Greenhouse Energy Use

- Energy
  - 3rd largest cost (~15%)
  - 70-80% for space heating
  - 10-15% Electricity
- The Agronomic-Economic Balance
  - Light transmission for plant growth
  - Environmental factors – humidity, temperature
  - Structure cost
  - Operating costs

Principles of Heat Loss

- Conduction
  - Heat conducted through a material
  - U-value – Btu/(hr-°F-sq.ft.)
- Convection
  - Heat exchange between a moving fluid (air) and a solid surface
- Radiation
  - Heat transfer between two bodies without direct contact or transport medium – Sunlight
- Infiltration
  - Exchange of interior and exterior air through small leaks/ holes in building shell

Greenhouse types

Structure Efficiency

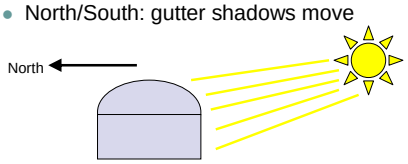
- Gutter Connected
  - Lower heat loss / less surface area
  - Better space utilization
  - 1.5 ratio – heat loss area to floor area (25,000 sq. ft.)
- Stand alone (quonset, gable, gothic)
  - Isolated growing conditions
  - Heat as filled
  - Natural Ventilation with open / roll-up side walls
  - 1.7-1.8 ratio - heat loss area to floor area (3000 sq. ft.)
- What shape would have the lowest heat loss area to floor ratio?

Structural Efficiency

- Space heating comparison
  - All Glazing – Double poly IR
  - 24,000 ft^2 growing area
  - Black fabric covered floor
  - LP power vent unit heaters @ 78% seasonal efficiency
- Farm A – Eight greenhouses – 30’ x 100’ x 15’H x 3’ side
  - Energy use – 1793 gallons LP per house (14,344 gal. total)
- Farm B – Gutter connected greenhouse
  - 5 bay – 30’ (150’) x 160’ x 10’H (15’ peak)
  - Energy use – 11,929 gallons
- Energy savings – 2415 gallons (18% savings)

Greenhouse Orientation

- Single span
  - East/West: maximize winter sunlight
- Gutter Connected – multiple bay
  - North/South: gutter shadows move



Glazing Materials

- Heat loss
  - Single pane glass
    - Highest heat loss (1.1 Btu/sq. ft.-hr-F)
    - Longest life (Unless large hail) – 25 years +
    - Highest cost structure – weigh of glass
    - High light Transmittance
  - Double Polyethylene Film
    - Low heat loss (0.5 to 0.7 Btu/sq. ft.-hr-F)
    - Shortest life – 3-4 years (UV degradation)
    - Low cost
    - Lowest Light Transmittance

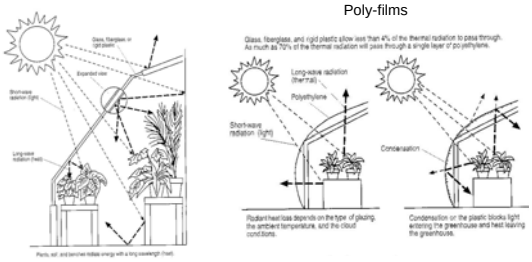
Glazing Material Comparison

Material	% Light Transmission PAR	% Thermal Transmittance IR	Conduction Heat loss U-Value	Estimated Life	Flammability
Glass					
Single	88-93	3	1.1	25+	none
Double, insulated	75-80	<3	0.7	25+	none
Acrylic					
Single	93	<5	1.1	20+	high
Double	87	<3	0.6	20+	high
Polycarbonate					
Single	91-94	<3	1.1	10-15	low
Double (6mm to 10mm)	78-85	<3	0.53-0.63	10-20	low
Fiberglass, reinforced					
Single	90	<3	1.2	10-15	high
Polyethylene					
Single	87	50	1.2	3-4	
Double	78	50	0.7	3-4	Varies
Double, IR	78	<20	0.5	3-4	

Infrared Radiation pathways

Glass or Polycarbonate

Poly-films



Radiation

- Solar or short radiation
  - Absorbed by plants, soil & greenhouse
- Re-radiate heat out - long wave or Infrared (IR) radiation
  - Varies with cloud cover
- Glass and rigid plastic glazing
  - Inhibit loss of IR radiation (< 4% loss)
- Polyethylene film
  - IR losses ~ 50%

