Farm Energy IQ

Farms Today Securing Our Energy Future

Greenhouse Energy Efficiency

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NORTHEAST SARE Sustainable Agriculture Research & Education

Greenhouse Energy Efficiency

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Presentation Outline

- Major energy uses in greenhouses include
  - Supplemental lighting (when used)
  - Temperature control (heating and ventilation)
- Note: Supplemental lighting (or refrigeration) is not part of this presentation

- Topics
  - Heat loss calculations (needed to evaluate or design heating systems)
  - Heating systems
  - Natural and mechanical ventilation
  - Energy conservation (screens, storage) and control
  - Alternative energy sources
  - Energy saving measures
  - Calculation tool

Greenhouse Heat Loss Calculations (Simplified)

- To size heating system (heater/boiler capacity), calculate:
  - Structural heat loss (conduction and convection)
  - Infiltration (air movement)
  - Perimeter heat loss (along outside walls)
- Make adjustments for high wind (over 15 mph) and/or large ΔT (over 70°F) if needed
- Total heat loss = sum of structural, infiltration, and perimeter heat loss (plus any adjustments needed)
- Overall equipment heating capacity must factor fuel conversion efficiency (so capacity > heat loss)

Structural Heat Loss

- Heat transfer through the structure depends on:
  - Heat transfer coefficient, U (U = 1/R)
  - Surface area, A
  - Temperature difference: $T_{inside} - T_{outside,\ 99\%}$ (ΔT)
- Equation:

$$Q = U \times A \times (T_{inside} - T_{outside,99\%})$$

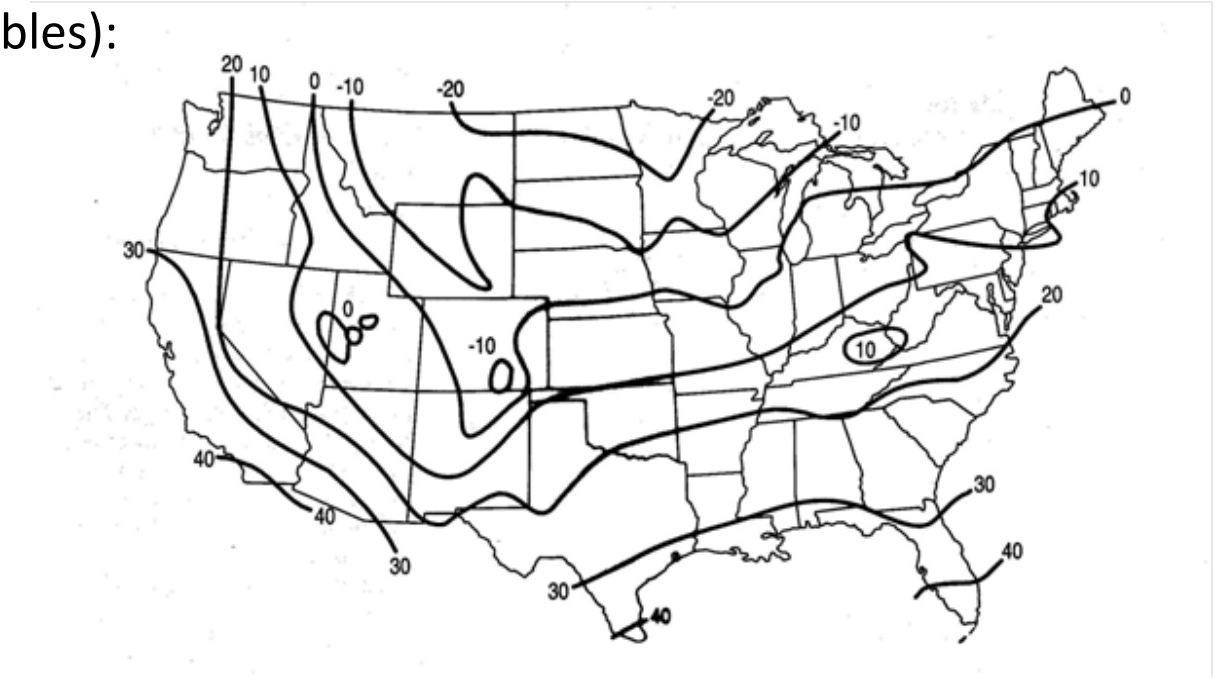
or

$$Q = UA\,\Delta T \qquad \text{[in Btu/hr]}$$

where: T_{inside} = nighttime temperature set point

Outdoor Design Temperature ($T_{outside,\ 99\%}$)

- For heating capacity calculations use the 99% outdoor design temperature $T_{outside,\ 99\%}$ (Engineering tables):
  - Burlington, VT: 11°F
  - Bangor, ME: -11°F
  - Concord, NH: -8°F
  - Albany, NY: 0°F
  - Worcester, MA: 0°F
  - Columbus, OH: 0°F
  - Pittsburgh, PA: 1°F
  - New Haven, CT: 3°F
  - Newark, NJ: 10°F
  - Atlanta, GA: 18°F
  - Portland, OR: 18°F
  - Tucson, AZ: 28°F
  - San Diego, CA: 43°F



Note: $T_{outside,\ 99\%}$ was determined for Dec., Jan., and Feb. i.e., 120 days or 2880 hours; 1% ≈ 29 hours, 1.2 days

U-Values

(higher U-value equates to more heat loss)

Material	U-value (Btu/hr per ft^2 per °F)*
Single (double) layer glass	1.1 (0.7)
Single (double) layer poly	1.1 (0.7)
Double layer + energy curtain	0.3 - 0.5
Double layer acrylic	0.6
Double layer polycarbonate	0.6
½-in. plywood	0.7
8-in. concrete block	0.5
2-in. polystyrene (R = 10)	0.1

