Keeping Crops Fresh for Market

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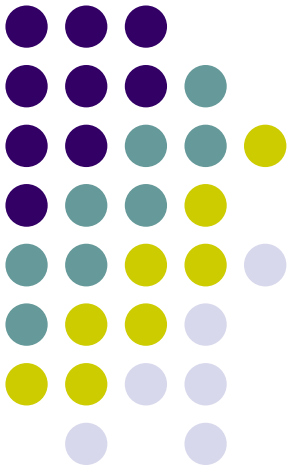

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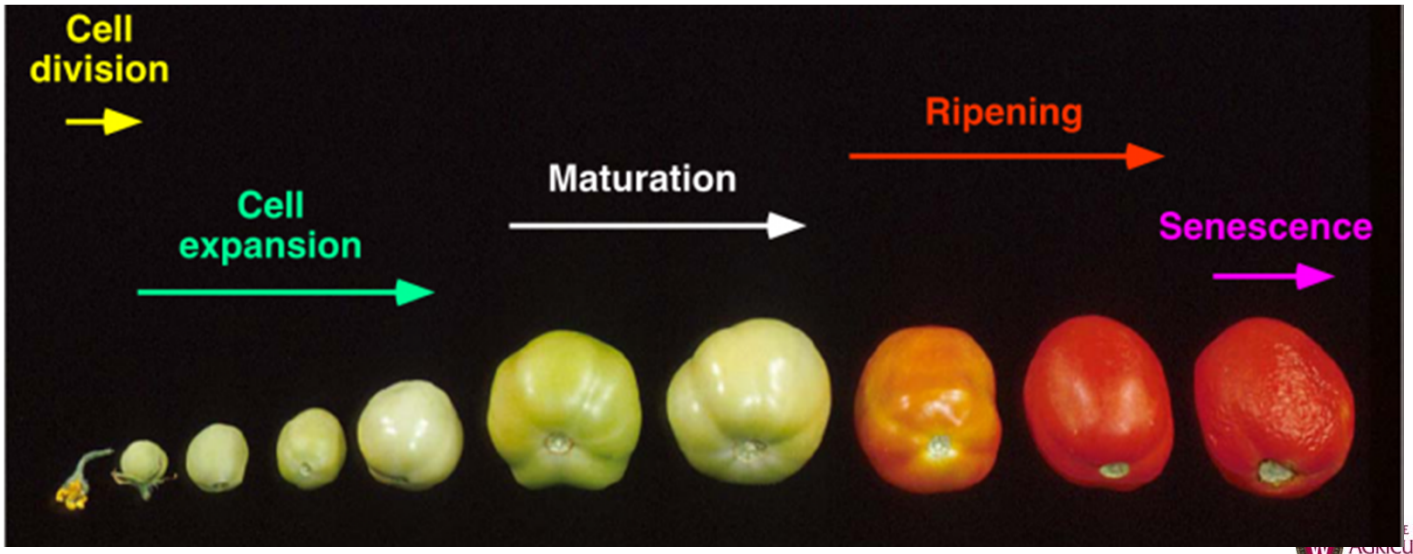
What affects length of storage?

- Temperature
- Humidity
- Quality of produce @ harvest
  - Stage of ripening
  - Disease - Decay
- Handling – harvest & post harvest
  - Bruises
  - Skin breaks
- Storage **cannot** improve Quality, only maintain it!

Physiological Breakdown

- Natural ripening
- Water loss
- Temperature injury
- Physical damage
- Invasion by microorganisms

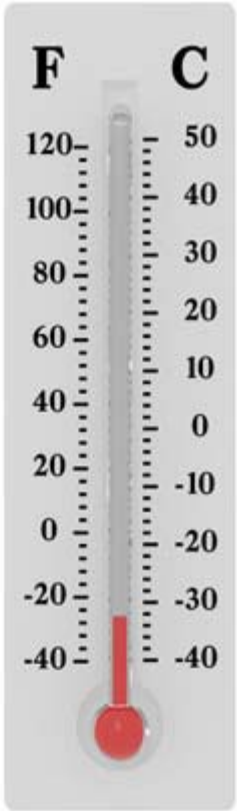
- Interactions between factors
- All influenced by Temperature



http://plantsinaction.science.uq.edu.au//figure_view/126

Temperature

- Critical factor
- Suppress enzymatic degradation (softening)
- Reduces respiration rates
- Slows water loss
- Slows growth of decay producing microorganisms
- Reduces ethylene production and reaction



Cooling – Field heat removal

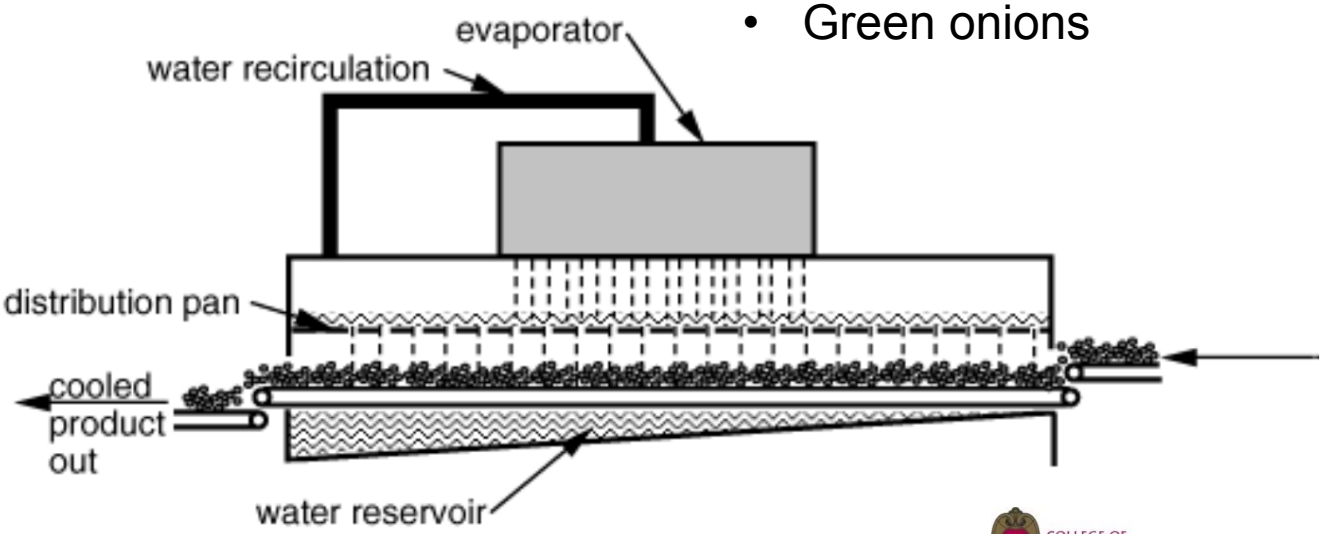
- Method of heat removal depend on commodity
- Type of produce – leafy, fruit, tuber
- Packaging – air flow through and around produce
- Volume of produce
- Mix of commodities
- Cooling capacity
- Economic constrains
- Market expectations / requirements

- Rate of cooling important for some commodities
- Curing required for some
  - Onions, potatoes, sweet potatoes

Pre-Coolers for field heat removal

- Hydro-cooling
  - Water bath or shower
  - 5X faster than air cooling
  - Disease / pathogen transmission
  - Sanitizer in water if recirculated

- Apples
- Asparagus
- Snap beans
- Cantaloupe
- Cucumbers
- Leafy greens
- Peas
- Green onions