Polyethylene film w/ IR additive

- Reduces IR heat loss by 15-20%
- Incremental Cost ~ $0.015 / sq. ft.
- Payback ~ 2-3 months / one season
- No light transmittance losses
- Diffuses light – faster, fuller more even crop growth
- Often combined with anti-condensate (AC) coating

AT Plastics	Dura-Film 4 Thermal AC
	Dura-Film 4 Thermal AC Plus
Covalence Plastics	Tufflite Infrared
Klerk's	K50 IR/AC
	K3 IR/AC
Green-Tek	Sunsaver
Ginegar Plastics	Sun Selector AD-IR / Suntherm

- Installation
  - IR film on inside with anti-condensate side down (inside greenhouse)
  - Standard poly film used for outer layer

Factors affecting solar gain

- % Light = % growth
- Glazing Transmittance
  - Differences between materials - (75% to 94%)
  - Condensation – can reduce light 15-25%
    - Anti-Condensate Films (additive)
    - Sun-Clear – Spray on anti-condensate
  - Dust
    - Anti-Dust additive

Double Poly Inflation Blower

- Located on inside but drawing air from outside
- Cold air has lower humidity
- Less condensation between sheets
- Jumpers to ensure proper inflation

Source: http://www.greenhousemegastore.com/Poly-Inflation-Fan-Kit/productinfo/GF-INFL/

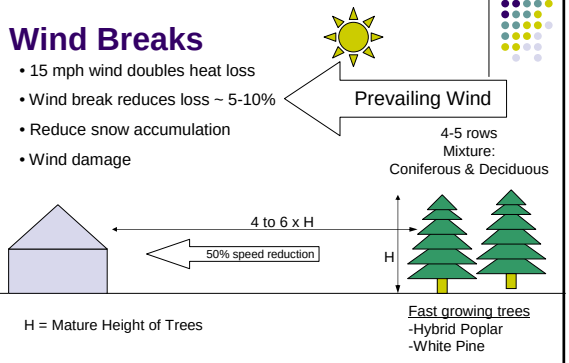
Glazing Materials vs Infiltration

- Infiltration Rates
  - Louvers, doors, holes, laps in glazing
  - Glass – high (2x compared with double poly)
  - Double Poly – lowest

	Air Exchanges Per Hour
New Construction	
Double-layer plastic film	0.5 to 1.0
Glass, fiberglass, polycarbonate, acrylic	0.75 to 1.5
Old Construction	
Glass, good condition	1.0 to 2.0
Glass, poor condition	2.0 to 4.0

Wind Breaks

- 15 mph wind doubles heat loss
- Wind break reduces loss ~ 5-10%
- Reduce snow accumulation
- Wind damage



Infiltration leaks

- Save 3-10% in heating costs
  - Check Roof and wall vents - seal tight
  - Tight Cover
  - Glazing / lap seals on Glass
  - Fix holes in cover
  - Weather stripping around doors
  - Door Sills
  - Roll-up doors – Seal for winter?
  - Ventilation louvers close tight
    - Dry Lubricant - use graphite
  - Cover unneeded fans / vents during winter
    - Foam and plastic
  - Plug gaps around foundation – Earth up to sill board
  - Double/Single polyethylene over glass – 40% savings

Conduction Heat Loss

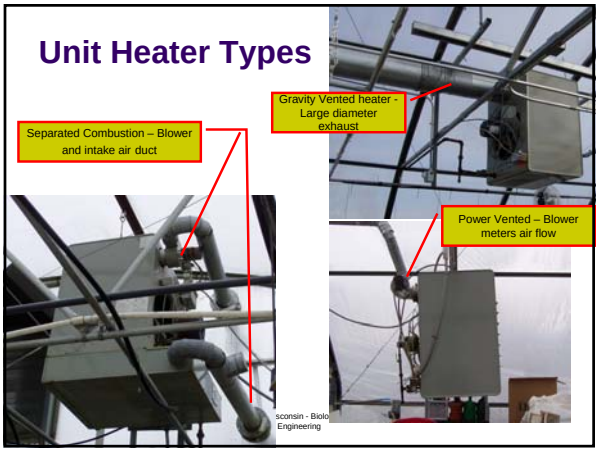
- Insulate side walls to plant height
  - Insulation must be sealed to wall
- North walls – insulate all opaque surfaces and more?
- Perimeter 24” below ground – 1 to 2” Foam
  - New construction
- Warning – Foam Board is flammable – keep away from stoves!

