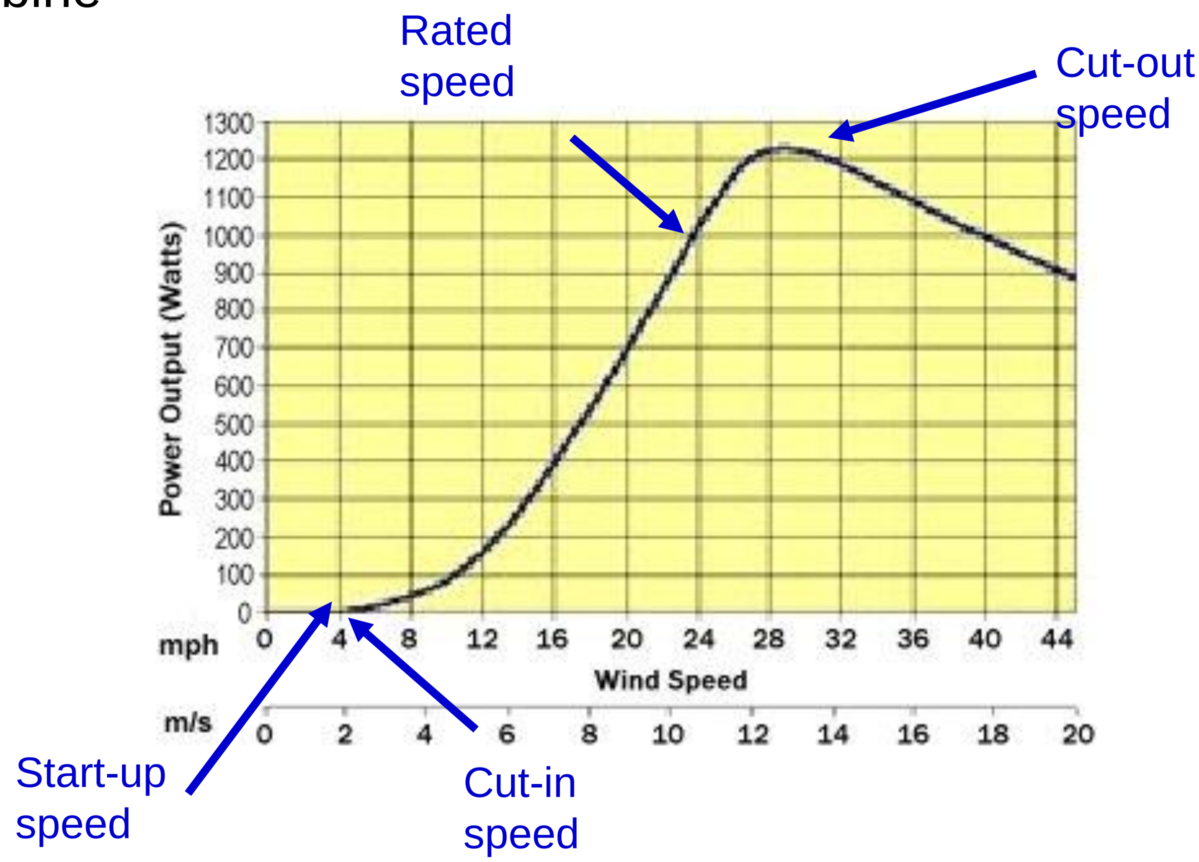
- Example of a 1.5 MW turbine



http://www.nrel.gov/wind/images/
power_curve_chart3.gif

Wind power curve example

- Example of a 1 kW turbine



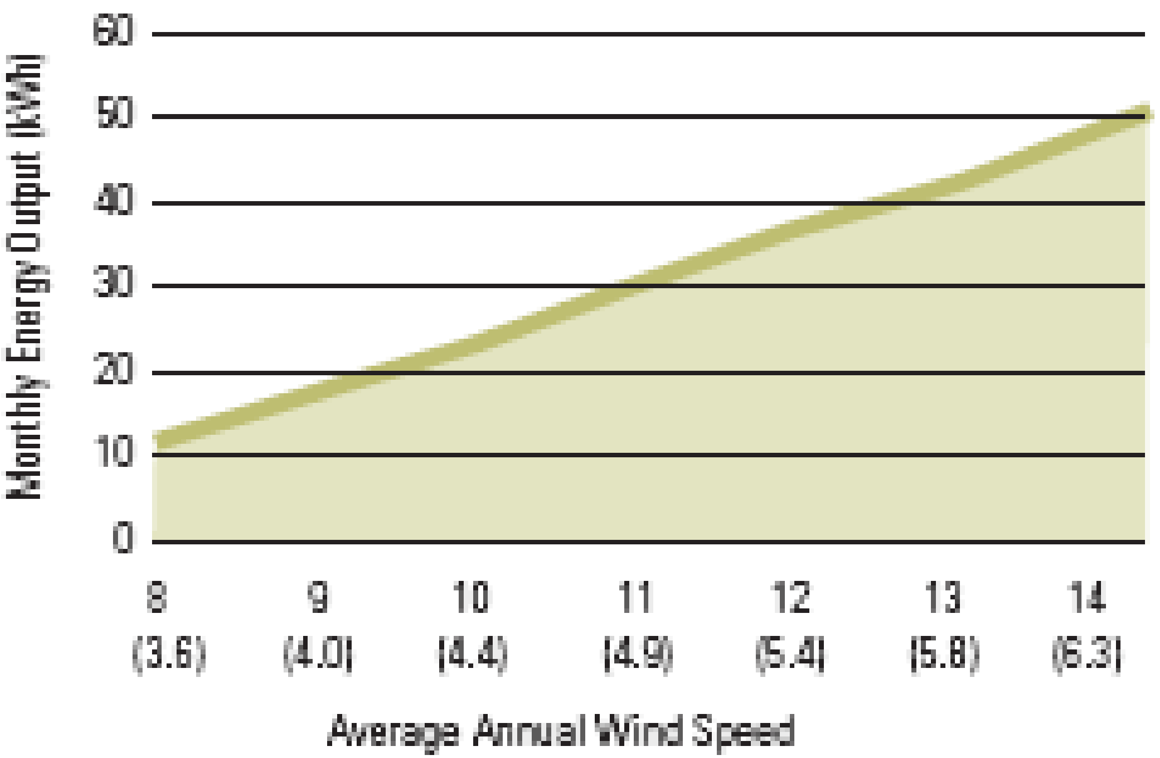
www.solaronline.com.au

General performance ranges

- Most turbines have rated output at 24-36 mph
- System efficiencies range from 25% to 45%

(Theoretical maximum is known as the **Betz Limit** at 59.3%!)

Figure 3. Representitive Energy Curve for 200 watt Wind Turbine



Canadian Wind Energy Assn

Example of output by wind speed

Example is a nominal 1 kilowatt turbine

Wind Class	Wind Speed (mph)	Average power (watts) per hour	kWh per year (W-hour **x** 8,760 hrs/yr) /1,000 W-hr/kWh
1	< 9.9	< 100	< 876
2	11.5	150	1,314
3	12.5	200	1,752
4	13.4	250	2,628

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A Cost / Benefit or Cash Flow Analysis

Years	Install	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Gross Cost	($17,500)															
30% Tax Credit	$5,250	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0	$0
Utility Savings	$0	$2,214	$2,298	$2,385	$2,475	$2,569	$2,666	$2,767	$2,871	$2,980	$3,092	$3,209	$3,331	$3,456	$3,587	$3,723
ANNUAL CASH FLOW	($12,250)	$2,214	$2,298	$2,385	$2,475	$2,569	$2,666	$2,767	$2,871	$2,980	$3,092	$3,209	$3,331	$3,456	$3,587	$3,723
Cumulative Cash Flow	($12,250)	($10,036)	($7,738)	($5,353)	($2,878)	($309)	$2,357	$5,124	$7,995	$10,975	$14,067	$17,276	$20,607	$24,063	$27,650	$31,373

Wind Energy Finance: On-Line Tool

http://analysis.nrel.gov/windfinance/login.asp

Inputs

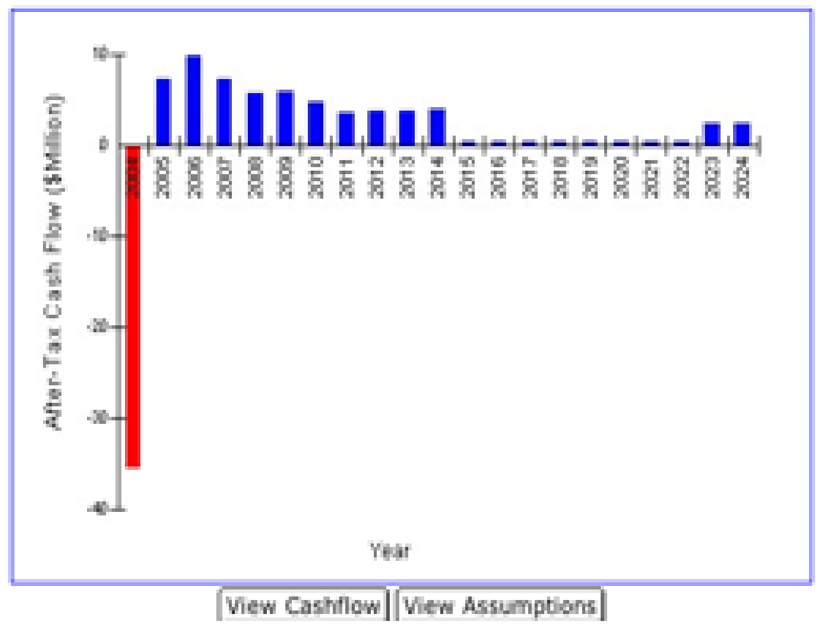
- General Assumptions (e.g. Project size, Inflation rate)
- Capital Costs
- Operating Costs
- Financing Assumptions
- Tax Assumptions
- Constraining Assumptions (e.g. Minimum IRR, Minimum Debt Service Coverage Ratio)