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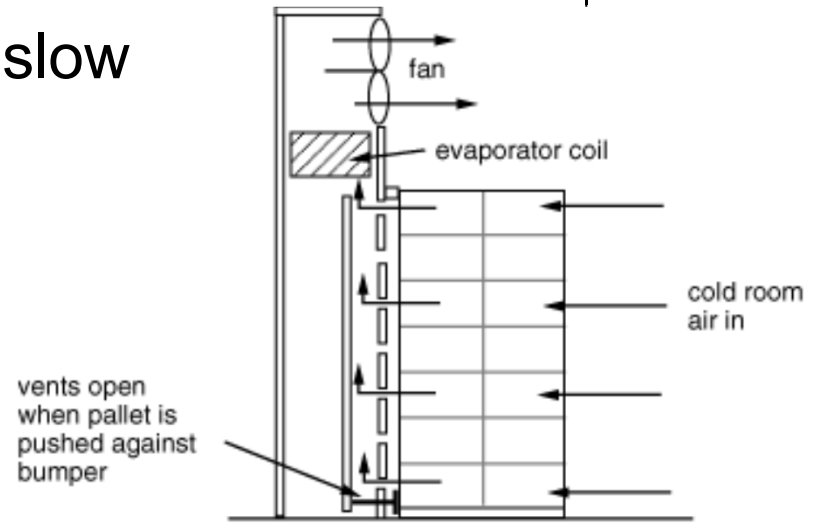
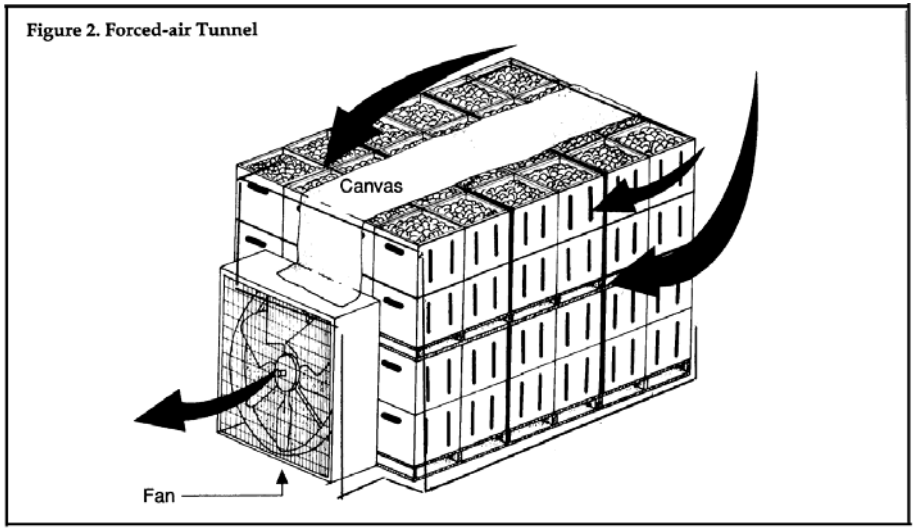
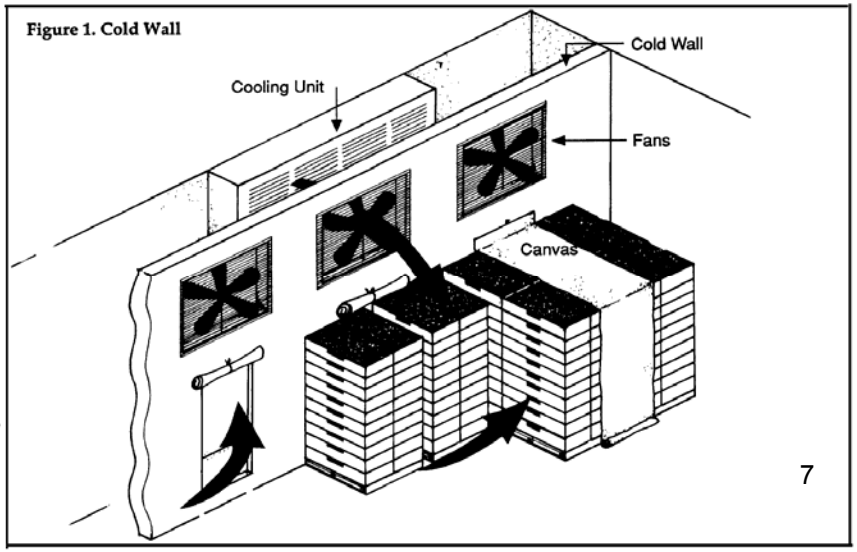
Source: USDA Agricultural Handbook Number 66, 2004

Pre-Coolers for field heat removal

- Dedicated Cooling Room – too slow
  - Plenum wall
- Forced air cooling
  - 75-90% faster than cooling room
  - Reduce air flow once cool







Source: USDA Agricultural Handbook Number 66, 2004

Precooling Produce – Gast & Flores, MF-1002, Kansas State U, 1991

Air Precooling

Pre-coolers for field heat removal

- Ice pack
  - 1 lb ice → 3 lb produce → 85 to 40°F
  - Asparagus, broccoli, cantaloupe, green onions, leafy greens, sweet corn

Reference: Li, Changying, Precooling Fruits and Vegetables in Georgia, C-1004, 12 pgs, University of Georgia Extension, 2011

Source: http://www.ipt.us.com/produce-inspection-resources/inspectors-blog/defect-identification/green-onions-discoloreddecayed-tops

Respiration Rates

Class	Commodity
Very low	Dried fruits, nuts
Low	Apples, garlic, grapes, onions, potatoes (mature), sweetpotatoes
Moderate	Apricots, cabbages, carrots, figs (fresh), lettuce, nectarines, peaches, pears, peppers, plums, potatoes (immature), tomatoes
High	Artichokes, brussels sprouts, cut flowers, green onions, snap beans
Extremely high	Asparagus, broccoli, mushrooms, peas, sweet corn

Postharvest Handling and cooling of fresh Fruits, Vegetables, and Flowers for small farms – Part I: Quality Maintenance, L.Gl Wilson, M.D. Boyette, E.A. Estes, HIL-800, North Carolina Cooperative Extension, 1999

Respiration Rates (Btu/ton/day)

Commodity	32 °F	40 °F	60 °F
Apples	660	1320	3190
Asparagus	11,770	21,010	53,570
Snap Beans	4400	7700	20,460
Beets – topped	1320	2090	4400
Broccoli	4400	7590	38,170
Cabbage	1100	2310	5720
Carrots - topped	3300	4290	8800
Leaf lettuce	5060	6490	13,750
Peas - unshelled	8470	14,410	41,910
Peppers, sweet		2200	5060
Potatoes		1320	1980
Squash, summer	2750	3630	18,150
Sweet potatoes (cured)			4840

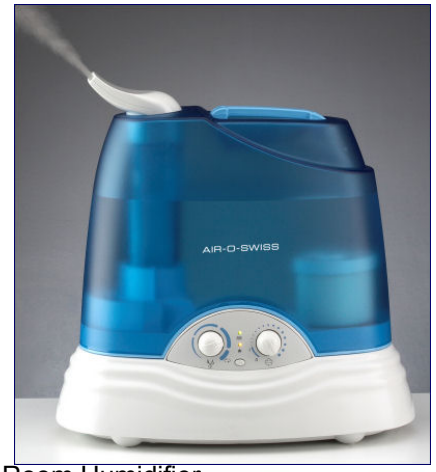
Source: Refrigeration and Controlled Atmosphere Storage for Horticultural Crops – NRAES-22