*For sound, well sealed structures

Air Infiltration Heat Loss

Equation: $Q = 0.02 \times V \times C \times (T_{inside} - T_{outside,\ 99\%})$

where

V = greenhouse volume (ft^3)

C = number of air exchanges per hour (hr^{-1})

Type of construction	C*
New, glass	0.5 - 1.0
New, double poly	0.75 - 1.5
Old, glass and good condition	1.0 - 2.0
Old structure and poor condition	2.0 - 4.0

*a conservative approach is to take the largest value for C

Rollup Vent Louvers

Credit: http://www.northerntool.com/

If using standard louvers (as shown above), make sure they seal properly (even after extended use). Some designs are more durable than others.

Perimeter Heat Loss

Equation: $Q = F \times P \times (T_{inside} - T_{outside,\ 99\%})$

where

F = perimeter heat loss factor

P = greenhouse perimeter (in feet)

F	(Btu/hr per linear ft per °F)
Uninsulated	0.8
Insulated	0.4

When the water table is high (i.e., when there is wet soil underneath the floor), consider heat loss to the soil underneath the greenhouse

Perimeter Insulation

- At least 1-ft deep (preferably 2 ft)
- At least 1-in. thick (preferably 2 in.)
- Larger numbers can be used for colder locations

- Avoid gaps
- Try to work neatly around post footings
- Can be difficult as retrofit

Side Wall Insulation (while still allowing light through)

Effect of Wind Velocity and ΔT ($T_{inside} - T_{outside,\ 99\%}$)

- If $\Delta T > 70°F$ (difference between inside and outside design temperature), and/or if average wind speed > 15 mph:

  Multiply the calculated heating requirement by:

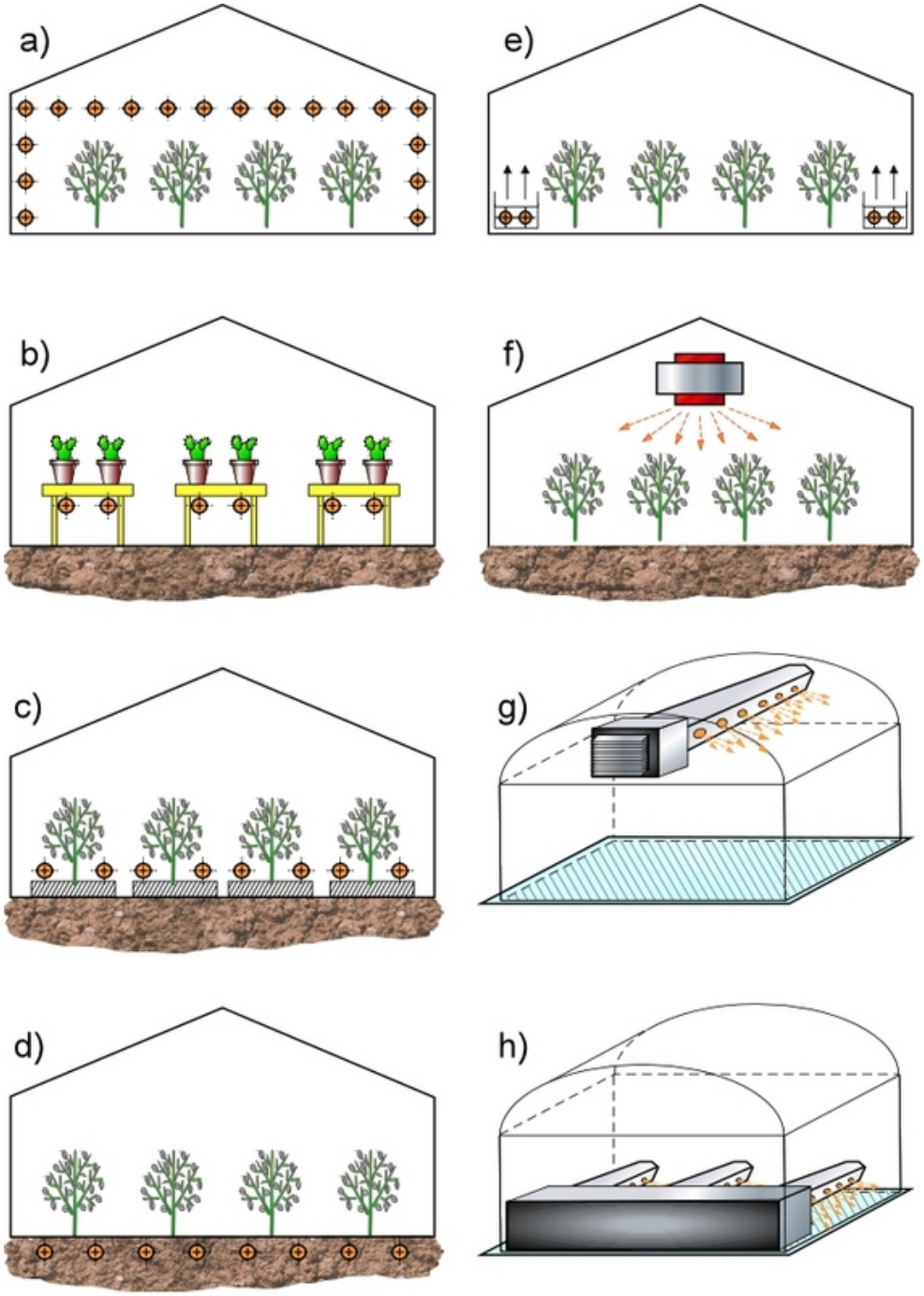
  - (1 + 0.08) for every increase in ΔT of 5°F
  - (1 + 0.04) for every 5 mph increase in speed