Outputs

- Internal Rate of Return
- Debt Service Coverage Ratio
- Net Present Value
- Cash Flows

Features

- Extensive help file explains each entry
- Easily handles a variety of tax parameters
- Exportable summaries and cash flows

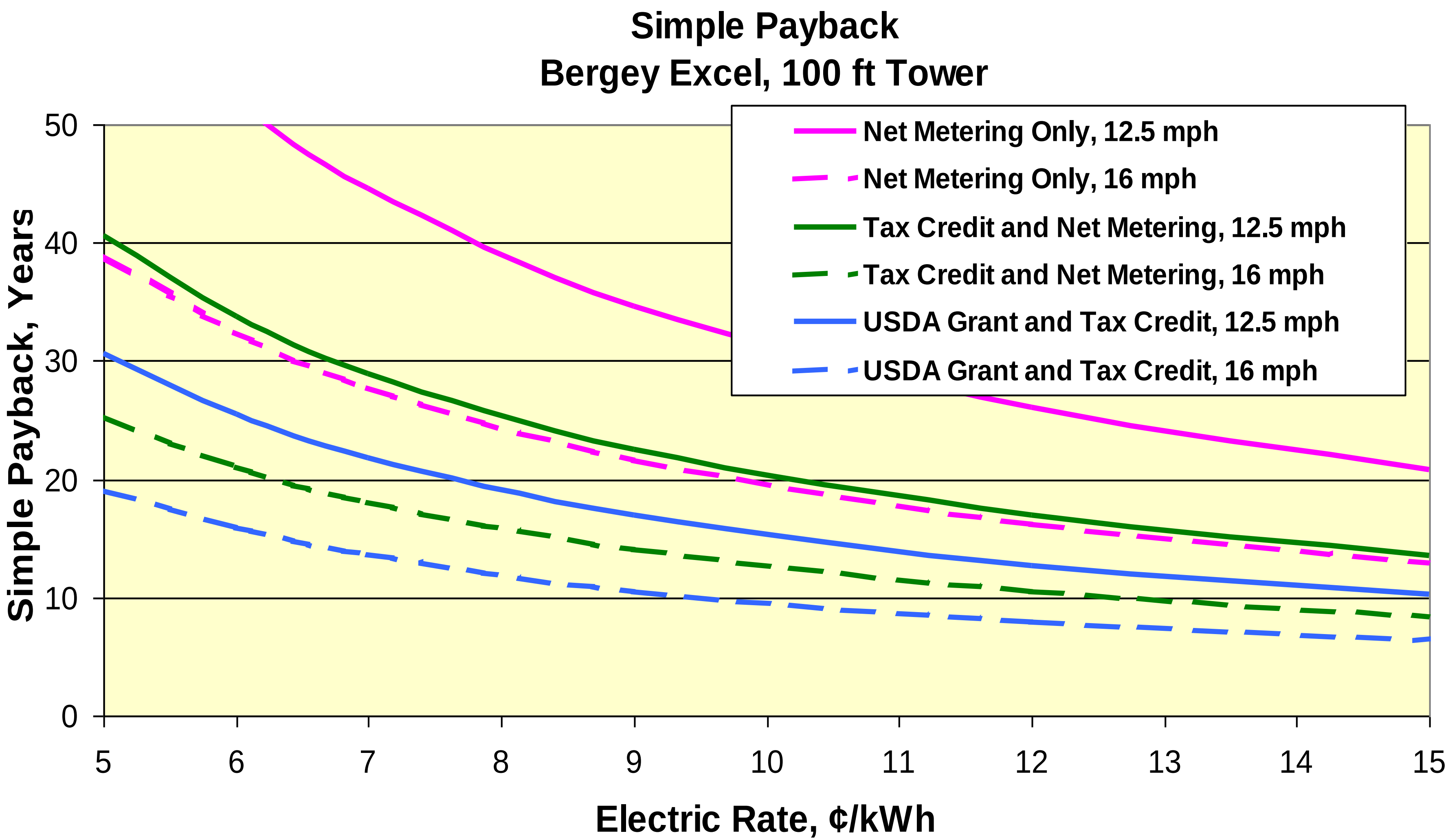


Wind Turbine Installed Cost: Example

Updated: 11-Oct-04

Bergey Excel-S (10 kW)		High Cost	Low Cost
Wind turbine & inverter	**$24,750**	$24,750	$24,750
Tower (100 ft guyed)	**$7,800**	$25,100	$6,200
Tower Wiring Kit	**$860**	$1,070	$860
Shipping	**$1,500**	$2,000	$1,000
Installation	**$8,000**	$10,000	$2,000
Permits/Fees	**$500**	$3,500	$0
Sales Tax, 5%	**$2,146**	9.3%	none
Total	**$45,556**	$72,272	$34,810
USDA Grant	$11,389	$18,068	$8,702
Adjusted Total	$34,167	$54,204	$26,108

Small Wind Economics: Examples



Assessment: A "Micro-siting" Checklist

1. Minimize turbulence.
2. Install the tower at least 30 feet above anything within 500 feet.
3. Note your prevailing winds and stay upwind of any obstacles.
4. Minimize compromises in location, voltage, and tower height.
5. Consider higher voltages.
6. Rougher surfaces produce gustier winds.
7. If downwind of obstacles, compensate with a taller tower.
8. Trees grow, tower don't.
9. Never attach the tower to your house.

General points on Wind Power

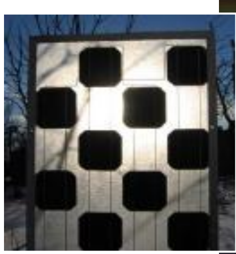
- LOCATION, LOCATION, LOCATION! - Average annual wind speed is paramount for financial feasibility of wind energy.
- Urban Turbines and building mounted turbines are feasible IF a full year of hard data obtained from the proposed location and elevation of a turbine indicates a Class 3 wind exists.
- "Community scale" wind turbines (50+ kW) in a Class 3 or Class 4 wind resource can be a worthwhile long term investment.
- Perhaps due to their kinetic nature, VAWT and HAWT will continue to be appealing to many for years, and may be worth the investment for other than purely the value of utility energy cost avoidance.

Photovoltaic Systems

PV array at the Vatican

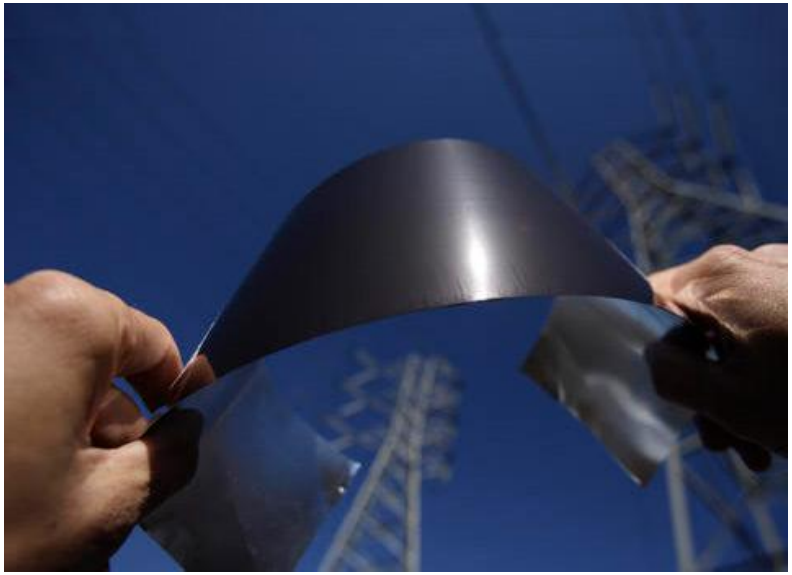
Types of PV: Mono-crystalline



Types of PV: Polycrystalline

Types of PV: Thin Film



http://www.solarite.ca/solar-news/blog-roll/richards-memorial-united-church/

Churches are GREAT places for PV!

Their roofs usually rise above any shadow interferences
and
many are often centrally located within communities so can serve as examples.

http://theenergyfix.com/2010/08/28/watch-a-22-kw-solar-system-sprout-on-this-church-roof/

http://www.epic-lincolnshire.org/low_carbon_community_network/

Hiding the PV arrays and roof integrity:

PV arrays on flat roofs avoid penetrating membranes, etc., by using ballasted pans for mounting racks.

St. Sarkis Church in Yerevan (Photo source: EU-Armenia Web Portal on Renewable Energy)

Installations can also be done “ugly.” Here, a 2 kW photovoltaic array was installed by the State Engineering University of Armenia

For vast areas of flat roof, and in cases where re-roofing with a white EPDM membrane,

there is *Solyndra*, offering thin film PV cylinders mounted on light weight racks that generate power from light coming from above, East / West, *and below!*

http://amsolution.wordpress.com/tag/pv/

St. Thomas of Canterbury Church, Smithtown, Long Island.