Effects of Humidity

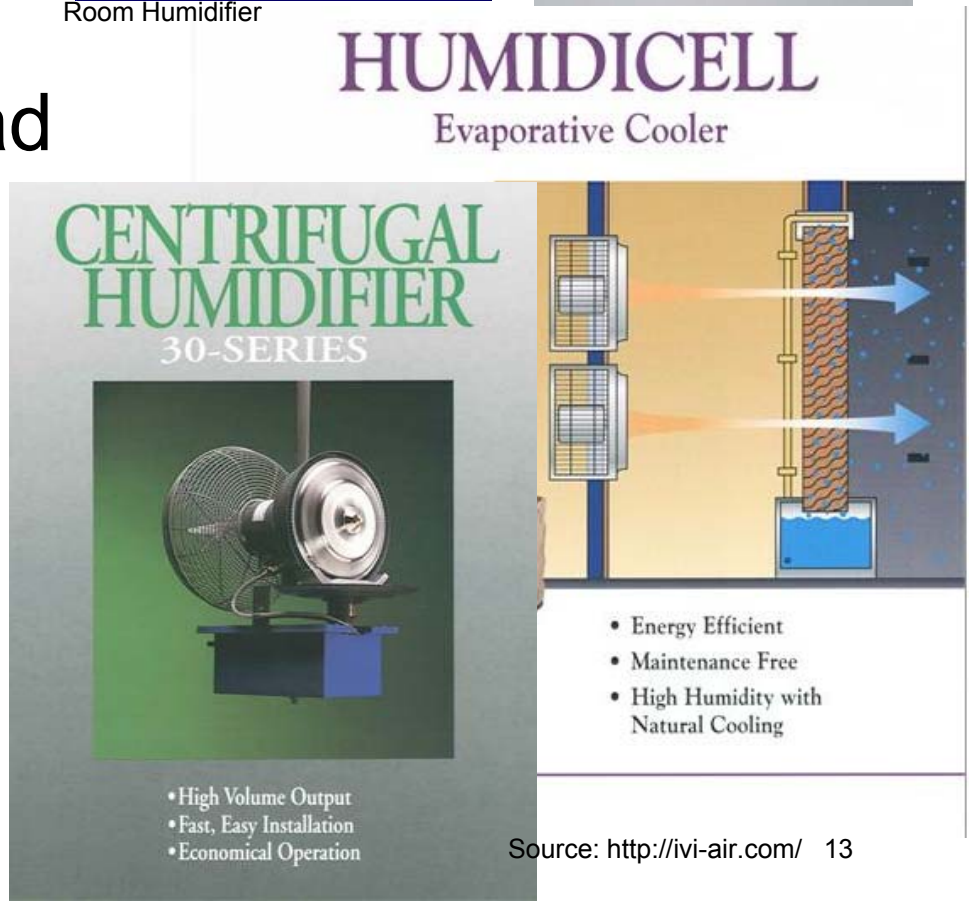
- What are you selling when you sell produce?
  - Loss of water – loss of profits.
- Water loss
  - Main cause of deterioration / loss of marketability
  - Wilting / shriveling
  - Increases with temperature
  - Increases with air speed
- Too much humidity
  - Disease & rots

Humidity control

- Add moisture to air to reduce crop moisture loss
- Evaporative cooler pad
- Centrifugal Atomizer
  - Fixed or variable rate
  - ~ $300 - $1700
- Ultrasonic Humidifier
- Pack in Plastic bag



Room Humidifier



Source: http://ivi-air.com/

Humidistat

- Accuracy range
  - Range to 99%
  - Accuracy - 3-4% or less
  - Resolution – 1% or less
    - Smallest display digit
  - Accuracy decreases >90%
- Remote sensor desirable
  - Locate in air flow
- Enclosure designed for wet environment
- Cost $140 - $500

Centrifugal Humidifier

- Utilities: Electric & Water

Humidity Control

- Refrigeration dehumidifies air
- Low temp drop → large evaporator surface area

Minimum Relative Humidity Levels[1] Developed at various Storage and Evaporator Discharge Temperatures			
Temperature Drop[2]	Storeroom Temperature, °F		
Across Evaporator, °F	**32°F**	**35°F**	**38°F**
-1°F	95.8	96.1	96.1
-2°F	91.2	92.3	92.4
-3°F	87.1	88.7	88.8
-4°F	83.0	84.7	85.3
-5°F	79.4	80.9	82.0
-10°F	62.7	64.1	65.3
-15°F	49.3	50.5	49.4

[1] Calculated from Psychrometric Tables

[2] Actual Airstream temperature drop between inlet and outlet. The coil TD will be approximately twice this value.

Source: Refrigeration and Controlled Atmosphere Storage for Horticultural Crops – NRAES-22

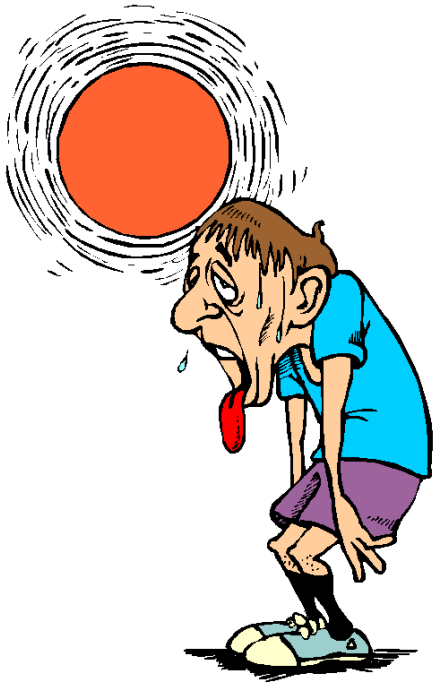
Temperature Ranges for crops

- Cold & Wet - 32°F & RH 95%+
  - Beets, cabbage, carrots, turnips, parsnips
  - Lettuce, peas, sweet corn, spinach, broccoli
- Cool & Wet - 40-50°F & RH 90-95%
  - Snap beans, cantaloupe, tomatoes
  - Potatoes – Summer 50°F, Fall – 40°F
- Warm & moist
  - Green tomatoes – 50-70°F & RH 90%
  - Cucumbers – 50-55°F @ RH 95%

Temperature Ranges for crops

- Cold & Dry - 32F & RH 65-70%
  - Onions, Garlic
- Warm & Dry
  - Winter Squash - 50-55°F & RH 50-70%
  - Sweet Potatoes - 55-60°F & RH 80-85%
  - Hot peppers – 50°F & RH 60-65%