For example, if $\Delta T = 80°F$ (1.16) and the average wind velocity is 25 mph (1.08): multiply the calculated heating requirement by a factor of: 1 + (0.16 + 0.08) = 1.24

Greenhouse Heating Systems

Common Greenhouse Hot Water and Air Distribution System Designs

a) Overhead and perimeter pipes
b) Bench heating
c) Intracanopy heating pipes
d) Floor heating
e) Perimeter heating
f) Overhead unit heater
(often installed at end walls)
g) Overhead polytube distribution
h) On floor polytube distribution
(often installed underneath benches)



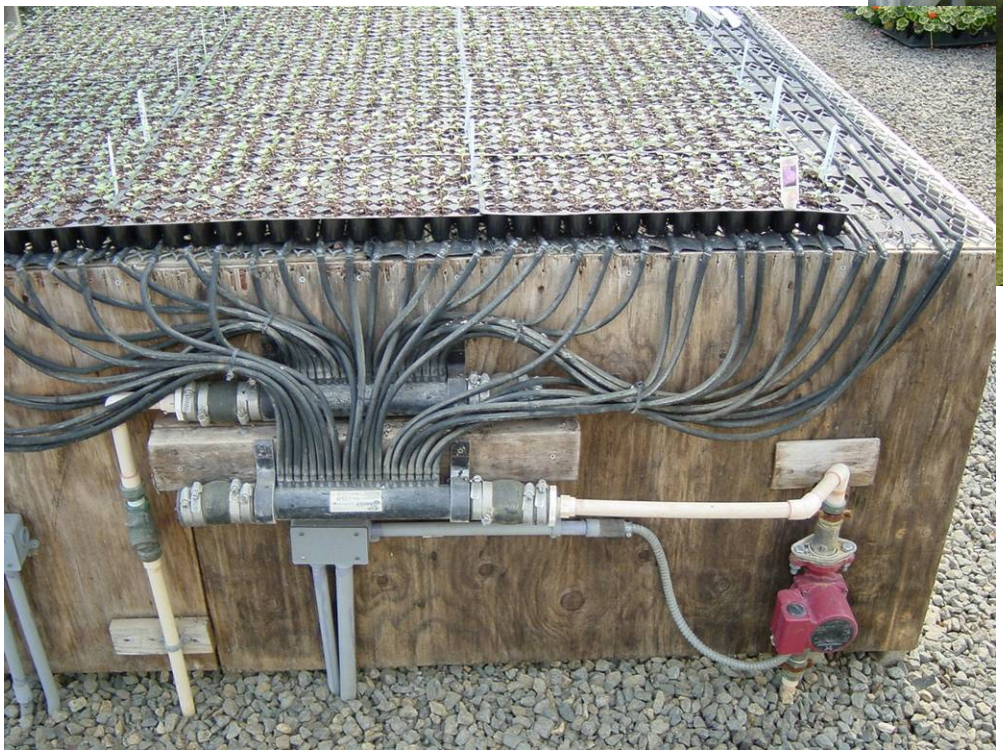
Source: http://www.iga.1it.pl

Heating with Hot Air or Hot Water

- Hot water is preferred over hot air
  - Improved uniformity
  - Flexibility of delivery (floor, bench, air, pre-heating)
- Hot air systems are cheaper to install
- Hot water systems require water treatment
- Root zone heating (floor and bench heating):
  - Uniform heat (typical range: 15-25 Btu/hr per ft^2)
  - Heat close to the crop (lower air temperature?)
  - Floor heating: acts as buffer in case of system failure
  - However, requires additional heat supply (because the root zone water loop temperature is typically kept between 90 and 110°F to prevent root damage)

Root Zone Heating (I): Bench heating

Underneath benches



Directly underneath flats, benchtop (not) insulated

Root Zone Heating (II): Floor Heating


Heated Ebb and Flood
Floor

Improving Temperature Uniformity in Greenhouses with Hot Air Heating Systems

- Poly tubes (heating and cooling)
- Horizontal airflow fans (HAF)
  - Need approximately 3 cfm per ft^2 of floor area

Radiant (Infrared) Heating?

- Only heats surfaces ‘in view of’ radiator
- Allows for lower air temperatures
- After absorption, heat is dissipated by re-radiation and convection
- As a result, potential uneven canopy heating
- Mounting at appropriate distance above the crop canopy can be a challenge
- Quick response time

Condensing Boilers (95-98% Efficient)

- Condensing boilers recover heat by condensing water vapor that was produced during combustion. They have a heat exchanger which pre-heats boiler water with heat recovered from combustion gasses
  - Made of stainless steel
  - Low mass (boiler components and water)
  - Operated on demand (no stand-by losses)
  - Heat delivery in minutes
  - Small foot-print
  - Low maintenance
  - Can be combined with high mass boilers

Greenhouse Ventilation (Natural or Mechanical)

Natural Ventilation

- For greenhouses and high tunnels
- No fans to draw air through the greenhouse
- Works on thermal buoyancy and wind effect
  - Thermal buoyancy: hot air rises
  - Wind effect: wind creates pressure differences
  - Wind effect dominates at speeds > 200 fpm (2.3 mph)
- Install side wall and/or roof vents
- Is not combined with evaporative cooling pads (too much resistance)
- Additional cooling requires a mist/fog system