A 10 kW system

Install Cost =
$55,000

Utility Rebate =
$27,500

Estimate of Annual
Electric Use: 100%

Likely Economically
Useful Life =
About 50 years

http://renewny.net/2011/04/11/smithtown-church-installs-10k-solar-system/

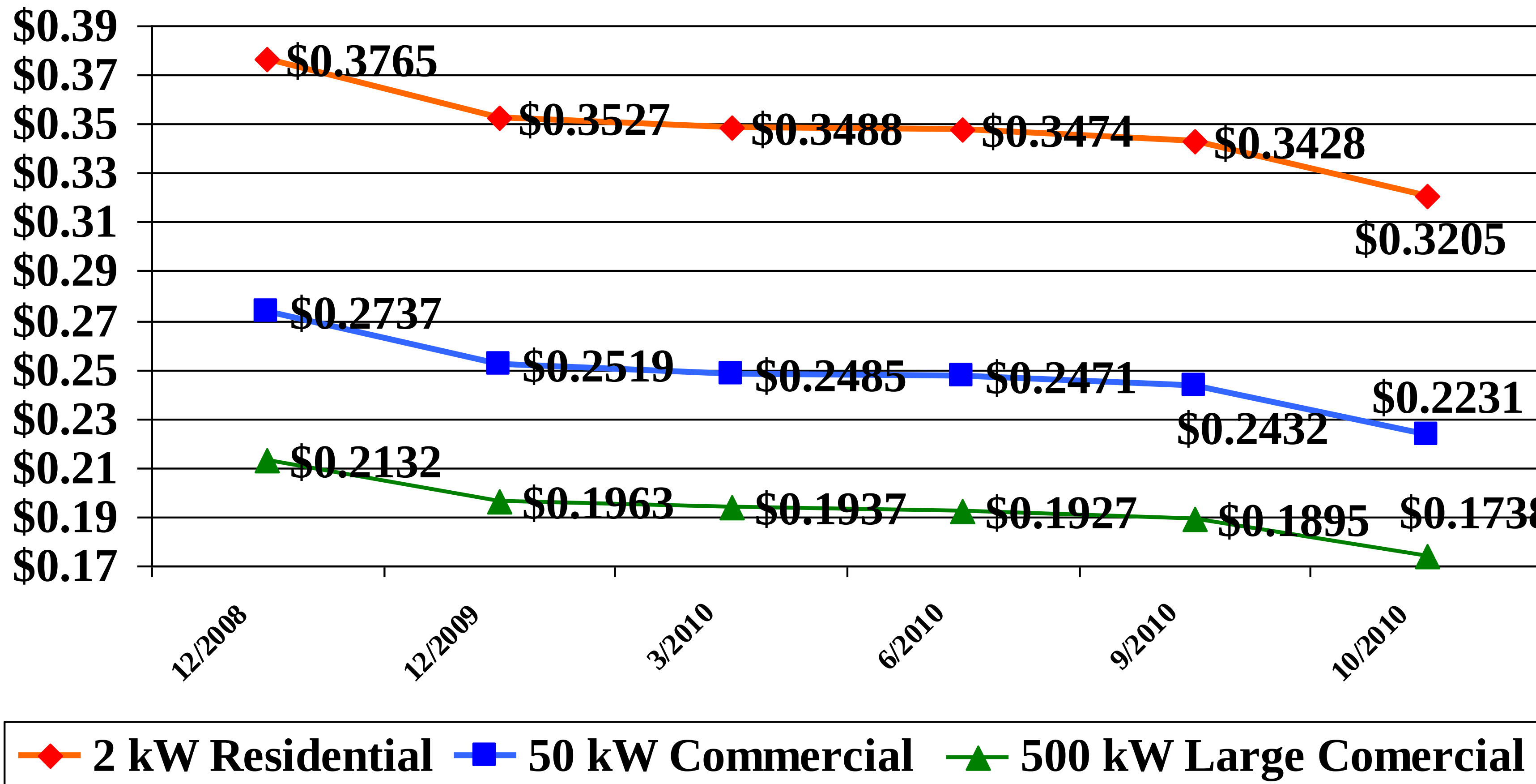
Solar carports!

Erecting a PV array over either new or existing Parking Lots and Garages has been making more and more sense to institutional facility managers. *Additional benefits abound, including reducing the paving contribution to Heat Island effects.*

http:///solar.calfinder.com/blog/solar-information/solar-groves - Photo Credit: kevindooley

Owners of PV Arrays above parking include: Commonwealth Edison, Oberlin College, UC San Diego, Google, WalMart, and a hundreds others like Zurora Software (SF), and McGurn Management (FL)

PV Installed pricing is slowly shrinking . . .



20 year life cycle cost of generating electricity **before incentives in** $/kWh

Source: Solarbuzz.com (LA area data)

General Points on Photovoltaic Power

- The initial investment in a Photovoltaic System is often daunting, but R&D spending on bringing the cost of manufacture down and world production capacity are both having positive effects: What was \$10/watt installed 5 years ago is \$8/watt installed today.

- PV offers about the most attractive overall LCC – due in large part to technology that has no moving parts and was once devised to prevail in the harsh environment of outer space.

- Among alternative energy investment globally, PV will catch up and may pass wind on a MW installed basis by 2020.

- There are exciting developments coming in BIPV, thin film, PV/T, and concepts like V2G involving a future smarter grid.

Geothermal Systems

Heat Pump Fundamentals

- Heat Pump = the machine pumps heat “uphill” from lower to higher temperature
- Only Work = what the “pump” uses to move heat
- Like AC units, but with reversible flow
- Heat absorbed = “source” and Heat delivered = “sink”
- Difference in temperature = “lift”
- The greater the lift – greater power input
- Geothermal (ground-source) heat pumps (GSHP) uses a constant temperature resource, Earth or GW
- Air-source heat pumps depend on the fluctuating outside air temperature, which is:
  - Lowest when heating demand is highest, and
  - Highest when cooling demand is highest

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

World Utilization of GSHP

- Largest geothermal direct-use growth
- Almost 9 times growth since 2000
- Mainly US, Canada & Europe – but in all, 43 countries
- Capacity: 35,200 MWt – 9,800 GWh/yr
- Typical unit: 12 kW (3.4 tons) - Range: 5.5 kW to 150 kW
- Approx. 4.0 million units installed worldwide, w/ LF = 0.19

- US: Most are sized for cooling load. *When sized for heating, it often results in being oversized for cooling.*

- Europe: Most are sized for base load heating

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

Leading Countries Using GSHP

Country	MWt	GWh/yr	Number
USA	12,000	13,200	1,000,000+
Canada	1,111	2,360	92,600
China	5,210	8,060	434,000
France	1,000	2,800	83,300
Germany	2,230	2,880	185,800
Netherlands	1,394	2,890	116,200
Norway	3,300	7,000	275,000
Sweden	4,460	12,580	371,700
Switzerland	1,017	1,830	84,800

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

US Installations

- US experience
  - 1,000,000 total installations (estimated)
  - Mainly in Mid-western and Eastern states
  - 100,000 to 120,000 installed annually
    - 45% horizontal closed loop (mainly residential)
    - 45% vertical closed loop (mainly commercial/institutional)
    - 10% water-source open loops
  - A “unit” = 2 to 6 tons of cooling (ice)
    - 12,000 Btu/hr/ton cooling capacity = 3.5 kW
    - 3 tons for a typical US home of 2000 ft^2 = 10.5 kW

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

GALT HOUSE HOTEL, LOUISVILLE, KY

- Among largest GSHP installations in US
- Heat & AC provided for
  - 600 hotel rooms
  - 100 apartments
  - 960,000 ft² of office space
  - Total 1,740,000 ft²

- Using 2,800 gpm from 4 wells @ 57°F
- Provides 15.8 MW cooling, 19.6 MW heating
- Energy approx. 53% of similar non-GSHP buildings
- Saving approx. $25,000 per month

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

BALL STATE UNIVERSITY, MUNCIE, IN

More than 40 buildings

Almost 4,000 borings

Most 400 ft. deep

Saving $2 mill./year

Avoiding 80,000 tons of carbon/year

Estimated 5,000 tons of cooling/heating

System is under almost continuous construction!

Cost: $70 million including $40 million from state and $5 million ARRA

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

Advantages of GSHP
(as compared to air-source)

- They consume less energy to operate
- They tap a constant temperature resource
- They do not require supplemental energy during extreme outside hot weather
- They use less refrigerant
- Simpler in design and maintenance
- Does not require a unit outside exposed to the weather
- Longer equipment life

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

Disadvantages of GSHP
(as compared to air-source)

- Higher initial cost due to excavation for piping or drilling of a well
- Lack of trained and experienced designers and installers
- Lack of understanding by government regulators

- Shallow horizontal heat exchangers are affected by surface (air and sun) temperature variations – thus, requiring 30 to 50% more pipe in the ground

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

Performance Ratings

- Coefficient Of Performance in the heating mode:

$$COP = Qh/Qe$$

= heating capacity (kW)/electric power input (compressor) (kW)

- Energy Efficiency Ratio & Seasonal Energy Efficiency Ratio in the cooling mode:

$$EER \text{ or } SEER = Qc/Qe$$

= cooling capacity (Btu)/electrical power input (compressor) (kW)