Temperature injury



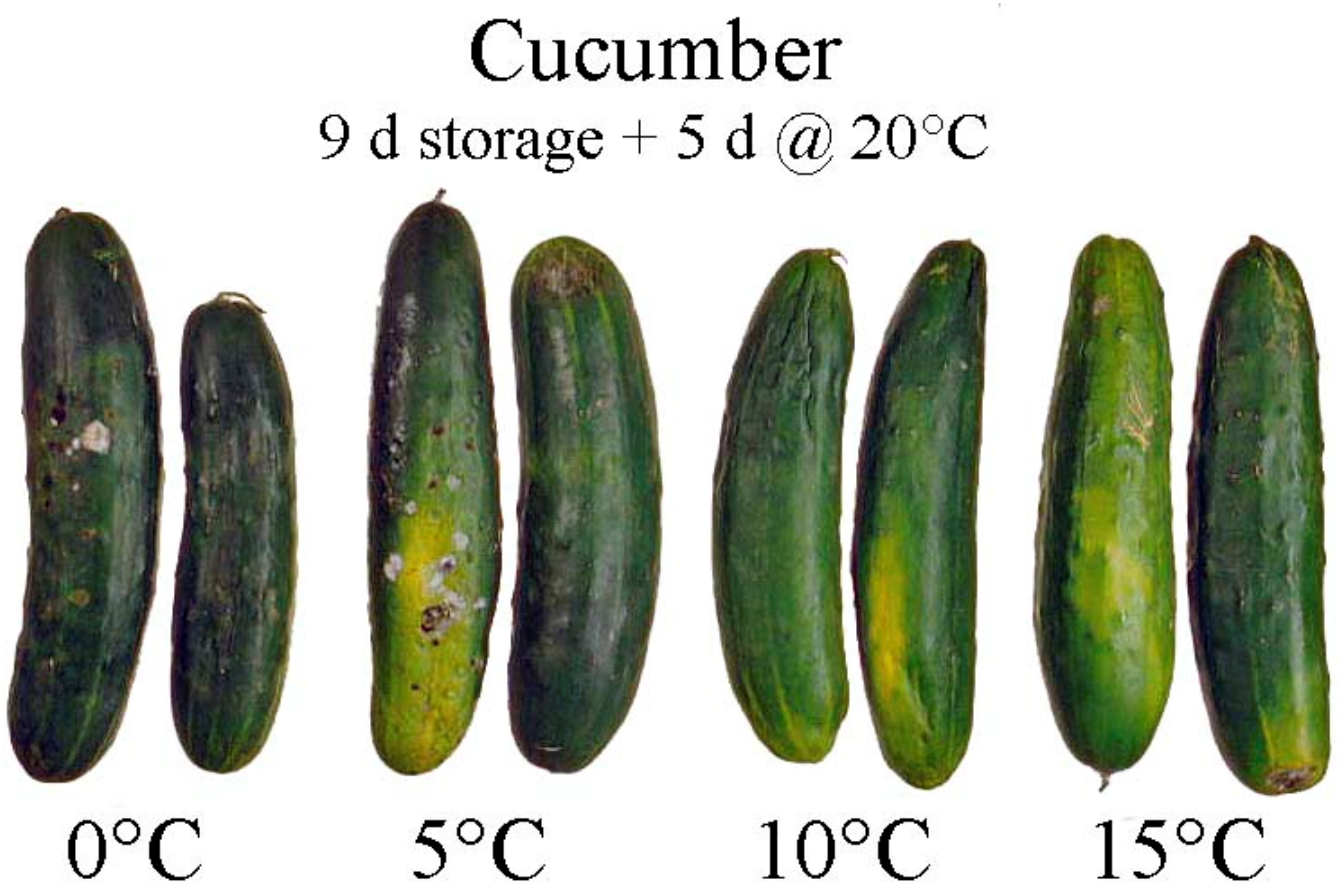
- Heat or cold
- Alternating temperatures
- Symptoms of Heat injury
  - Bleaching
  - Surface burning
  - Uneven ripening
  - Excessive softening
  - Desiccation

Temperature injury

- Symptoms of Chilling injury
  - Plants of Tropical origin typically
  - Pitting, surface decay - snap beans, cucumbers
  - Internal browning - apples, sweet potatoes
  - Surface scald - eggplant
  - Objectionable flavor – watermelon
  - Water soaking – ripe tomatoes
  - Poor color when ripe – green tomatoes
  - Sweetening – potatoes
  - Hard when cooked – sweet potatoes
  - **Injury may be hidden**

Temperature Injury

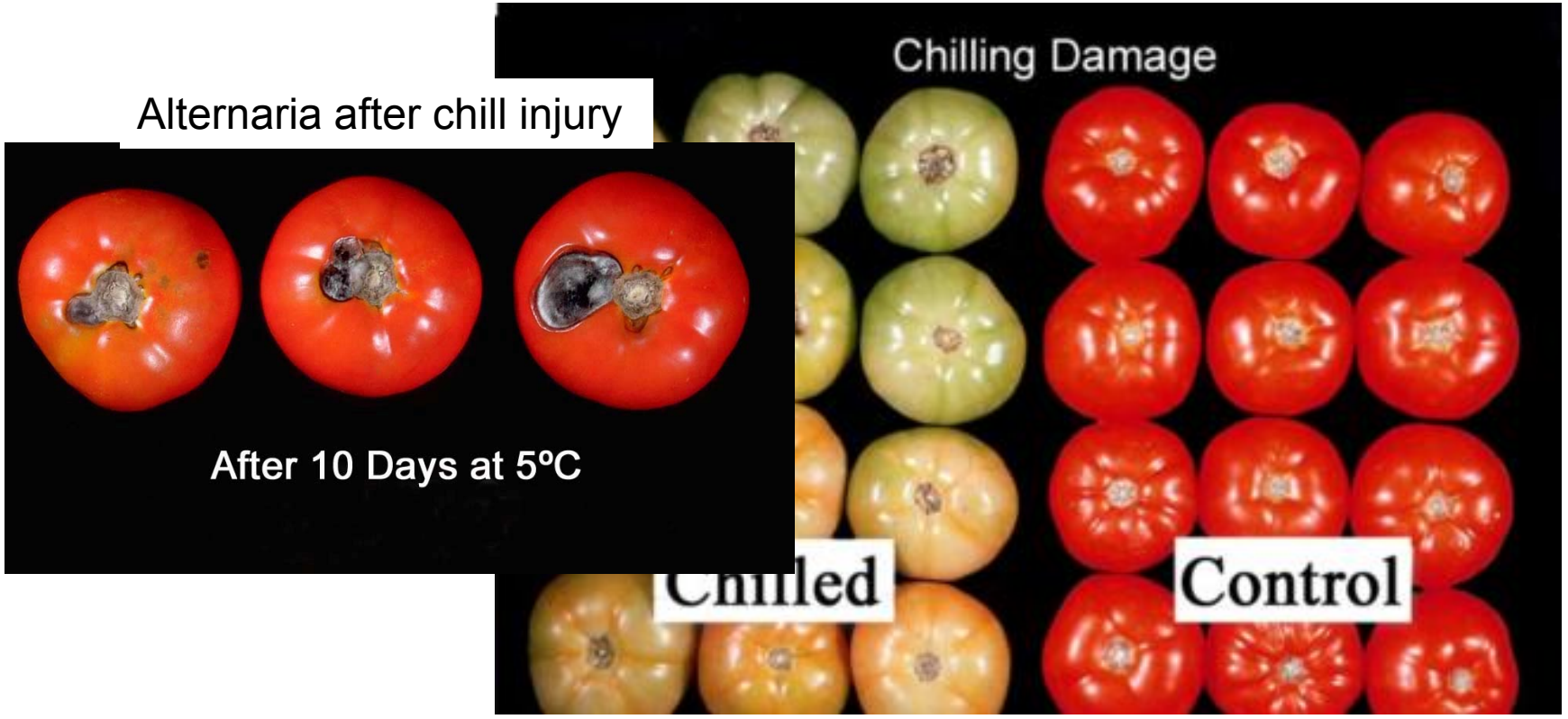
- Recommended storage - 10-12.5°C (50-55°F) @ 95% RH



Source: University of California, Davis - Postharvest Technology Center

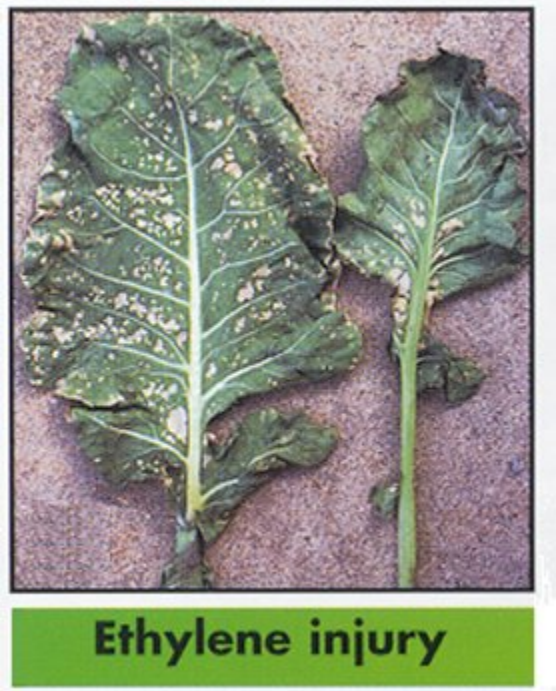
Temperature Injury

- Recommended storage - 12.5-15°C (55-60°F) @ 90-95% RH
- Ripening – 65-70°F or 57-61°F for slow ripening