- **Insect Screening (with natural ventilation)**

Accordion-shaped insect screens

Mechanical Ventilation

- Fan parameters
  - Capacity (cubic feet per minute, cfm)
  - Static pressure (inches of water; AMCA sticker)
  - Ventilation Efficiency Ratio (air flow per watt)
  - Power requirement (motor horsepower)

- Inlet openings
  - Continuous windows or louvers
  - Should close tightly to reduce heat loss
  - 1.4 ft^2 of inlet opening per 1,000 cfm of fan capacity
- Fan louvers
  - Preferably on the inlet side of the fan housing
  - Should close tightly to reduce heat loss

Sizing Exhaust Fans (I)

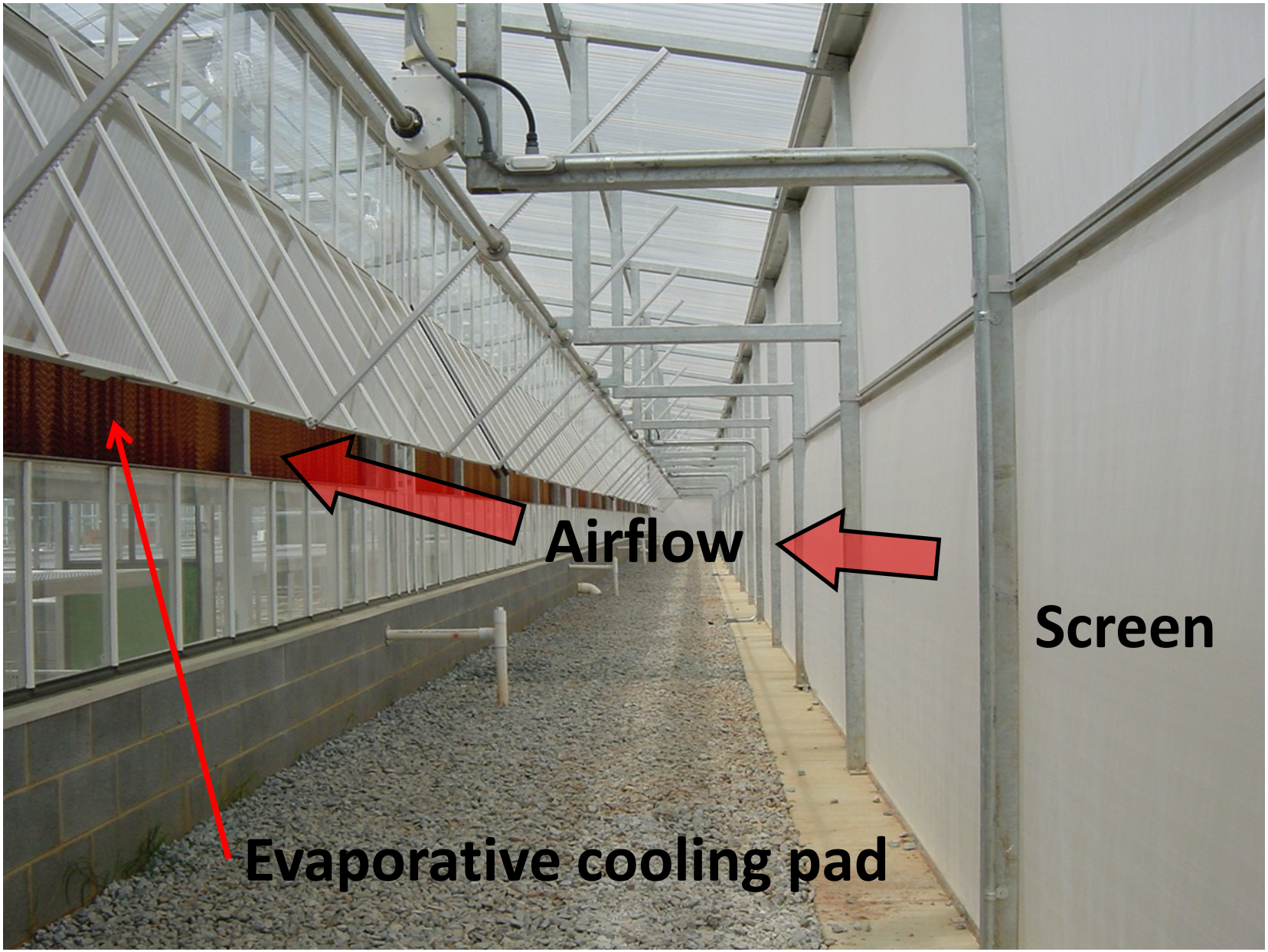
- Design for the maximum cooling load (summer)
  - 8-10 cfm/ft^2 of floor area (with shade screen)
  - 10-12 cfm/ft^2 of floor area (without shade screen)
  - 15-17 cfm/ft^2 of floor area (with evaporative cooling pads)
- Note: Don't use the "one air exchange per minute" rule!