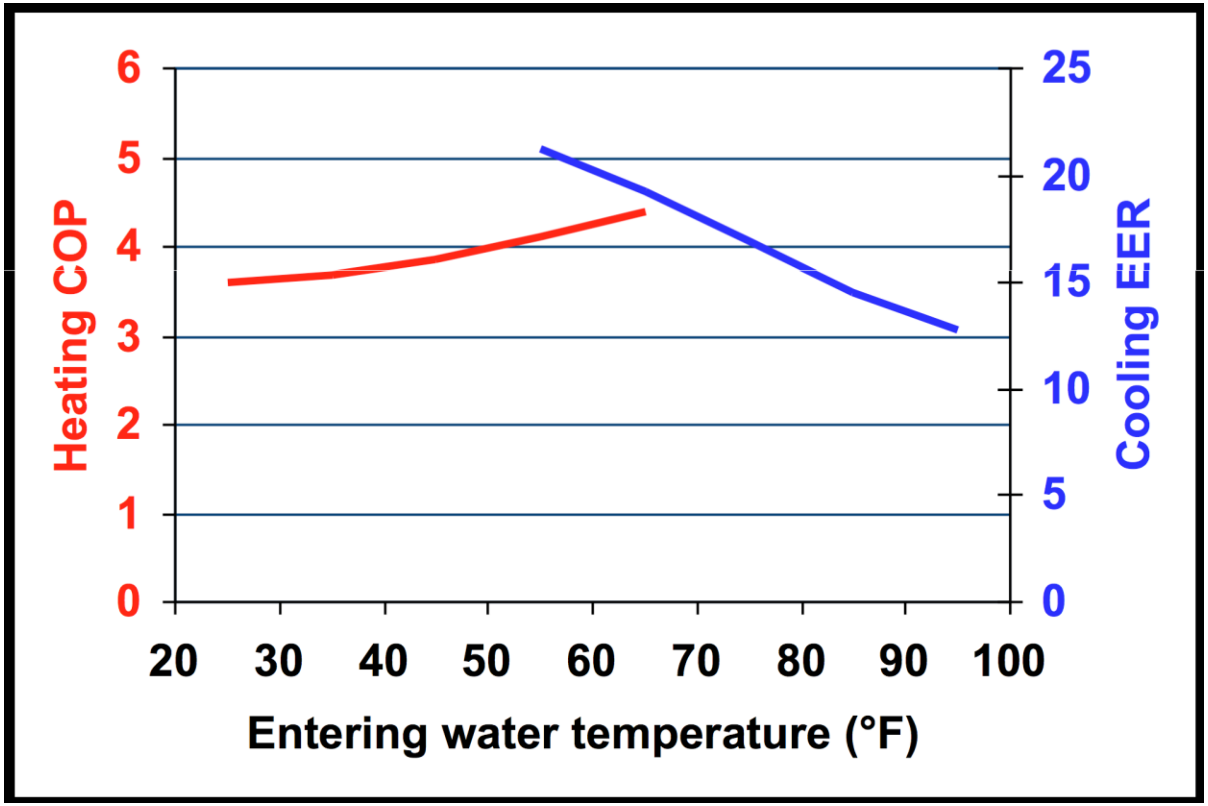
- For a COP of 4, for every unit of electrical input, the system puts out 4 units of heat energy

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

GROUND SOURCE HEAT PUMPS
Efficiency versus Return Water Temperature

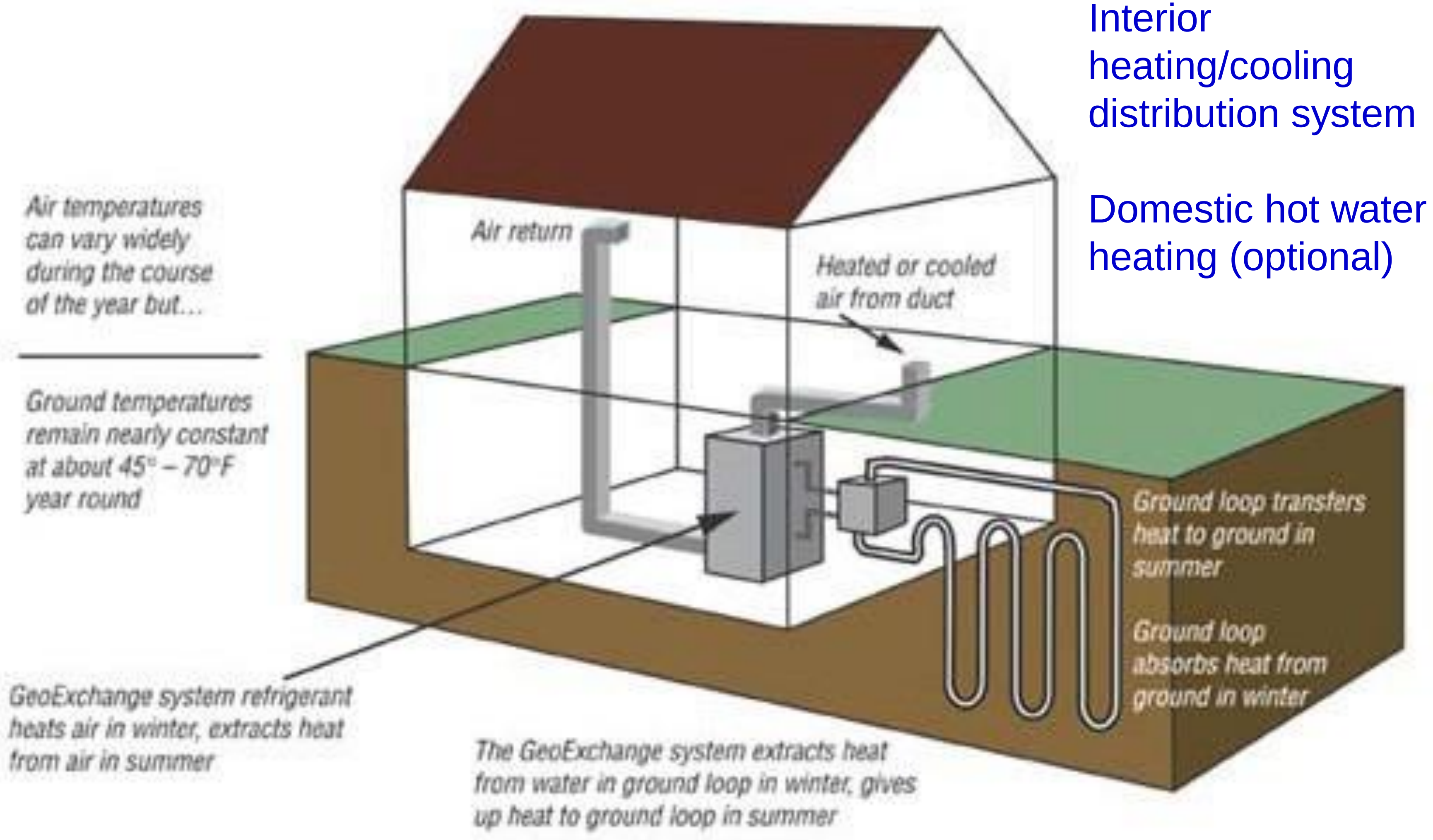
Return water is the HTF as it leaves the building and is pumped (returned) to the ground loop.

Note that the COP & EER values are not constant – they vary according to Return Water temperature. Why?



Source: Shonder, ORNL

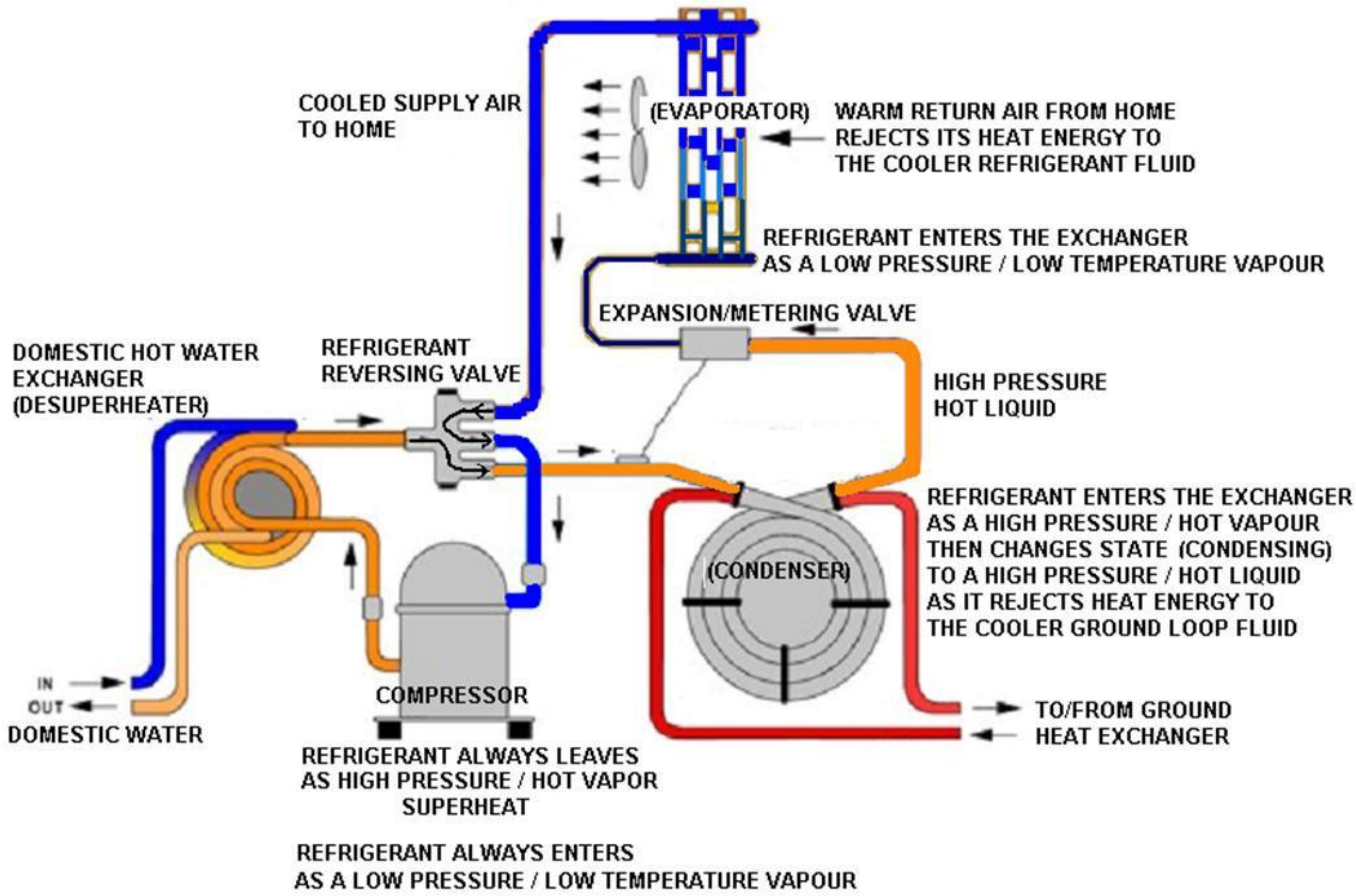
GROUND SOURCE HEAT PUMPS
Basic Schematic