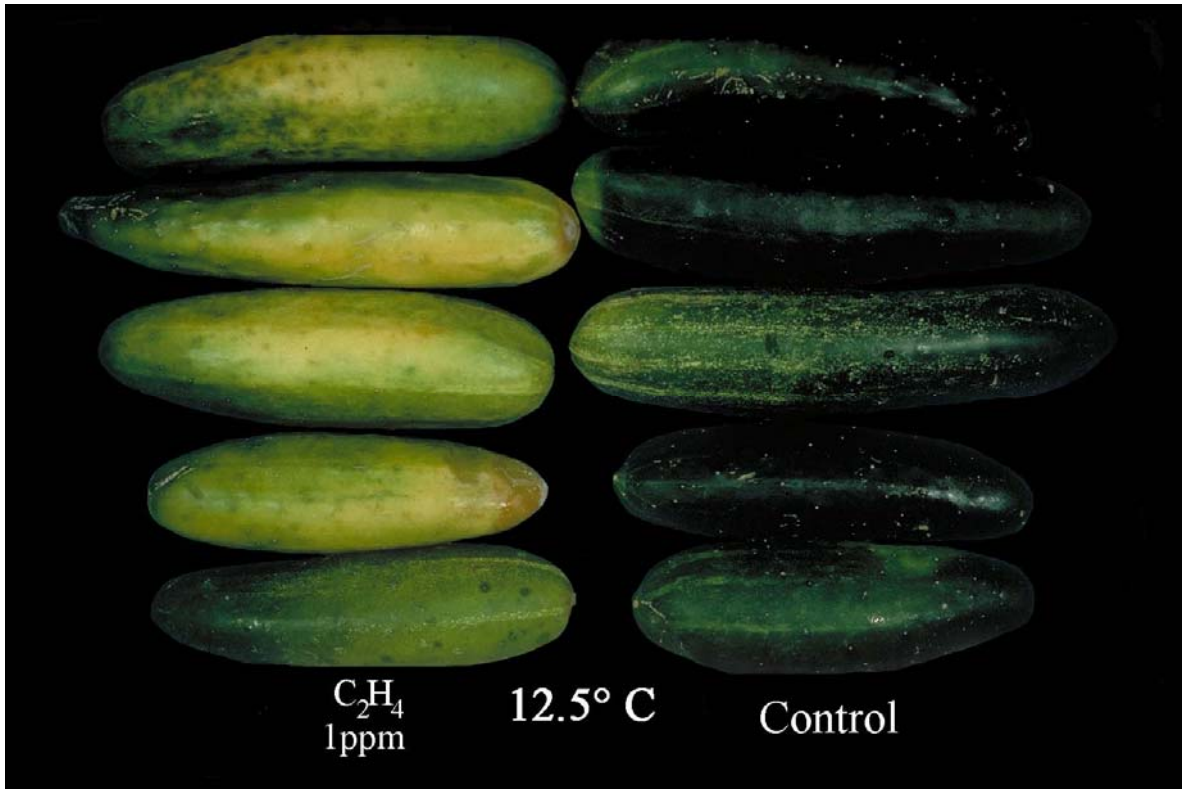


Source: University of California, Davis - Postharvest Technology Center

Ethylene injury



Source:
http://ipm.ncsu.edu/vegetables/pamphlets/crucifer/



Source: University of California, Davis - Postharvest Technology Center

Table 2.3 Products which are incompatible in long-term storage.

Products			Effects
Apples or Pears	with	Celery Cabbage Carrots Potatoes Onions	Ethylene from apples and pears damages or causes off flavors in vegetables. Potatoes cause "earthy" flavor in fruit. Potatoes are injured by cold temperatures. High humidity causes root growth in onions. Ethylene causes bitterness in carrots.
Celery	with	Onions or Carrots	Odor transfer occurs between products.
Meat Eggs Dairy	with	Apples and Citrus	Fruit flavors are taken up by the meat, eggs, and dairy products.
Leafy Greens and Flowers	with	Apples Pears Peaches Tomatoes and Cantaloupe	Ethylene produced by the fruit crops damages greens and flowers.
Cucumbers Peppers and Green Squash	with	Tomatoes Apples Pears	Ethylene from tomatoes, apples, and pears causes loss of green color. This is aggravated by storage temperatures of 45-50°F which are too warm for apples and pears.

Modified from Hardenburg et. al. (1986).

Length of Storage

- Need to market produce within normal storage life
- Awareness of produce quality entering storage
- Storage management
  - Monitor for disease / rots
  - Humidity / Temperature
- Awareness of freezing point / chill point

Length of Storage

Commodity	Opt Temp F	Opt Humidity %	Storage Life
Asparagus	36	95-100	2-3 weeks
Snap Beans	40-45	95	7-10 days
Broccoli	32	95-100	2 weeks
Cabbage, early	32	98-100	1-2 months
Cucumbers	45-55	95	2 weeks
Leafy Greens	32	95-100	1-2 weeks
Peas	32	95-98	1-2 weeks
Peppers	45-50	90-95	2-3 weeks
Squash, summer	45-50	95	1-2 weeks

Length of Storage

Commodity	Opt Temp F	Opt Humidity %	Storage Life
Apples	30-40	90-95	1-4 mo (air) up to12 mo CA
Beets - topped	32	95-98	8-10 mo
Brussel Sprouts	32-34	95-98	4 weeks
Cabbage, late	32	95-98	5-6 mo
Carrots – topped	32-34	95-98	5-9 mo
Celeriac	32-34	95-98	6-8 mo
Garlic	32-34	60-70	5-8 mo
Onions	32-34	60-70	6-9 mo
Parsnips	32-34	95-98	4-6 mo
Potatoes. late	40-45	95-98	5-8 mo
Squash, winter	50-55	50-75	2-3 mo
Sweet potatoes	55-60	85-90	4-7 mo
Turnips	32	90-95	4-5 mo

Adequate Refrigeration Capacity?

- Field heat removal
- Heat of respiration
- Conduction heat gain / loss
- Infiltration heat gain / loss
  - Air exchange (opening of door)
  - Leaks – door, seams
- Equipment heat gain
  - Lights, fans, fork truck

Refrigeration Requirement

- Field heat Removal
  - Largest component
  - Short duration
  - Smaller for Fall harvested crops
  - ΔT x lbs x SH
  - Slow removal effect produce