Thermal / Shade Screen

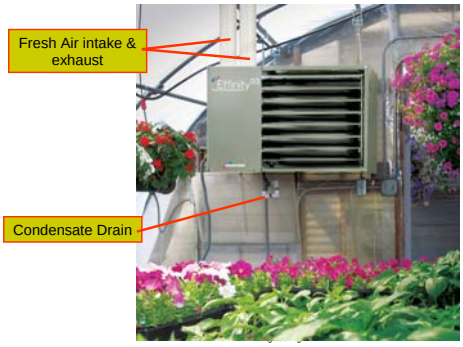
Greenhouse unit heats

- Low cost
- Ease of installation
- Low installation costs
- Easily staged
- Reliable

Unit Heater Types



High Efficiency Condensing Unit Heater



Vented Unit Heaters –Thermal Efficiency

	TE*	Cost#
• Gravity Vent heaters	80%	$ 1810^
• Power Vent Heaters	80%	$ 1910
• Separated Combustion	80%	$ 3443
• HE Condensing SC	93%	$ 3798

*TE – Thermal Efficiency –Combustion and heat transfer efficiency.
Manufacturer's Suggested List Price – Actual cost may be less.
^ Manufacturing of Gravity Vented heaters has been discontinued cost is estimated based on historic pricing.

Vented Unit Heater – Seasonal Efficiency

	TE*	SE*
• Gravity Vent heaters	80%	~ 65%
• Power Vent Heaters	80%	~ 78%
• Separated Combustion	80%	80%
• HE Condensing SC	93%	93%

- TE – Thermal Efficiency –Combustion and heat transfer efficiency.
- SE – Seasonal Efficiency – Includes TE plus heat loss out exhaust vents when heater is idle and warmed air used for combustion.

Case Study
Unit Heater cost justification:
Which heater is the most cost effective?

- Greenhouse 30 x 96 located in Madison, WI
- Two LP gas unit heaters
  - One heater can supply all heating needs ~ 90% of the time
- Temperatures:
  - Day-time - 68°F
  - Night-time - 60°F
- All other costs assumed the same
  - LP gas cost - $1.50/gal
- Growing season Feb 1 to June

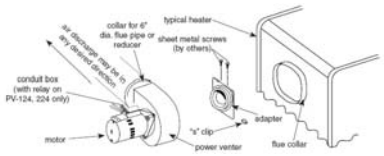
Fuel Savings and Payback

Heater Type	Incremental Cost	Est. Fuel (Gal.)	% Fuel Savings	Fuel Cost Savings*	Simple Payback (yrs)
Gravity-Vented #&	___	2494	___	___	___
Power-Vented #	$ 200	2078	16%	$ 624	0.3 (39 days)
Separated Combustion #	$ 3246	2026	19%	$ 702	4.6
HE Condensing Sep. Combustion ^	$ 3956	1743	30%	$ 1126	3.5
HE Condensing & Power-Vented	$ 2068	1810	27%	$ 1026	2.0

* $1.50/gallon LP gas, # 250,000 Btu/hr rating, ^ 215,000 Btu/hr rating, & manufacturing discontinued

Gravity Vent Conversion kits

- Convent to Power Vented unit
- 13% increase in seasonal efficiency
- List price (2007): $438 plus installation
- Payback – 1 or 2 seasons



Non-vented unit heaters

- Fuel savings
  - 99% Thermal Efficiency
  - 80% Seasonal Efficiency
- Increases CO_2 levels
  - Good for plants - Daytime
  - Could be used in place of a CO_2 generator
- Increases H_2O levels
  - Can increase / cause disease problems
  - Increased condensation – lower light levels
- MUST be used with fresh air intakes
  - Oxygen depletion in tight greenhouses ~ poor combustion
  - 1 in^2 air intake area per 1000 to 2000 Btu/hr of furnace capacity
    - 12" diameter opening for a 250,000 Btu/hr heater

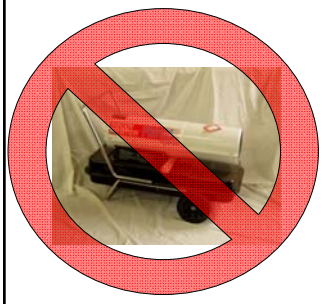
Non-electric unit heaters

- Convection heat flow
- Venting required
- Low Btu / hr capacity
- Multiple units needed per greenhouse
- Air intake for combustion air