- Make adjustments for: ($F_{House} = F_{Elev.} \times F_{Light} \times F_{Temp}$)
  - Elevation > 1,000 ft ($F_{Elevation}$ = 29.92/barometric pressure)
  - Light intensity > 5,000 footcandles (F_{Light} = foot candles/5,000)
  - Temperature increase < 7°F (F_{Temp} = 7/delta T)
  - Inlet to fan distance < 100 ft ($F_{Velocity} = 10/\sqrt{D}$)
  - Total cfm = L x W x 15 x F_{House} (or $F_{Velocity}$ if larger)

Sizing Exhaust Fans (II)

- Design for the minimum cooling load (winter):
  - 10 - 15% of maximum cooling load, or
  - 1 - 1.5 cfm/ft^2 of floor area (w/ shade screen)
  - 1.5 - 2.0 cfm/ft^2 of floor area (w/o shade screen)
- Final steps (combining min and max load calculations):
- Use the calculated total cfm requirements to select your fans based on manufacturer's data
- Use a minimum static pressure of 0.1-0.125 inches water gauge
- Use a higher static pressure with insect screens
- Install fans evenly across the growing space
- Use fan staging: e.g., 10 (winter)-40-100 (summer)%
- Consider VFD controls

Insect Screening (with mechanical ventilation)



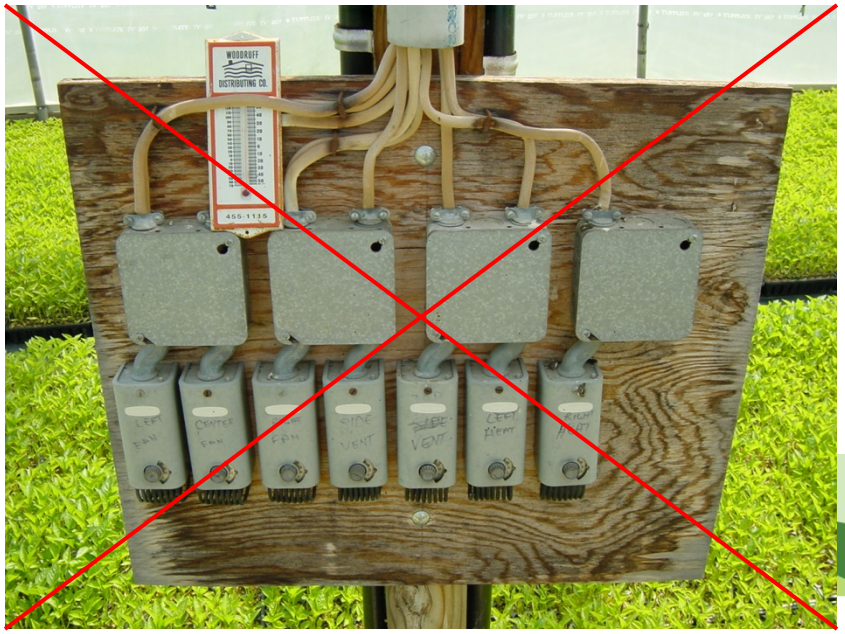
Energy (and Shade) Curtain

Heat Storage (insulated water tank)

Can be used to optimize the efficiency of a heating system

Proper Control

- Use a reliable temperature sensor (e.g., RTD)
- Put the sensor inside an aspirated box (protected from sunlight and moisture)
- Locate sensor near the plant canopy
- Place sensor at a representative location