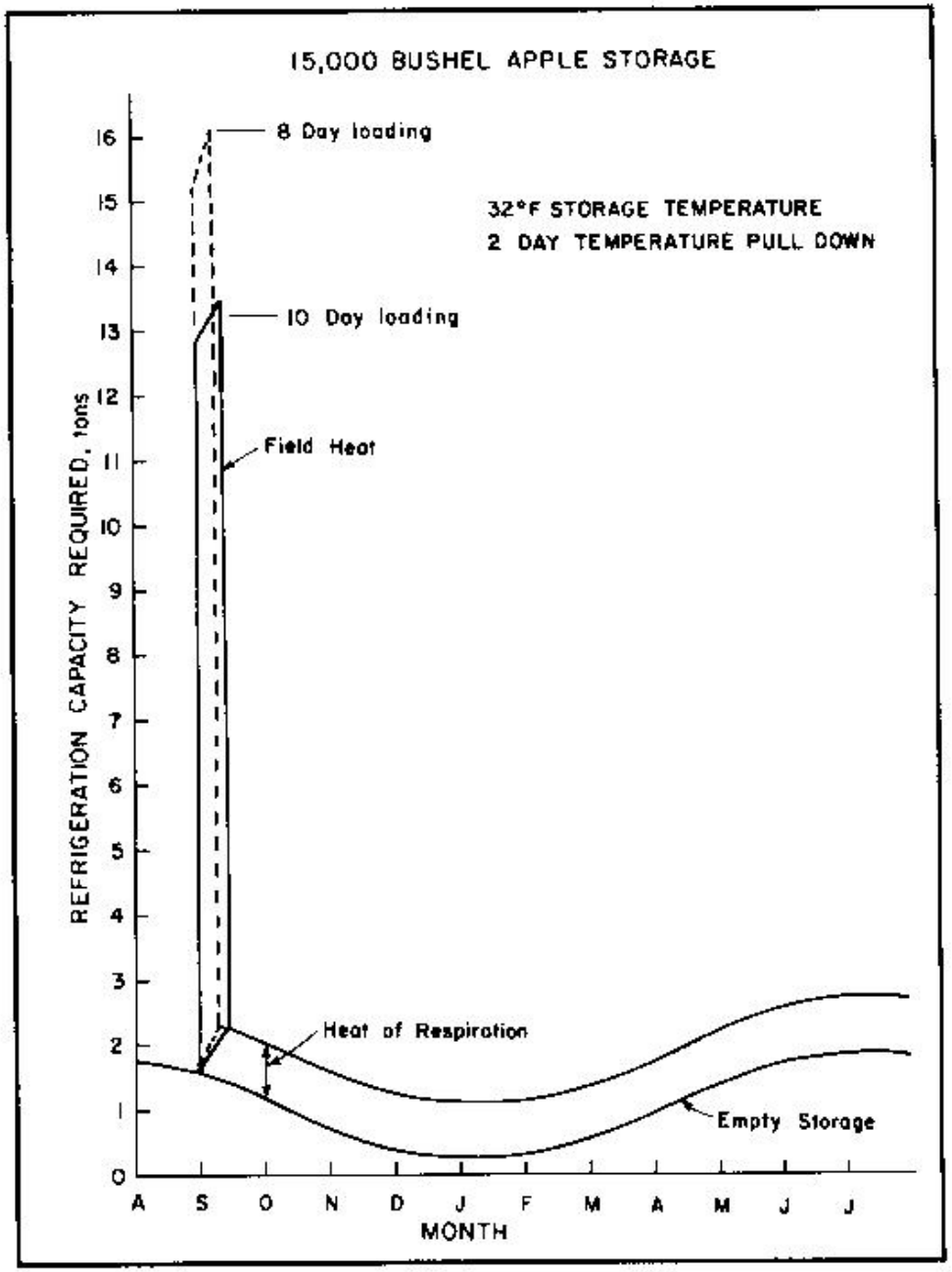
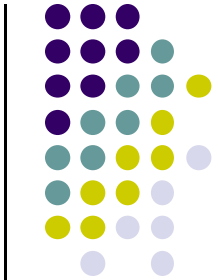


Figure 8. Refrigeration Capacity Needed to Cool and Maintain 15,000 Bushels of Apples

Source: Refrigeration and Controlled Atmosphere Storage for Horticultural Crops – NRAES-22

Factors - field heat removal rate

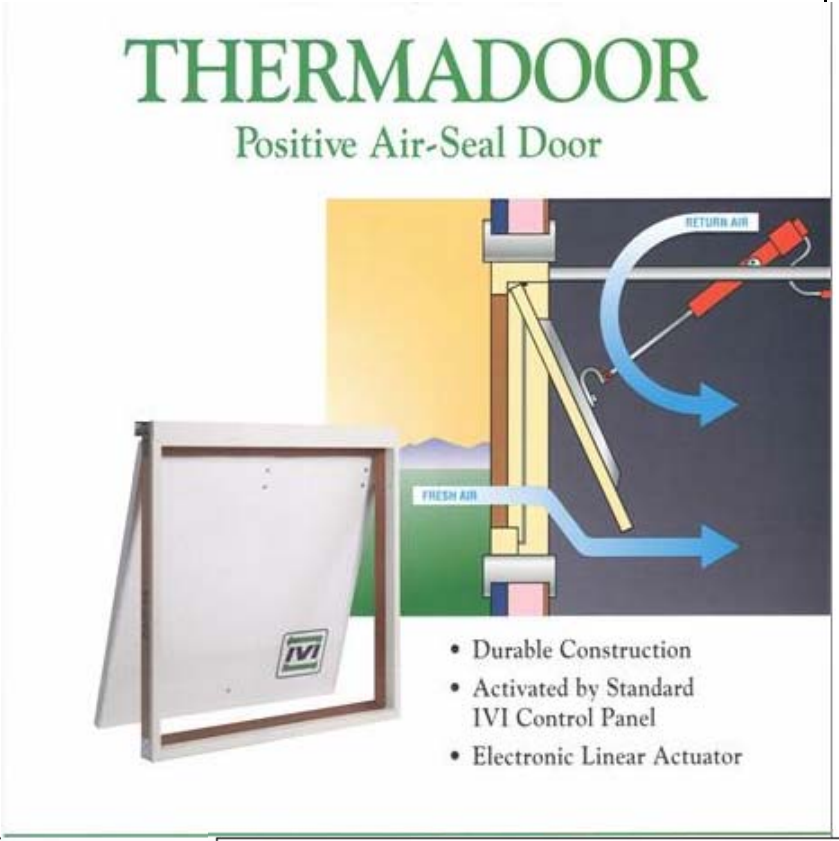


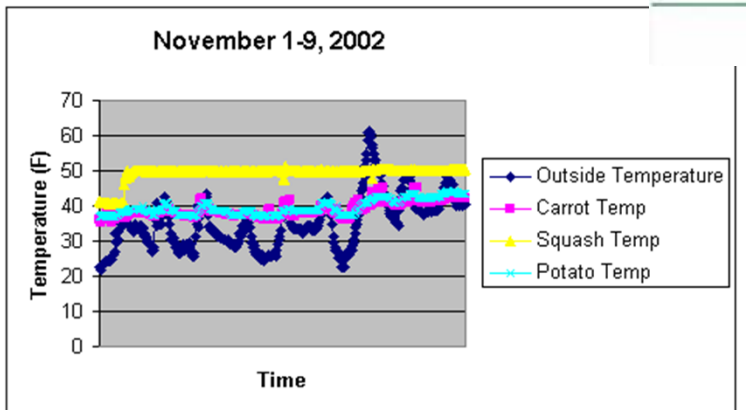
- Type of packaging / container
  - Solid sides/bottom versus slotted
  - Bagged
- Low Refrigeration Capacity
- Air flow rate

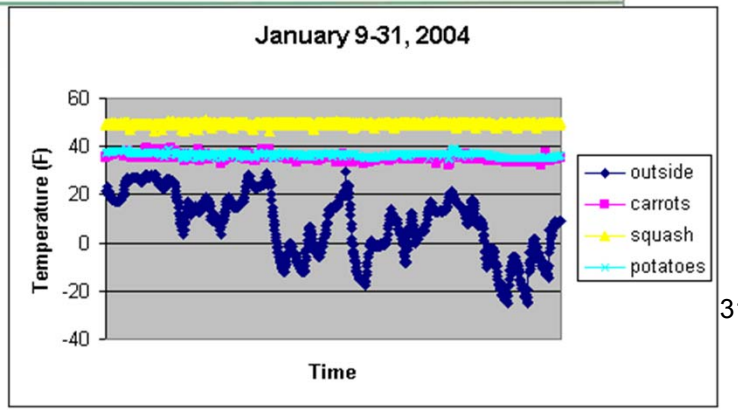
- Reduction in quality if field heat is not removed rapidly enough.
  - Shorten shelf life
  - Wilted