Interior heating/cooling distribution system

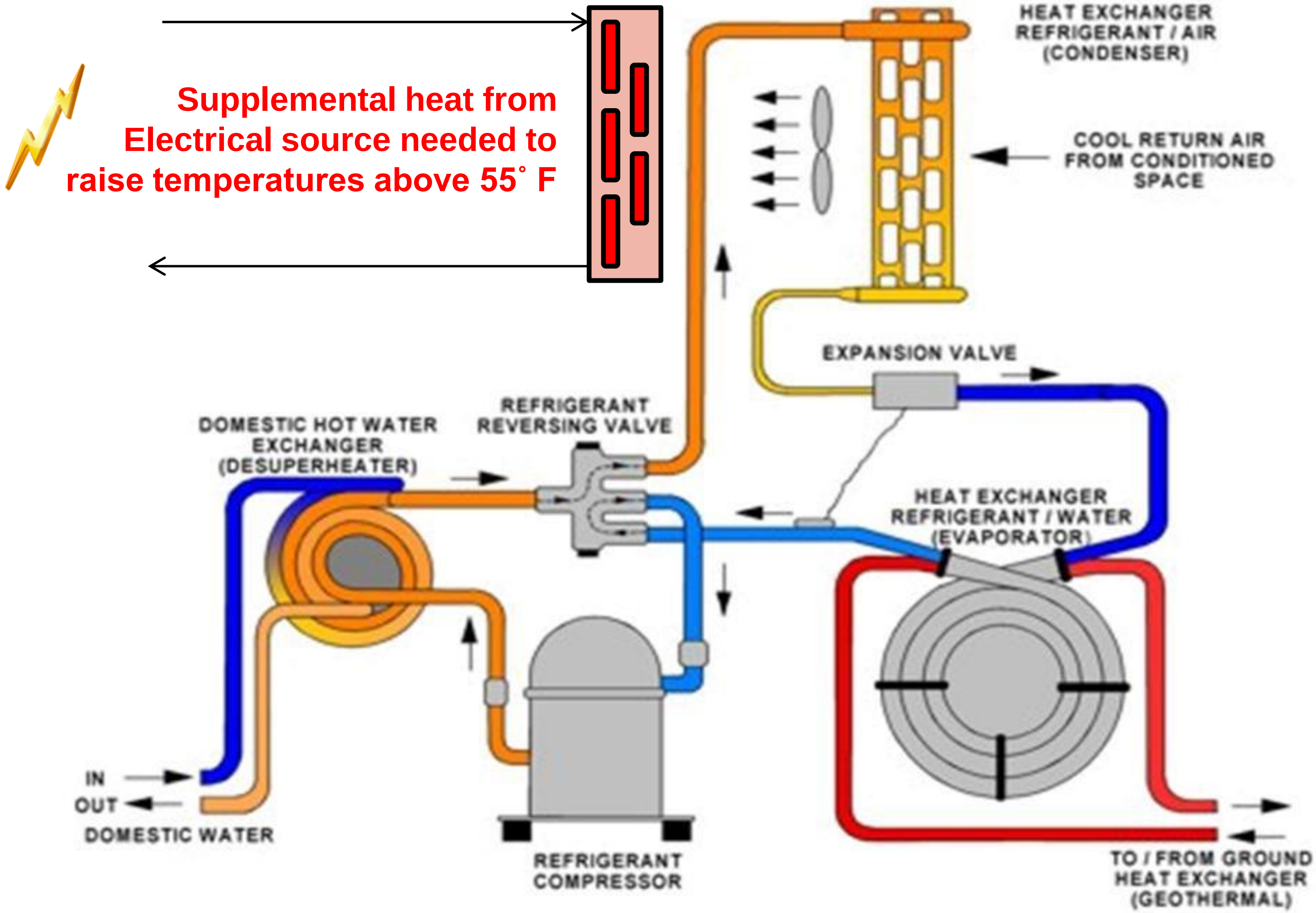
Domestic hot water heating (optional)

GROUND SOURCE HEAT PUMPS
Cooling



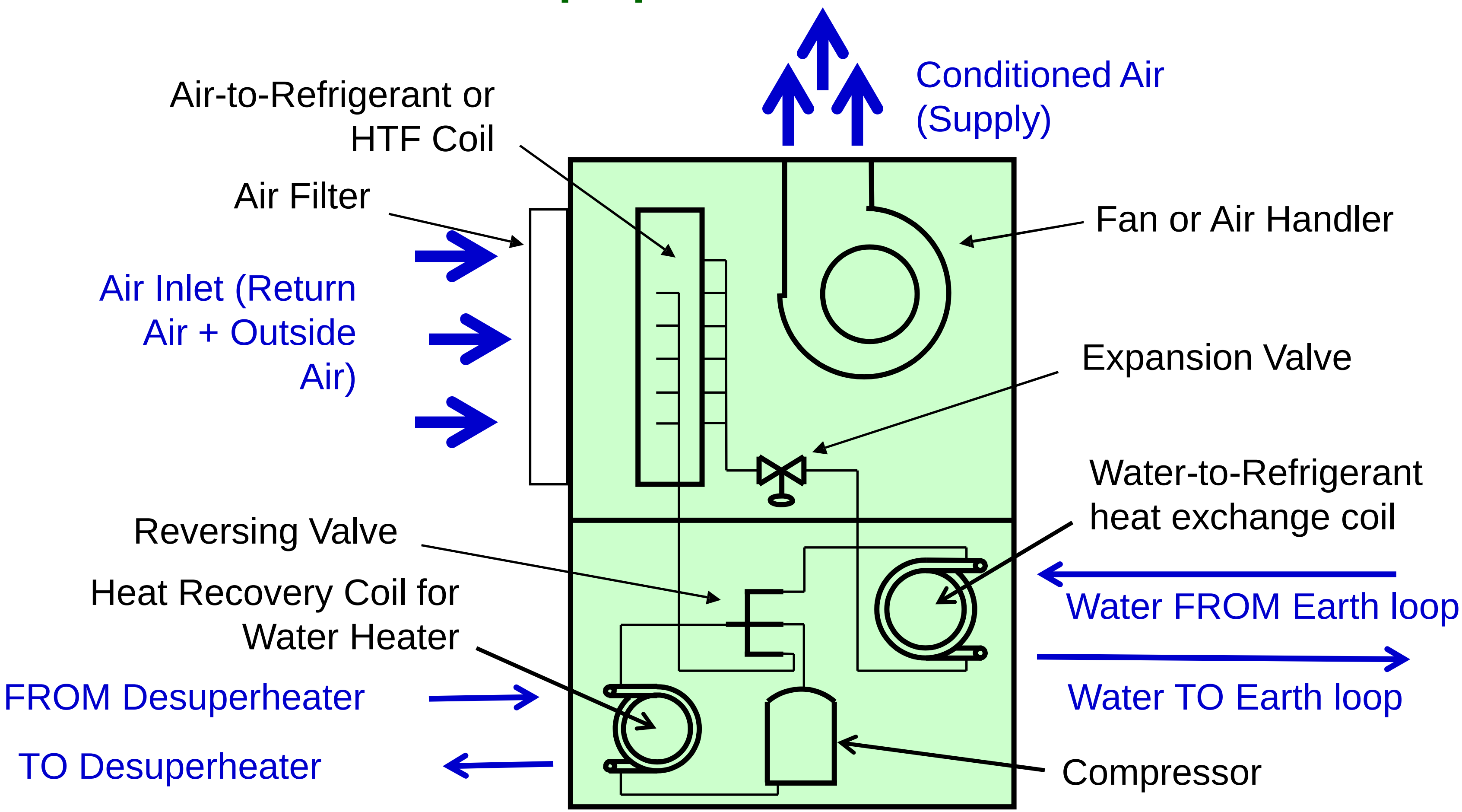
GROUND SOURCE HEAT PUMPS
Heating

Supplemental heat from Electrical source needed to raise temperatures above 55˚ F



Courtesy IGSHPA

GROUND SOURCE HEAT PUMPS
Inside Equipment Schematic



Q: What is a Desuperheater?

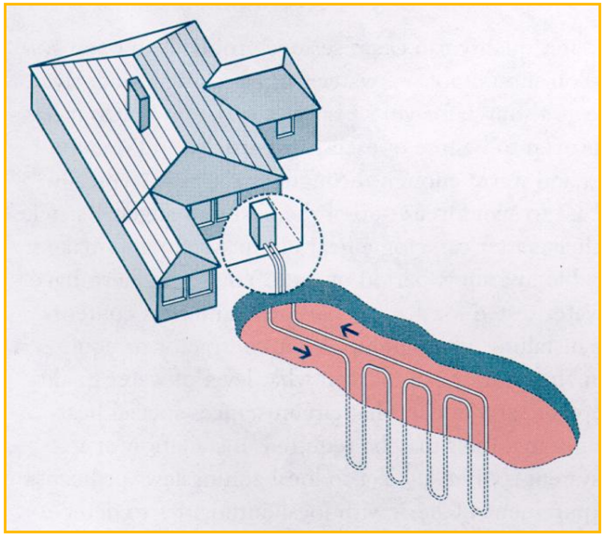
A: It is an "option" used for heating Domestic Hot Water in Summer – so it uses "waste" heat!