Source: http://www.southernburner.com/

- Thermostat
  - Single stage Thermostat
    - Maintains same temperature day or night
  - Set-back Thermostat
    - Battery operated clock
    - One setting for day time
    - One setting for night time
    - Mount away from heater

Portable Kerosene/Oil Heaters



- **Only recommend using NG or LP gas for emergencies**
  - Combustion byproducts from oil / kerosene harmful to some plants (tomatoes) and people
  - Ethylene, Sulfur Dioxide, Nitrous Oxide, CO
- **Venting REQUIRED**

Heating System Distribution Location

- In-Floor heating w/ Floor growing system
  - Concrete or dirt floor
  - Hydronic heating (hot water)
- Bench / Under-Bench heating
  - Lower heating costs 20-25%
    - Hydronic or forced air
- Study - 7% increased yields for tomatoes
- Forced Air Under-bench distribution
  - Poly tubes under bench
- Approximately equivalent to a 5-10F reduction in greenhouse temperature.

Under-Bench Forced Air

Under-bench Hydronic heating

Under-bench Hydronic heating

- Natural Convection / Thermal buoyancy
- No pumps

Supply from boiler

Distribution to pipes running under benches

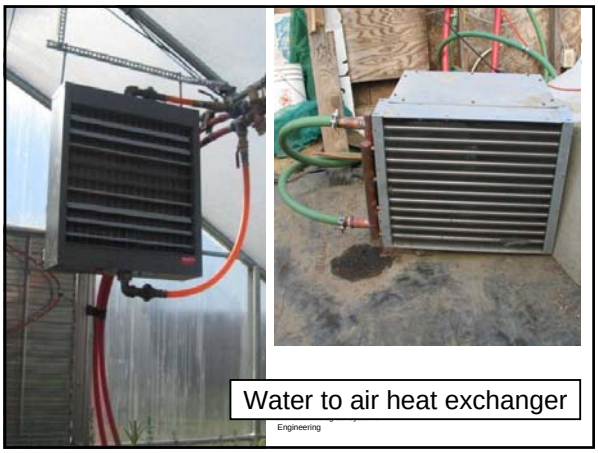
Return piping to boiler

Heating Maintenance

- Heat Equip. Maintenance
  - Insulation of pipes and ducts in head-house
  - Clean Air heat Exchanges
  - Lubricate motors & fans
  - Remove Soot – can reduce fuel consumption by 10%
  - Steam trap maintenance
  - Burner tune up
    - Change fuel filter
    - Correct nozzle
  - Thermostat – Calibrate annually
  - Up to 20% fuel savings
- Provide air intakes for Boilers and unit heaters
  - Smell of combustion gases indicated lack of large enough air intakes

High Efficiency Boiler Systems

- High Efficiency– 90%+
  - Hot water boiler systems
  - Modulated firing rates
  - Condensing Boiler – up to 98% AFUE
  - Add on to existing boiler
    - HE Boiler Primary
    - Old Boiler Secondary
  - Numerous Manufacturers



Radiant / Infrared Heating Systems

- Heats objects not air
- Can burn plant leaves
- Heat distribution varies along pipe on many systems
- Best Uses
  - Loading docks
  - Work areas
    - Transplanting
    - Seeding
  - Warehouse

Publication: Gas-Fired Infrared Heating for Greenhouses

By manufacuturer Roberts Gordon LLC

http://www.greenhouse-heater.com

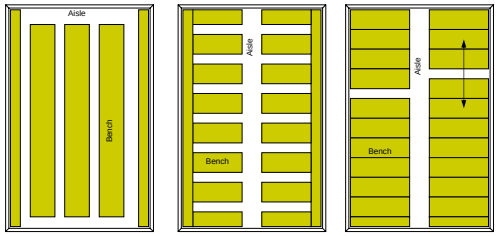
Environmental Controls

- Central Control Unit to control:
  - Heaters
  - Fans
  - Louvers / Vents
  - Irrigation
  - Lighting
  - CO_2
- Ensures systems are not competing
  - Example - Heater on while vents are open
- Computer tied to on site weather data
  - Anticipates heating and ventilation needs
- Use DIF – difference between day and night
  - Plants see average daily temperatures
  - 75°F day, 65°F night - same as 70°F - Save 5% / 10°F DIF