Outdoor air to reduce refrigeration

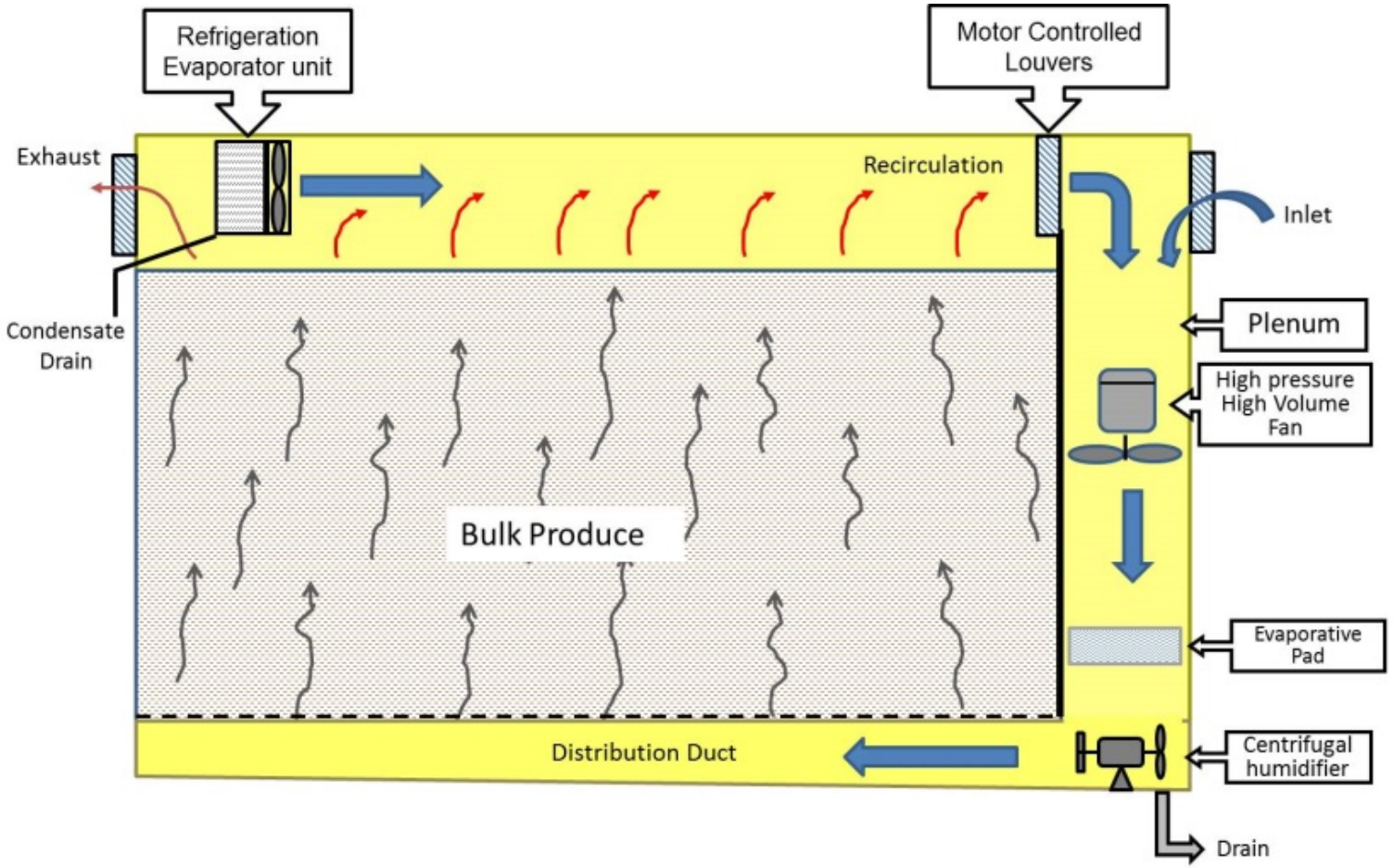
- Exchange air
- Controls
  - Manual
  - Automatic
    - Temperature
    - Time of day
- Disadvantage
  - Loss of humidity
  - Colder air is dryer