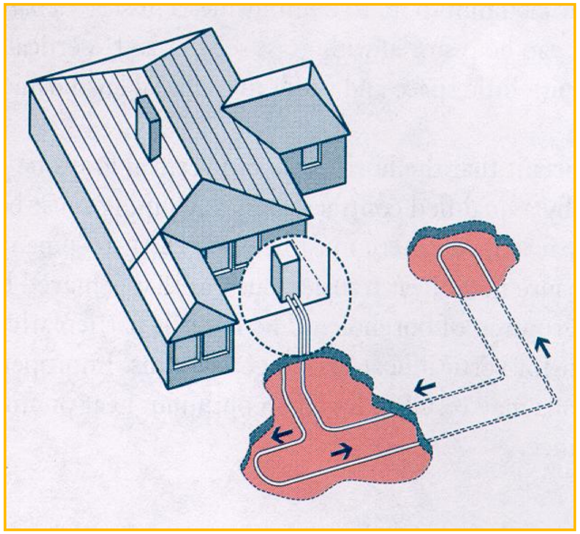
GROUND SOURCE HEAT PUMPS
Fundamental Classifications for Systems

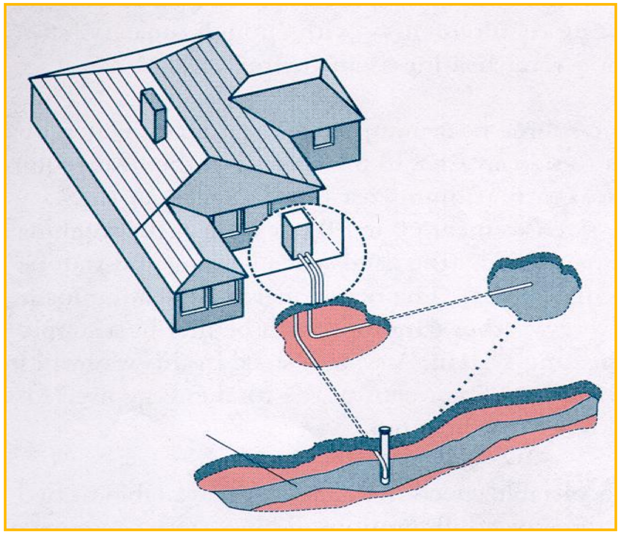
- Vertical (GSHP)
- Rocky ground
- More expensive
- Little land used
- High efficiency

- Horizontal (GSHP)
- Most land used
- Less expensive
- Small buildings
- Temp. varies

- Groundwater (GWHP)
- Aquifer + Injection
- Least expensive
- Regulations
- Fouling



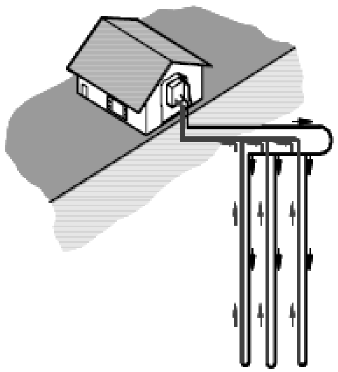




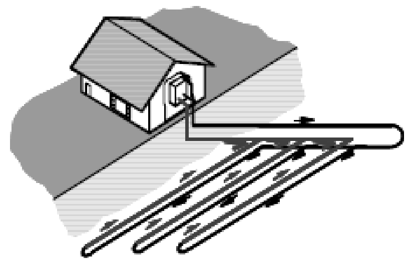
GWHP includes both two well and one well systems

Content & Images courtesy of:

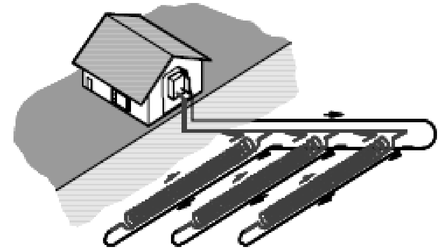
GROUND SOURCE HEAT PUMPS
Ground & Groundwater Thermal Fields



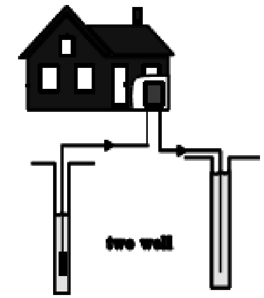
(a) Vertical ground-coupled system



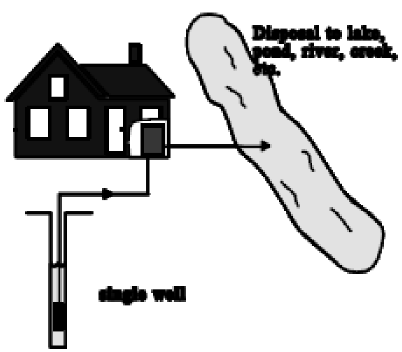
(b) Horizontal ground-coupled system



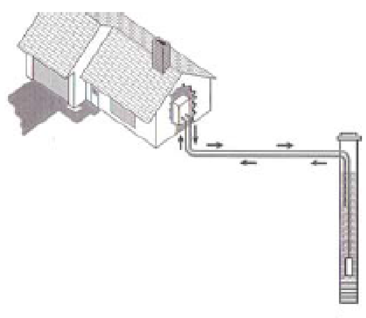
(c) Horizontal slinky ground-coupled system



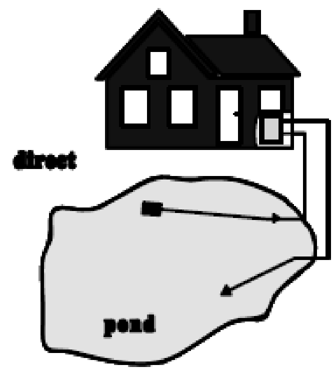
(d) Ground water heat pump systems with supply and re-injection wells



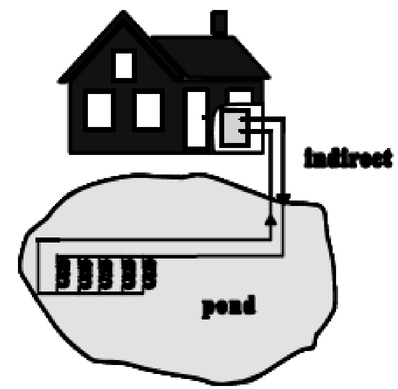
(e) Ground water heat pump systems with disposal at surface



(f) Standing Column Well



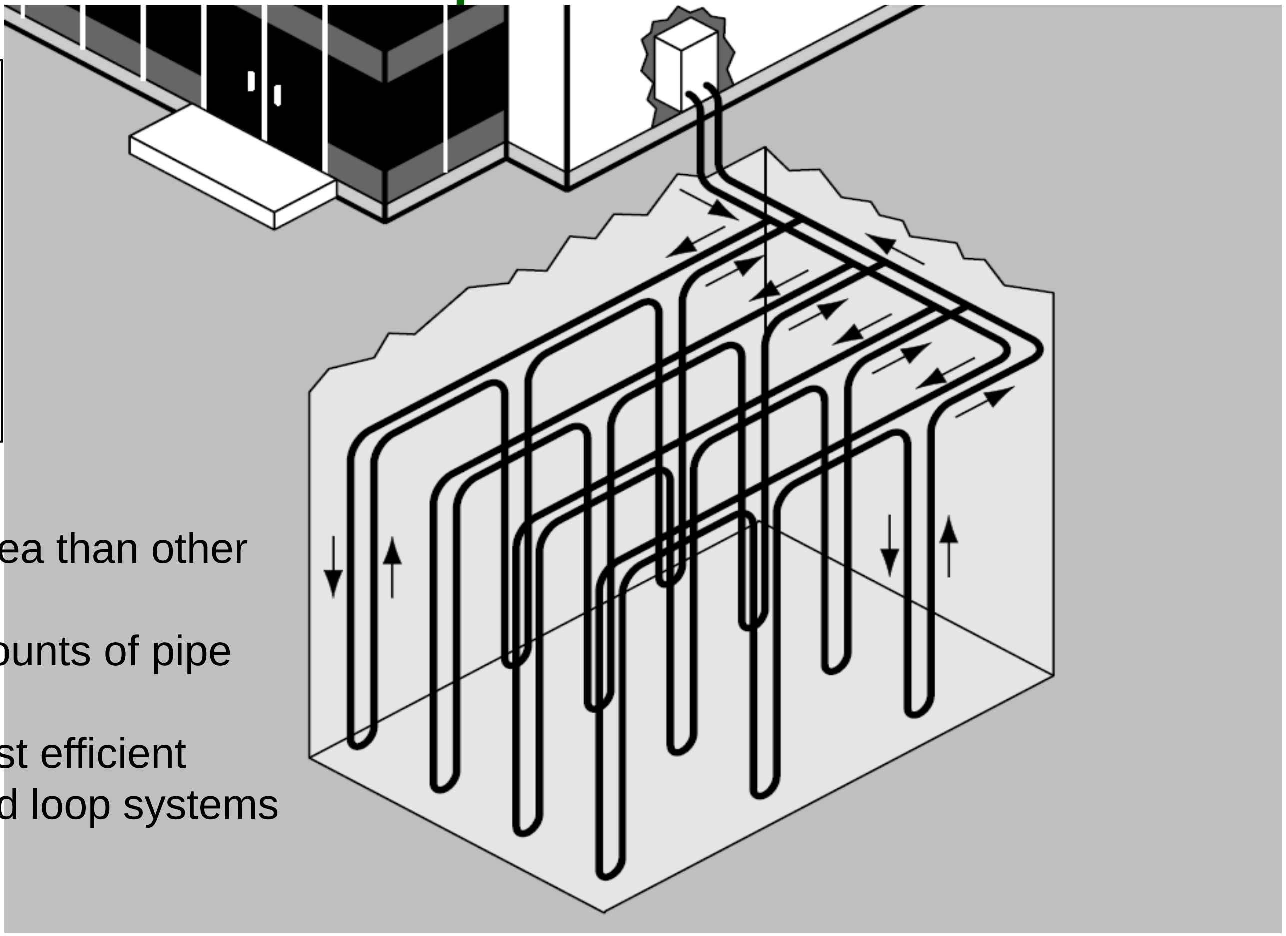
(g) Surface water heat pump system



(h) Surfact water system with indirect coupling

GROUND SOURCE HEAT PUMPS
Vertical Ground Coupled Thermal Field

Piping is inserted into deep vertical boreholes. Boreholes are grouted to improve heat transfer by coupling pipe to surrounding Earth and to protect groundwater.