Space Utilization - Bench Layout

Bench Area Percentage

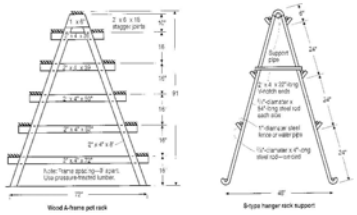
Longitudinal	Peninsula	Movable
59%	69%	81%



Source: Greenhouse Engineering, pg 45 – NRAES-33

Space Utilization

- Racking Systems
  - Take advantage of different plant light and temperature requirements



Hanging Basket Systems

- Pipe system with automatic watering

- Cable system with automatic watering

Circulation fans

- Mix air to prevent stratification of air
- Reduces heating
- Dries wet leafs faster – prevents disease

Greenhouses - Ventilation

- Energy-Efficient Fans
  - 48” fan - efficiency
    - Ranges from 12 to 27 CFM/watt
  - Test data available at:
    - BESS Lab - http://www.bess.uiuc.edu/index2.htm
      - Agricultural Ventilation Fans, Performance and Efficiencies ($9 + $3.50)
      - 332 Agricultural Engineering Sciences Building, Urbana, IL 61801
      - 217-333-9406
  - 36” or 48” fans – efficiency greater than 20 CFM / watt @ 0.05” H_2O
  - Larger diameter fans more efficient

Motor Efficiency – Single Phase

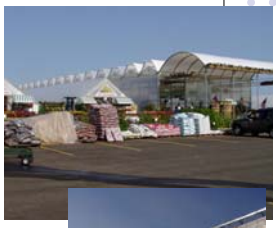
Horse Power	Typ. Std. Eff Motor	High Efficiency
1/4	55%	74%
1/3	60	77
1/2	62-68	78.5
3/4	74	84
1	67	82.5
1-1/2	75.5	84
2	75.5	82.5
3	78	85.5
5	80-82.5	86.5

Greenhouses - Ventilation

- Fan Maintenance
  - Shutter lubrication (dry lubricant – graphite) / maintenance
    - Shutter can reduce air flow by 40%
  - Belt tension / alignment – Automatic tensioners
    - Loose belt can reduce air flow by 30%
  - Trim weeds & shrubs
  - Bearing lubrication?
    - Should be using Totally Enclosed motors (with sealed bearings)

Greenhouses - Ventilation

- Shade Curtains
  - Aluminized shades – 10ºF lower air temperatures
  - Internal Shade cloth can double as thermal curtain
- Evaporative cooling
- Misting
- Roll-up side walls
- Open Roof Designs
- Variable speed fans
  - Winter ventilation

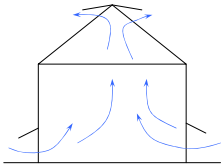


Natural Ventilation - Open Roof

- Large vent area
- ½ acre greenhouse with no fans
- Likely increased infiltration rates

Natural ventilation

- Inflated side walls
- Ridge vents
- Convection air flow



Pneumatic Vent controls

- Gas Charged Cylinder
- Opening Range
  - Adjustable
  - 59 to 77F
  - Gradual opening over ~20°F
- Lift Capacity-15-35 Lbs
- Springs for closing vent
  - Vertical vents - counter weigh
- $ 35 to $175
- Wind can wrench vents open

Roll-up side walls

- Good summer ventilation
- Not useful for winter venting or heating
  - Single layer glazing
  - Higher infiltration rates
  - Recommend sealing sidewall with film from the inside for winter

Supplemental lighting

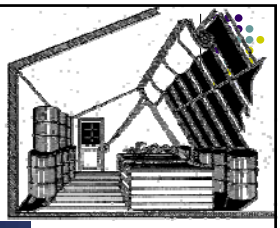
- Shorten / predictable time to market
  - Plant later
  - Less heating
  - Earlier Flowering
- Response and effect varies greatly
- Plug and Liners – more root development
- Greenhouse Veg. – High daily light integral (DLI) requirements.
- Cut Flowers – supplemental lighting common

- T-8 Fluorescent lamps – Growing Chambers
- HID lamps – Greenhouse
  - High Pressure Sodium – most energy efficient
  - Pulse Start Metal Halide – more blue light
  - Typically use 50% HPS, 50% MH
- Use Off-Peak electric?