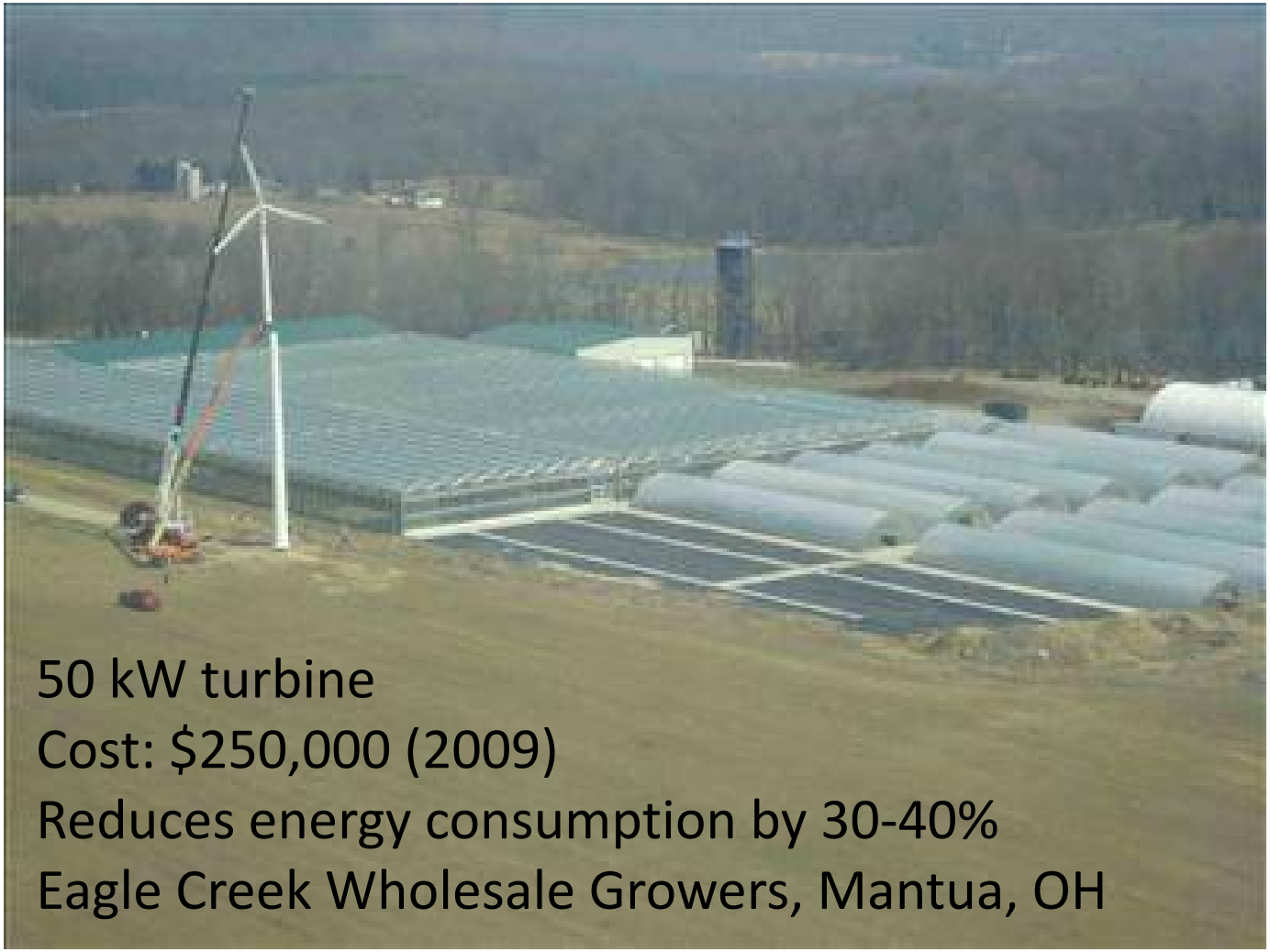
Alternative Energy Sources

- Solar (electricity, hot water heating)
- Wind (electricity)
- Geothermal (hot water heating)
- Ground-source heat pump
- Wood (waste wood, fire wood)
- Other solid biomass (corn, switchgrass)
- Biodiesel (diesel equivalent from biomass)
- Waste oil (fast food industry)
- Waste hot water (power plants, industry)
- CHP/Cogeneration (e.g., microturbines)