Advantages

- Requires less land area than other closed loop systems
- Requires smaller amounts of pipe and pumping energy
- Likely to yield the most efficient performance of closed loop systems

Disadvantages

- Higher initial cost due to the cost of drilling boreholes
- Problems in some geological formations

Source: 2003 ASHRAE Applications Handbook

GROUND SOURCE HEAT PUMPS
Horizontal Ground Coupled Thermal Field

- Known as a Slinky Coil

- Depth is from 5 down to 10 feet
- More commonly, the coil is laid horizontally

Boise, 2005

GROUND SOURCE HEAT PUMPS
Horizontal Ground Coupled Thermal Field

- A horizontal closed loop, 6 ton system, 3840 SF house in Colorado

Placement of straight loops or “slinky” piping in shallow (6ft to 8ft) horizontal trenches

Advantages

- If space is available, less expensive to install than a vertical “bored” system
- Requires less specialized skill and equipment to install.

Disadvantages

- Needs lots more space!
- Ground temperature and thermal properties fluctuate more due to season, rainfall, depth.
- Lower overall efficiency than vertical bored systems
- Problems in some geological formations.

Source: 2003 ASHRAE Applications Handbook

GROUND SOURCE HEAT PUMPS
Surface Water (lake) Thermal Field CLOSED Loop

- Typically 15 tons/acre (depth15-20 ft) or as high as 85 tons/acre for well stratified deep lakes.

Placement of HDPE coils in loose bundles but anchored

Advantages

- Usually the lowest installation cost, especially in larger applications
- Uses less space

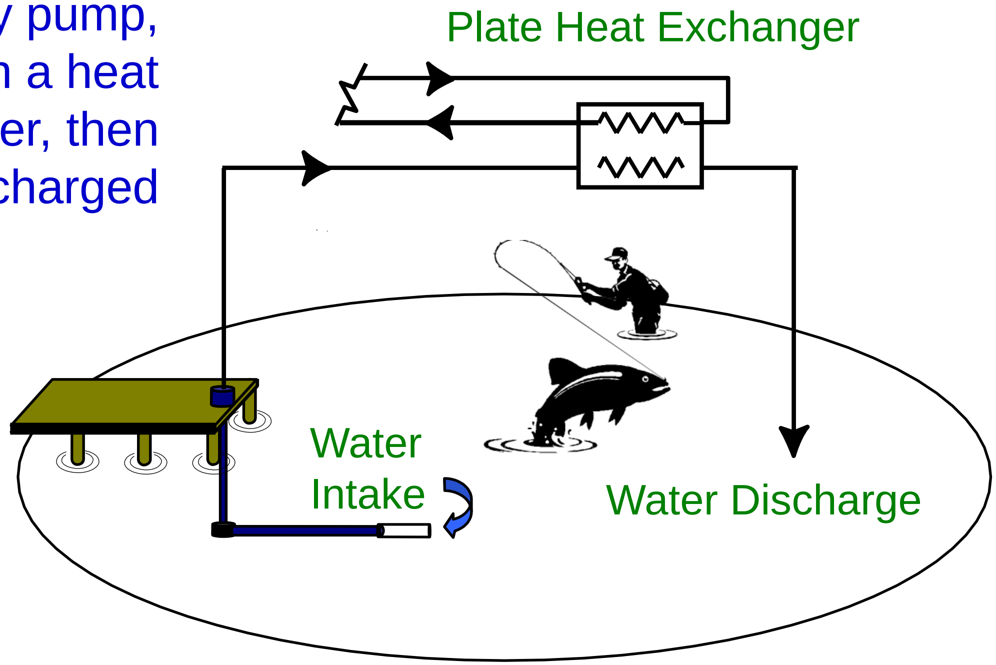
Disadvantages

- Homeowner associations, local water & environmental regulations may restrict use!
- Very limited water front property!
- May need fouling precautions (anchors), possibly use of chemicals to suppress algae, etc.
- Depth of many small lakes varies over the seasons, some freeze full depth!

Source: 2003 ASHRAE Applications Handbook

GROUND SOURCE HEAT PUMPS
Surface Water (lake) Thermal Field OPEN Loop

- Water is taken up by pump, passed through a heat exchanger, then discharged



Best suited for warmer climates or cooling only applications

<u>Advantages</u>

- Lowest installation cost

<u>Disadvantages</u>

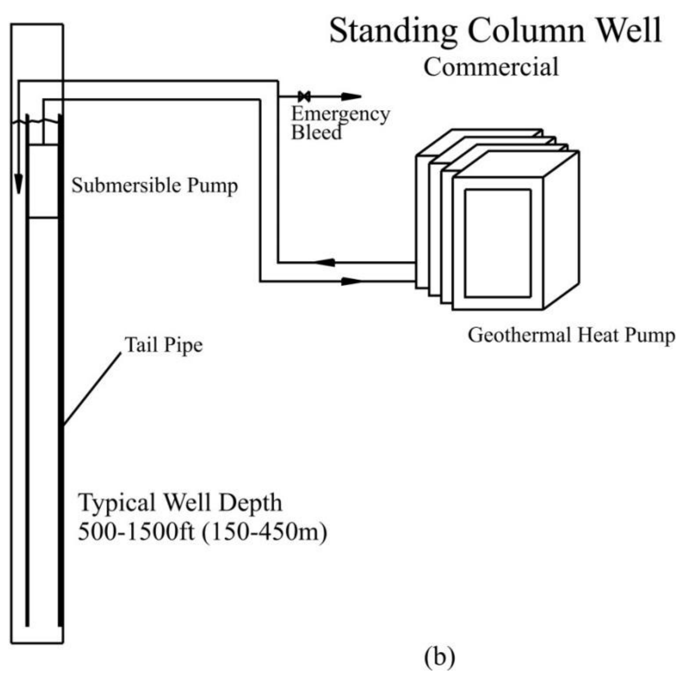
- Higher maintenance due to untreated water being taken in. May need fouling precautions
- Higher energy use for pumping.
- <u>Very</u> limited water front property!
- (anchors), possibly use of chemicals to suppress algae, etc.
- Not suitable for any shallow water circumstances

GROUND SOURCE HEAT PUMPS
Ground Water Thermal Field OPEN Loop

- Two kinds of systems: One boring and Two borings.

One Boring: Water is pumped from bottom of a well, then re-injected at the top of the same well. During peak heating or cooling the system can use a bleed cycle to control water column temperature

Two Borings: Water is pumped from one well, then discharged to another.



<u>Advantages</u>

- Heat exchange rate is enhanced by the pumping action
- Often used where land is limited or bedrock is shallow

<u>Disadvantages</u>

- Borings can be expensive if through rock.
- Water table depth and aquifer productivity can be insufficient or change over time.
- Injection wells of any sort can be too regulated for many to deal with.

Inside Equipment

- Most common – water-to-air heat exchangers
  - Refrigerant-to-water heat exchanger
  - Refrigerant piping and control valves
  - Compressor
  - Air coils (heats in winter; cools and dehumidifies in summer
  - Fan
  - Controls

  - Desuperheater: Water to Water heat exchanger for heating domestic hot water in summer seasons

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

Estimate of Annual Energy Consumption

Steamboat Springs, CO:

Annual Loads: 750 FLH cooling (>65°F)
750 FLH heating (<65°F)

System	Cooling (kWh)	Heating (kWh)	DHW (kWh)	Total (kWh)
Natural Gas	47,100	137,500	10,000	**194,600**
Electric	45,000	110,000	8,000	**163,000**
ASHP	30,000	55,000	8,000	**93,000**
GSHP	23,550	27,500	4,000	**55,050**

For a 10,000 ft^2 commercial building with a de-super-heater:

Estimated annual savings @ 8¢/kWh = \$8,640 (electric vs. GSHP),
= \$3,040 (ASHP vs. GSHP).

For natural gas at \$12/million Btu, the annual savings would be = \$5,700 compared to GSHP = 8 year payback for new construction for 35 tons and 16 years for retrofit.

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

Installation Cost

- Costs more than conventional system; however, savings are greater
- Costs depend on:
  - The availability and experience of contractors
  - Cost of drilling or trenching (or well)
- Total installed cost (10.5 kW – 3 tons) for a 2000 ft^2 home with duct work and controls
  - ASHP and Gas with AC ~ US$ 4 to 5,000 ($1300–1,700/ton)
  - GW GSHP ~ US$ 7,000 (+ well cost) ($2,450/ton)
  - Ground-coupled GSHP ~ US$ 8 to 9,000 ($2,700 – 3,000/ton)
- Costs can variation by 2x to 3x!

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

Cost of Installation - Details

- Installed cost – ground loops
  - Ground coupled – horizontal: $750/ton
  - Ground coupled – slinky: $900/ton
  - Ground coupled – vertical: $1,025/ton
  - Ground water (3 ton): $570/ton (w/o well)

- Water-to-air heat pump units
  - 8.8 kW (2.5 tons): $2,750 ($1,100/ton)
  - 10.5 kW (3.0 tons): $3,000 ($1,000/ton)
  - 14.1 kW (4.0 tons): $3,600 ($900/ton)

- Costs Vary Widely!

- *Ref: Kavanaugh & Gilbreath (1995), and Rafferty (2008)*

Large Scale Savings Example

- Assuming a rebate by local government of $200/kW ($2,000 per home)
- 5 kW reduction in peak heating demand
- 2.5 kW reduction in peak cooling demand
- 200,000 new homes produce 1000 MW savings
- Power plants installed cost = $3,000/kW
- Thus, cheaper to provide rebates than build newer power plant ($200 vs $3,000/kW)
- Rebates offered in US ($500 to $2,000 per home) to installed heat pumps

Source: John Lund, PE, Geo-Heat Center, Oregon Institute of Technology

Commercial Installations
(large-scale)

- Cooling demand usually the largest
- Using central or multiple control units
- Groundwater systems the oldest and most widely used approach – with two wells, often reversing source from winter to summer
- Multiple ground-coupled system becoming popular – vertical bore holes 100 to 400 ft. deep in large fields under parking lots
- Ref: Kavanaugh & Rafferty, ASHRAE, 1997

General Points on Geothermal Systems

- Installation costs for Geothermal systems very widely across the US.