Solar / Thermal mass

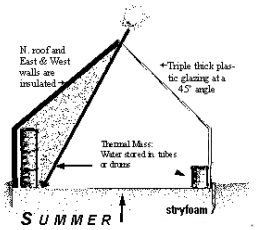
- Water, Rock, stone, brick
- Walls, Under-bench, foundation / under Floor
- Replace ~ 25% of night time heating costs
- Temperature must be allowed to vary
- Supplemental heating
  - Must heat thermal mass to increase temperature
- "Solviva" by Anna Edey
- Passive Solar Energy Handbook
  - by Edward Mazria

The Passive Solar Greenhouse

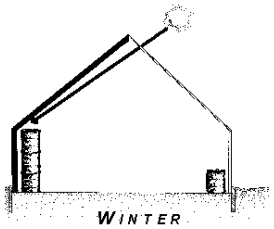


Systems

Passive Solar Greenhouse



Sun is higher in the sky and casts a shadow over the water-filled tubes and drums of the Botanic Gardens greenhouse helping to keep the greenhouse cool.



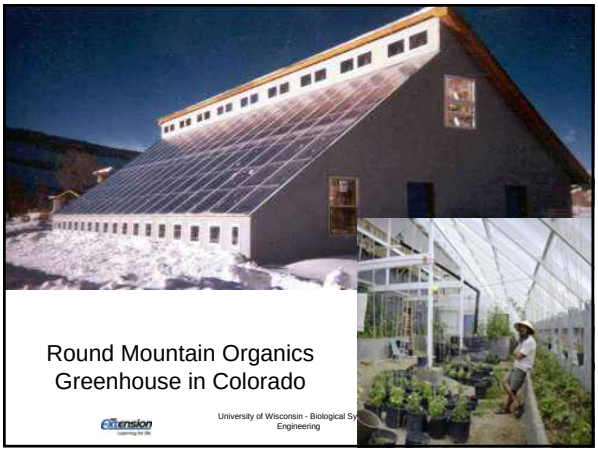
Sun is lower in the sky shining directly into the Botanic Gardens greenhouse directly illuminating and warming the water-filled tubes and drums. This helps keep the greenhouse warm.

University of Wisconsin - Biological Systems Engineering

Three Sisters Farm

Sandy Lake, Western PA

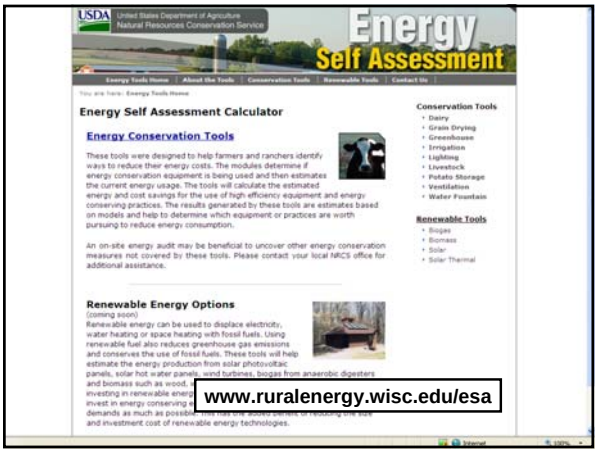
Heated by the sun and firewood



Round Mountain Organics Greenhouse in Colorado

University of Wisconsin - Biological Sy Engineering

Volunteer watering Plants. Water barrels are part of our passive solar system



Greenhouse Tools / Resources

- AgEnergy Resource web site
  - www.uwex.edu/energy
- "Energy Conservation for Commercial Greenhouses", NRAES-3, Ithaca, NY, 2001.
- Greenhouse Engineering, NRAES-33, Ithaca, NY, 1994.
  - www.nraes.org
- Lighting Up Profits, Paul Fisher & Erik Runkle, 2004
  - Ball Publishing
  - www.ballbookshelf.com/detail.aspx?ID=367
- National Greenhouse Manufacturers Association
  - www.ngma.com

Contact Information

Scott Sanford
Sr. Outreach Specialist
Focus on Energy / Rural Energy Issues
Biological Systems Engineering
University of Wisconsin – Madison
460 Henry Mall
Madison, WI 53706
608-262-5062
sasanford@wisc.edu
Energy Resource Site - www.uwex.edu/energy

www.focusonenergy.com 1-800-762-7077