PV Panels Integrated in Greenhouse Roofs

Photo: http://www.duijnisveld.nl

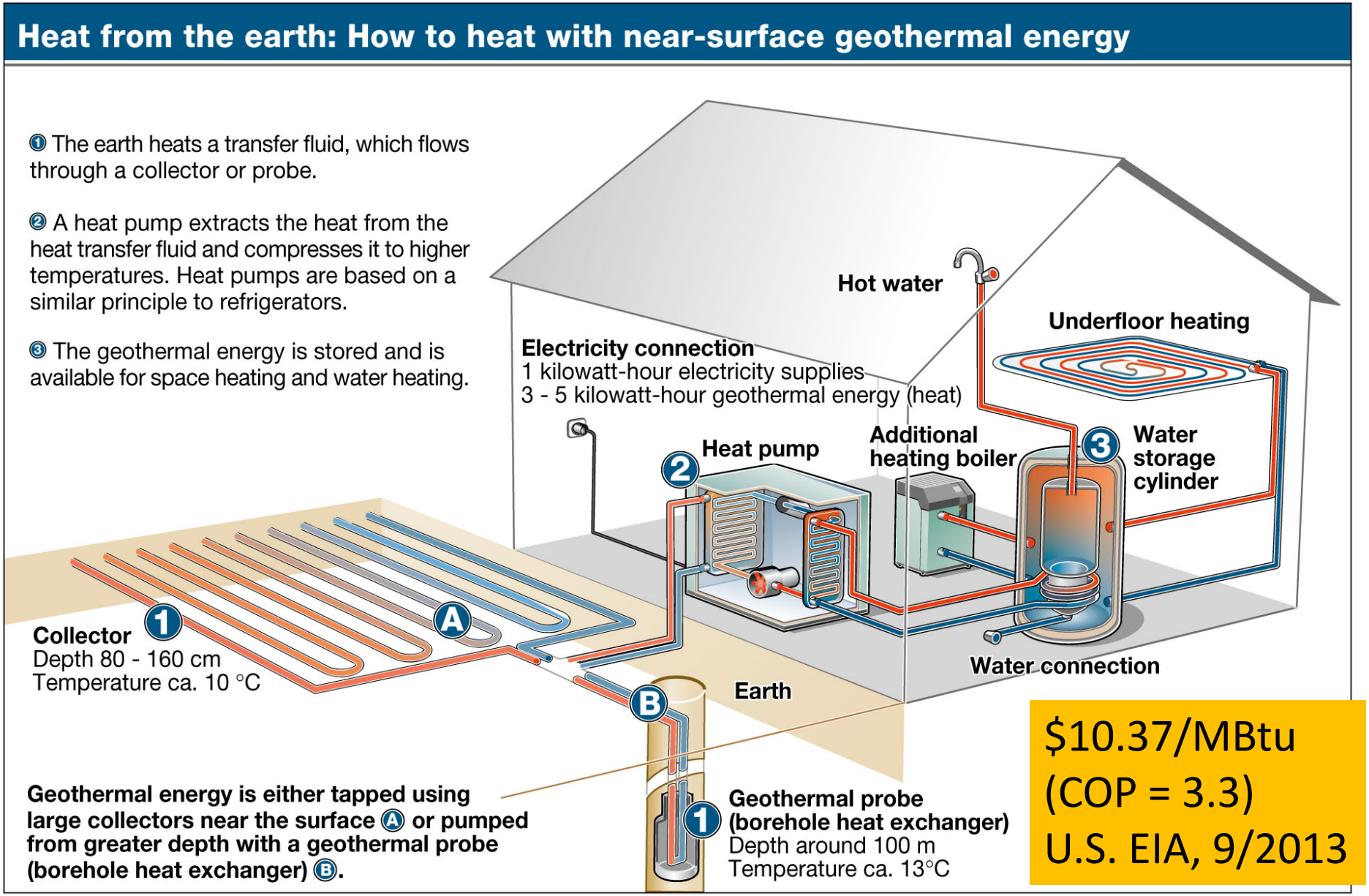
Wind Energy



Source: http://www.greenhousegrower.com

Ground Source Heat Pumps

Source: http://www.unendlich-viel-energie.de



$10.37/MBtu
(COP = 3.3)
U.S. EIA, 9/2013

COP = Heating or cooling energy delivered/electric energy consumed

Burning Shredded Wood

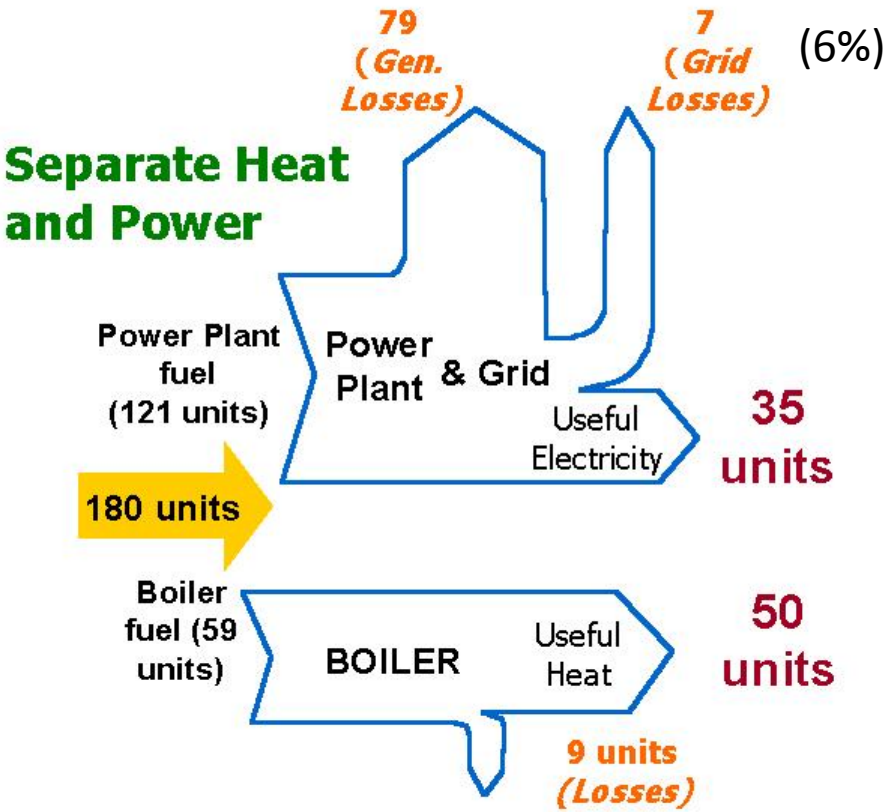
Outdoor Wood Stove

Waste Hot Water

Combined Heat and Power, NJ EcoComplex

Fuel: landfill gas
(could also be designed to operate on natural gas)