- High ground water tables (as opposed to seasonal perched GW) can be a boon to a proposed geothermal well field.

- Boise, Idaho, has operated several district scale open loop GWHP systems for several decades, serving both private and public buildings in its downtown core.

- Some US military bases and a few European municipal district GSHP systems use underground water distribution piping for the GSHP thermal fields.

Part 3: Financing & Resources

An incentive & financing glossary

Information resources

Types of Incentives for Renewables

- **Policy – encouraging or making things happen**
  - Renewable Portfolio Standards
  - Net metering and interconnections
  - Supportive code and zoning standards
- **Incentives/subsidies – generally compliance**
  - Tax credits *(not applicable for tax exempt entities)*
  - Grants, rebates
  - Loan guarantees or interest buy-downs
- **Revenue – performance based**
  - Feed in Tariffs (FIT)
  - Renewable energy credits (REC's, "green tags")
  - Power purchase agreements (PPA)

Renewable Portfolio Standards (RPS)

- Usually a statewide requirement imposing a certain percentage of electricity/energy to be either used or generated from designated renewable energy sources (wind, solar, biomass and other sources).

- Percentages vary, as do designated energy sources and penalties (if any) for non-compliance.

- RPS may require certain amounts or percentages of energy to come from within a locality, state or region.

- RPS may require different types of technologies (solar, wind, bioenergy, etc).

- RPS may require different sizes of systems for equity and diversity.

Net Metering & Interconnection

- NET METERING – the agreement between the electric utility and the account holder over how solar or wind generated electricity is collected, measured & valued.

- INTERCONNECTION – the actual hardware and installation procedure used for the installation – details typically stipulated by the utility, and often regulated by a public utility rate entity.

Economics – Simple Analysis

- Payback
  - How fast investment is recovered by avoided utility costs
  - Inherently a short term method of analysis, not appropriate for long-term infrastructure investment decisions.
- Modified Payback
  - Same as payback but adjusted for inflation
- Life Cycle Assessment & Cost
  - Addresses need for any capital outlay to be economically useful beyond its “pay-pack” period. Its value must be greater than 1!

Financing Investment in Renewables

- THIRD PARTY FINANCING
  - Someone else owns the system and puts it in your property
  - They get the incentives
  - You get a discount on energy
  - You may have the option to buy during certain times of the lease (10 yrs, 20 yrs)

More ways to finance

- MERCHANT POWER
  - Instead of the system belong to or serving end user, it is sold “on the market” to a buyer offsite
  - Often used for large (multi-megawatt) plants

Kinds of Finance Sources

- TWO TYPES
  - Compliance
    - System has to be installed according to standards but funding is not dependent on performance
  - Performance
    - System has to perform to certain standards or funding will be less than should be

Examples of COMPLIANCE funding

- Investment Tax Credits (ITC)
- Income Tax Credits – Federal or State
- Sales Tax Exemptions
- Depreciation
- Grants (before system installation)
- Rebates (after system installation)

Examples of PERFORMANCE funding

- Production Tax Credits **(PTC)**
  - Paid on how much is generated
    - Federal PTC is for 10 years

- Power Purchase Agreement **(PPA)**
  - Agreement with purchaser, usually utility
  - Can be competitive or non-competitive
  - Period is 10-20 years
  - Utility usually gets all environmental benefits
  - Penalties for non-performance

Examples of PERFORMANCE funding

- Feed-in-tariff **(FIT)**
  - A set rate by utility or public entity (regulatory agency) for (usually) electricity
  - FIT can be for various types and sizes of systems (wind, PV, residential, commercial, customer onsite or merchant)
  - Terms are usually 10 to 20 years

Examples of PERFORMANCE funding

- Renewable Energy Certificates or Credits **(REC's)**
  - Once called "green tags"
  - They are environmental (non-polluting) aspect of renewable (usually) electricity generation
    - **Usually units of 1 megawatt-hour**
  - Usually for shorter terms (1-3 year), with rates subject to variability

REC
MWh

Other types of financial instruments

- Loan guarantees
  - Reduces interest rate risk
- Property Assessed Clean Energy **(PACE)**
  - Loans made on property taxes
  - Presently held up by mortgage agencies
- Tax Incremental Financing **(TIF)**
  - Use of property tax revenue from area

Some Useful Resources

- www.ases.org American Solar Energy Society (ASES)
- www.awea.org American Wind Energy Association (AWEA)
- www.dsireusa.org Database of State Incentives Renewable Energy *(DSIRE)*
- www.irecusa.org Interstate Renewable Energy Council
- www.nrel.gov National Renewable Energy Laboratory
- www.seia.org Solar Energy Industries Association
- www.igshpa.okstate.edu Int'l Ground Source Heat Pump Association
- www.geoexchange.org Geothermal Heat Pump Consortium
- www.uschpa.org United States Clean Heat & Power Association
- www.fchea.org Fuel Cell and Hydrogen Energy Association

A Summary

PART 1:

- Conservation before Efficiency, and Efficiency before Renewables!

- Investing in RE Systems means collecting **wild** energy, then taming it enough for immediate on-site use, *so know the physics of the resource!*

- Energy Auditing: Know your Footprint before you map your Footpath!

PART 2:

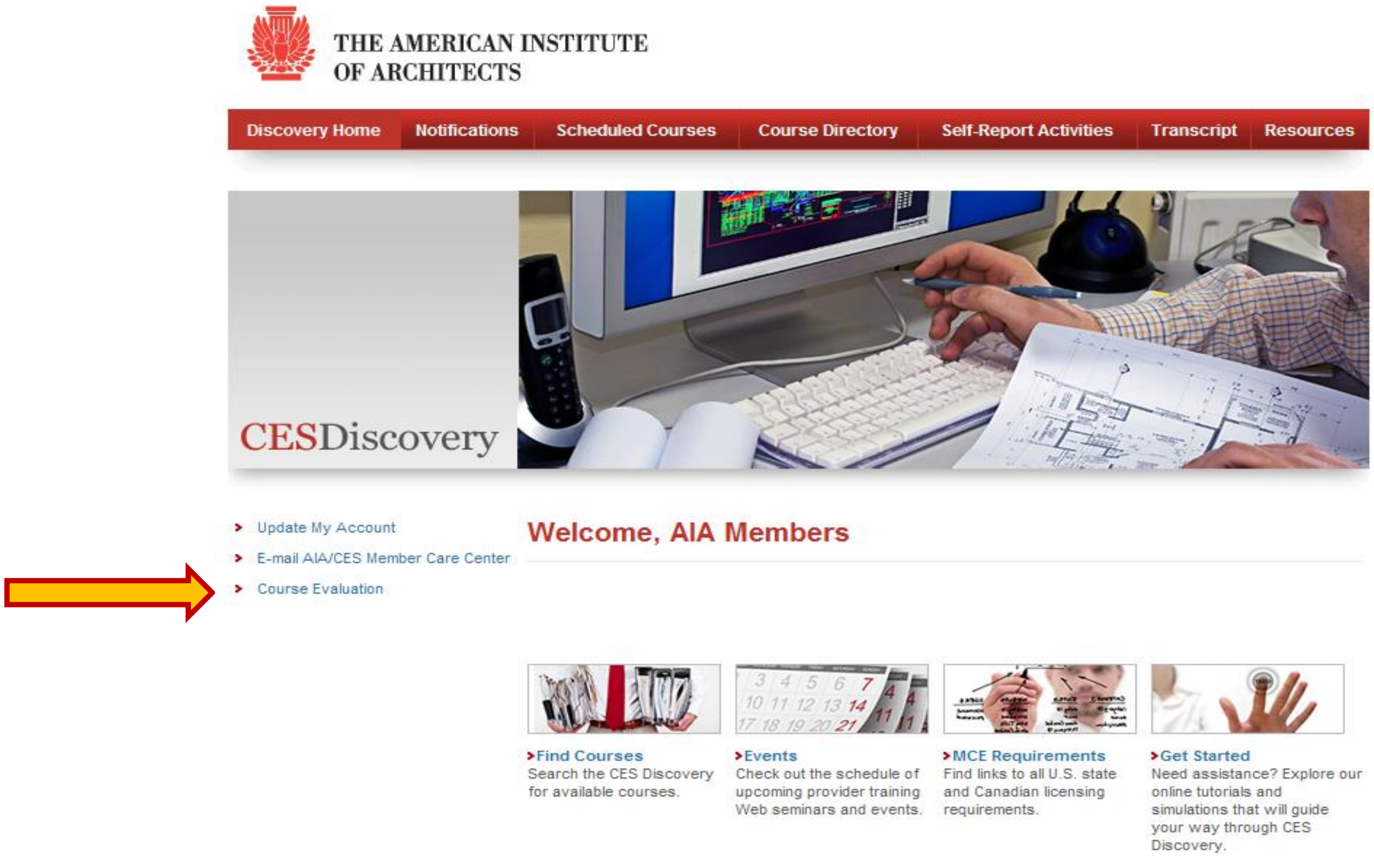
- CHP: A most promising EE strategy
- Wind: So often the most popular among RE ideas
- Solar PV: Often the best full Life Cycle Cost ratios of all alternatives!
- Geothermal: Borrowing & depositing the energy bank below your feet

PART 3:

- Some cost analysis and financing terms
- References & Sources for more information

Course Evaluations

In order to maintain high-quality learning experiences, please access the evaluation for this course by logging into CES Discovery and clicking on the Course Evaluation link on the left side of the page.



Thank you for your time!

QUESTIONS??

This concludes The American Institute of Architects Continuing Education Systems Course

EASE, LLC &
The Conference for Catholic Facility Management (CCFM)

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