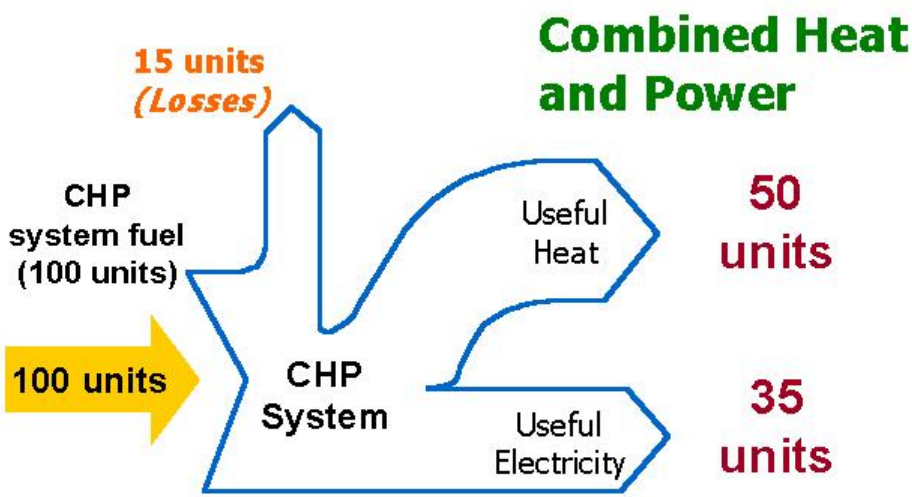
Comparing Efficiencies



Electricity:
29% efficiency
71% loss

Overall:
47% efficiency
53% loss

Heating:
85% efficiency
15% loss

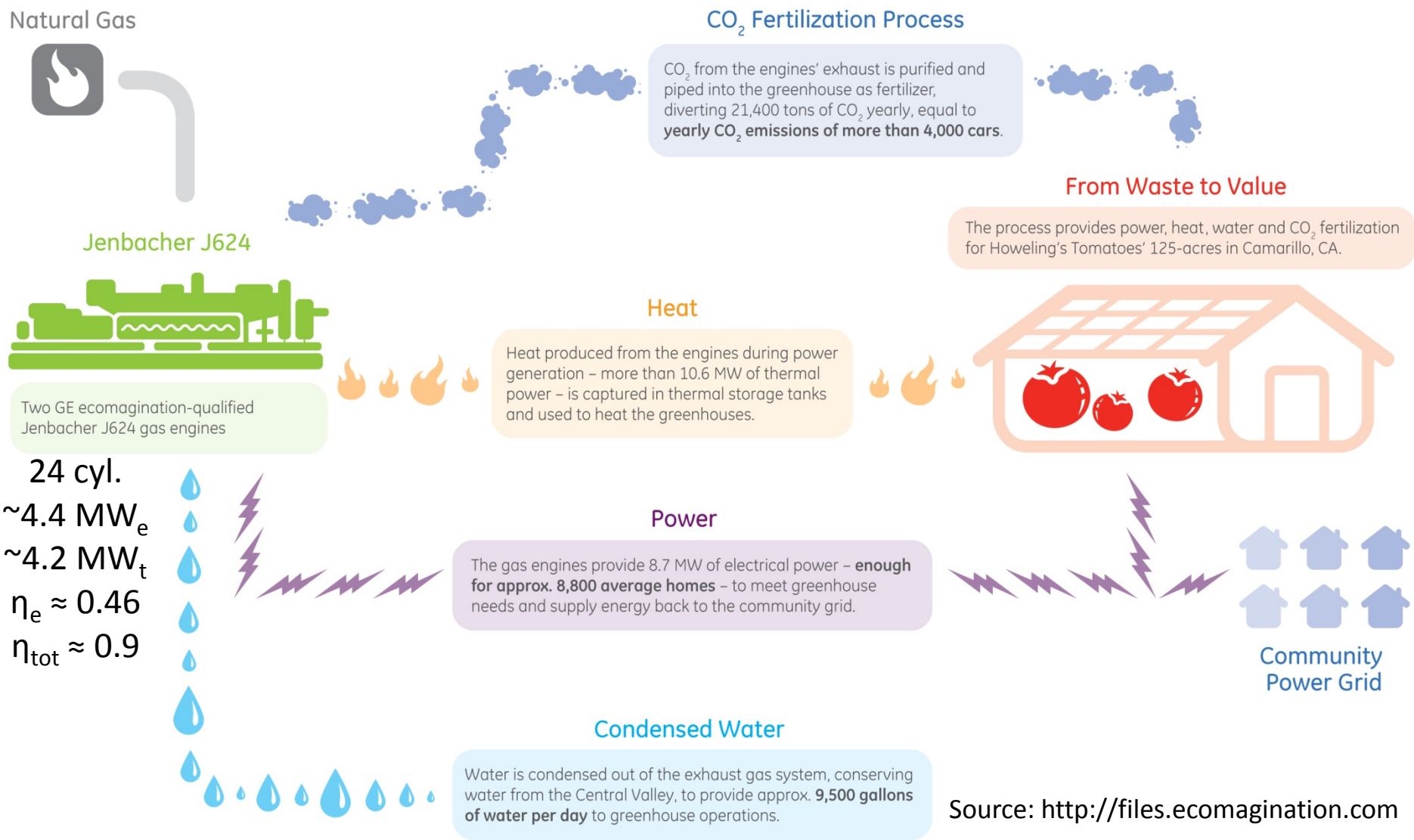


Overall:
85% efficiency
15% loss

http://www.gasairconditioning.org/

Growing a "Greener" Tomato

One of North America's largest greenhouse tomato growers, Houweling's Tomatoes, built the first combined heat and power (CHP) greenhouse project in the U.S. that captures carbon dioxide (CO_2) for use in plant fertilization.



Source: http://files.ecomagination.com

Comparing Energy Prices (national averages)

Fuel	unit	$/unit	Btu/unit	$/MBtu	Typical η (%)*	$/Mbtu
Electricity	kWh	0.125	3,412	36.64	98	37.38
Oil (#2)	gal	2.60	138,690	18.75	78	24.03
Natural gas	therm	1.12	100,000	11.20	82	13.66
Propane	gal	2.70	91,333	29.56	78	37.90
Kerosene	gal	3.15	135,000	23.33	80	29.17
Coal (anthracite)	ton	200	25,000,000	8.00	75	10.67
Wood	cord	200	22,000,000	9.09	63	14.43
Wood pellets	ton	250	16,500,000	15.15	78	19.43
Corn	ton	200	14,000,000	14.29	78	18.32

*steady state efficiencies, seasonal efficiencies are lower (they take into account e.g., heat losses when the heater/boiler is off and losses due to a continuous pilot light). Some manufacturers offer heating system models with higher conversion efficiencies.

Source: U.S. Energy Information Administration (1/2015)

Reducing Energy Costs
(note: savings can not be summed)

- Always start with conservation measures!
- Use an energy/shade curtain (30%)
- Avoid unintended cracks/openings (2-10%)
- Consider high efficiency heaters/boilers (20-40%)
- Consider condensing boilers (10-20%)
- Perform timely maintenance (5-10%)
- Use computer control and variable speed motors and pumps (5-10%)
- Lower heating system temperature (5-10%)
- Use highest R-value for insulation (5-10%)
- New installations: consider co-generation (50%)

Calculation Tool: Virtual Grower

- The software can:
  - Determine heating costs
  - Help identify savings
  - Predict real-time energy use
  - Determine the impact of lighting
  - Predict crop growth
  - Assist with crop scheduling
  - Help identify potential energy savings (evaluate what-if scenarios)

Available (free of charge) from: http://www.ars.usda.gov/Research/docs.htm?docid=19961

Useful References

- *Energy Conservation for Commercial Greenhouses*, NRAES 3, PALS Publishing
- *Greenhouse Engineering*, NRAES 33, PALS Publishing
- ASABE Engineering Practice 406, *Heating, Ventilating and Cooling Greenhouses*
- ASABE Engineering Practice 460, *Commercial Greenhouse Design and Layout*
- NGMA Standards (http://www.ngma.com/)
- http://www.hrt.msu.edu/Energy/Notebook.htm
- http://learningstore.uwex.edu/Energy-Environment-C13.aspx (A3907-01 to -05)
- http://aesop.rutgers.edu/~horteng

Thank You!!!

Questions?

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