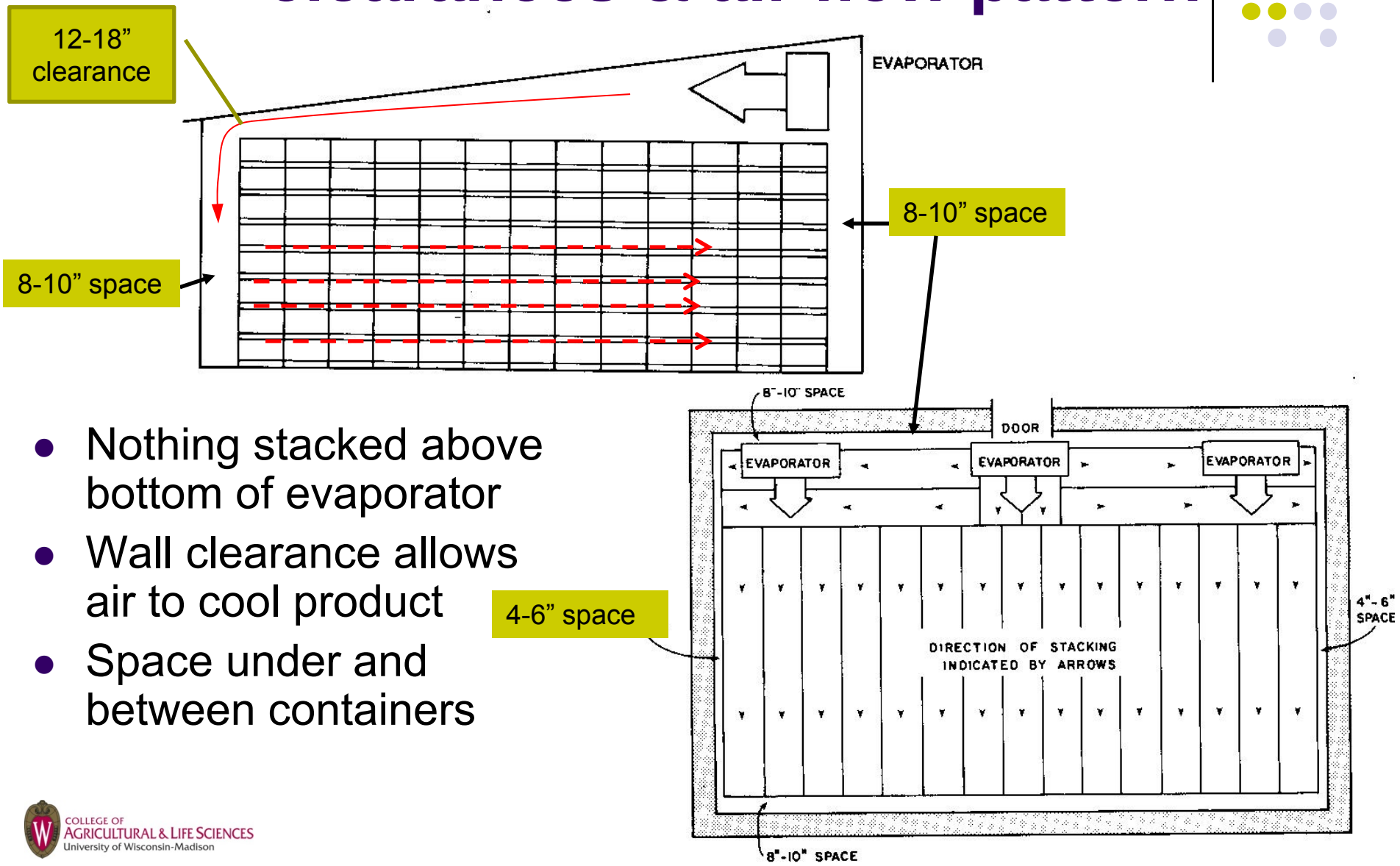


Bulk Storage Air Flow



Bulk Potato storage

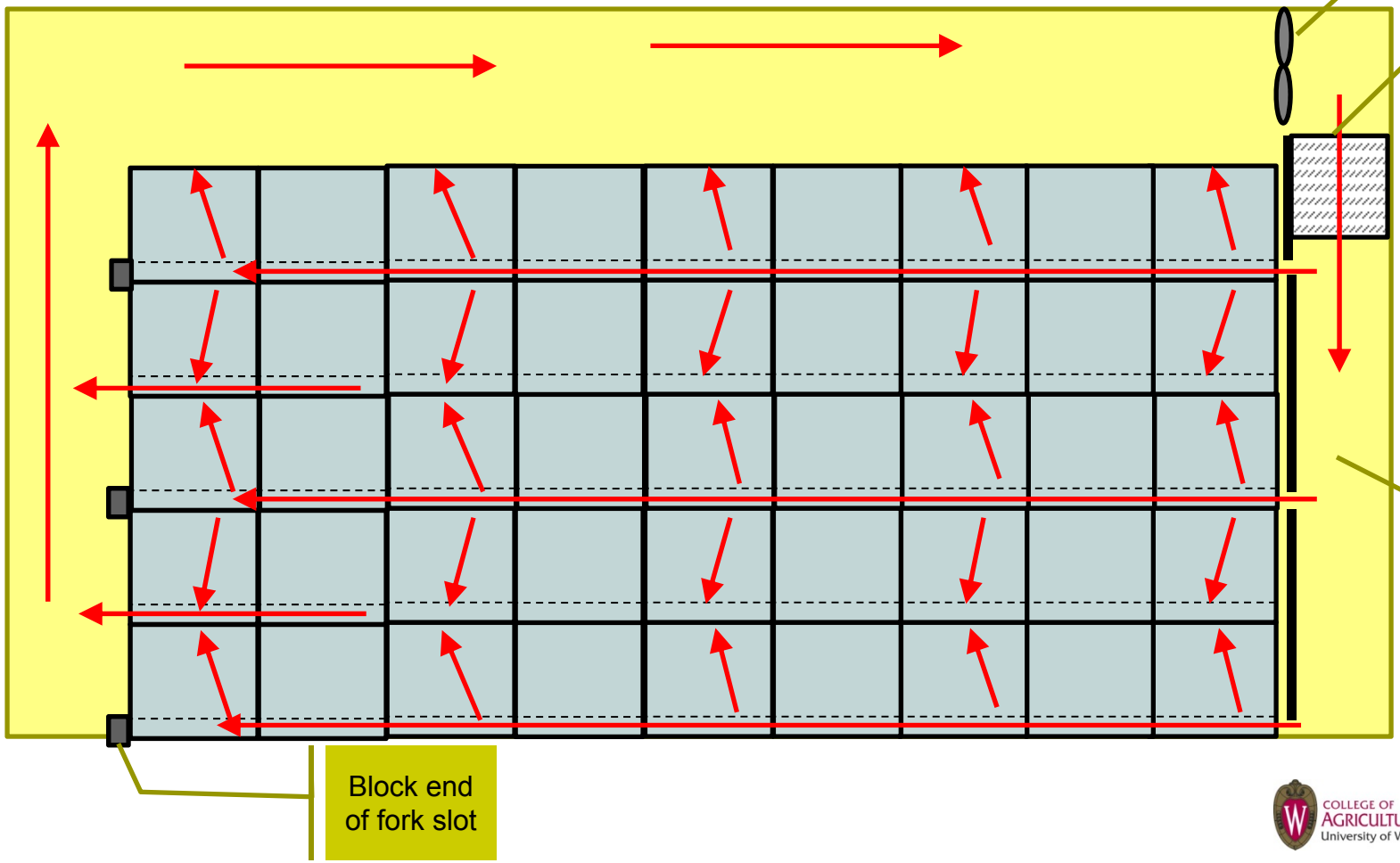
Cold storage – clearances & air flow pattern



- Nothing stacked above bottom of evaporator
- Wall clearance allows air to cool product
- Space under and between containers

Air Flow with Plenum Wall

- Horizontal slots in plenum wall
- Bins stacked tight
- 2-way fork slot – air duct
- Use for Force-Air pre-cooling
- Humidification in plenum

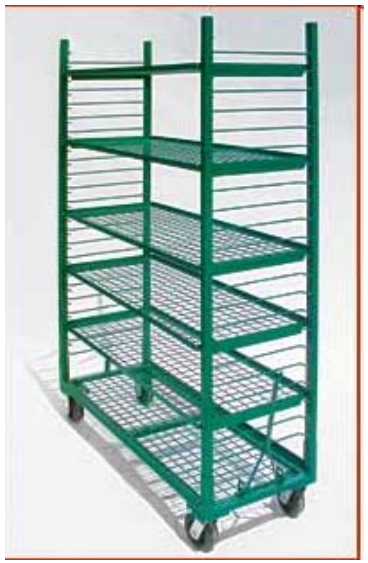


Bins

- Materials:
  - Wood – heavier, absorb moisture, repairable
  - Plastic – FDA approved, easily sanitized, repairable
- Rated for loading
- Stackable (without lid)
- Covers/lids available
- Vented / solid sides / bottom
  - Minimum 8-11% of bottom open
- Handle with Fork Truck or Pallet Jack
- Fit standard racking
- Sized to fit cooler dimensions

Racking

- Allows better access to individual containers
- Better ventilation and cooling
- Keep containers off floor
- Wire shelving – better air flow
- Rolling racks for small walk-ins



Source: http://ervojic.hr/images/uploads/paletni-regali-velika.jpg
http://www.ancostorage.co.uk/acatalog/Kwick_Rack.html
http://www.martforcarts.com/carts/3.html

Material Handling Equipment

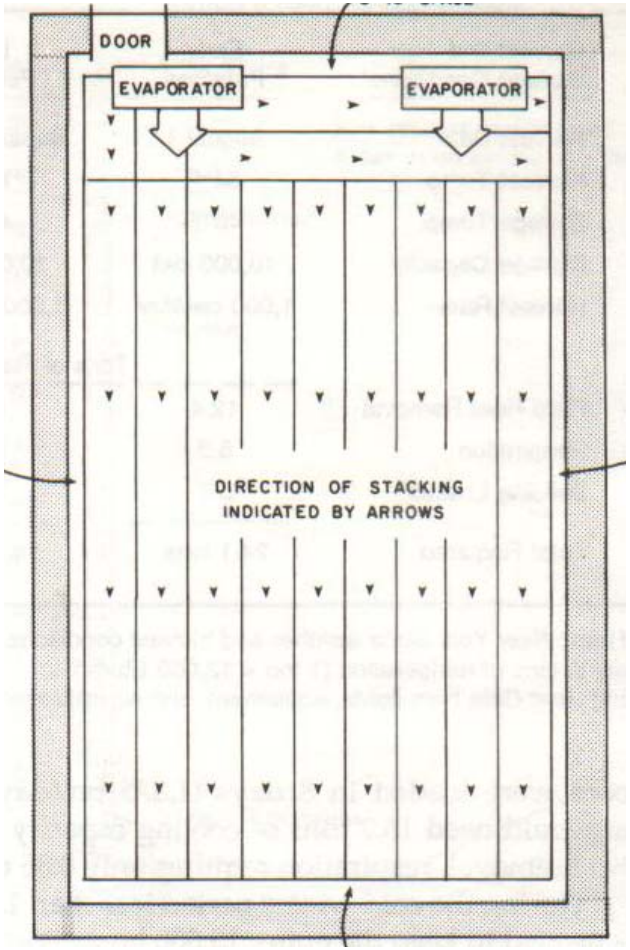
- Pallet Jacks
- Pallet Lift
  - Need smooth level hard surface
  - Narrower aisle than needed for fork truck
- Fork Truck
- Skid Steer w/ Pallet Forks

Source: http://www.getprice.com.au/images/uploadimg/910/350__1_pallet_jack.jpg

Source: http://www.beechhandlingservices.co.uk/
http://www.prestolifts.com/stuff/contentmgr/files/f243d69b64cf66fa30c5f6092fccb8ec/misc/pallet_stacker.jpg

Traffic & Material Flow

- Room to maneuver
  - Type material handling equipment
- Access without moving many things
- Order of use
  - First in, First out
  - Last in, First out
- Pedestrian and vehicle paths separated
- Convenient to packaging & processing area

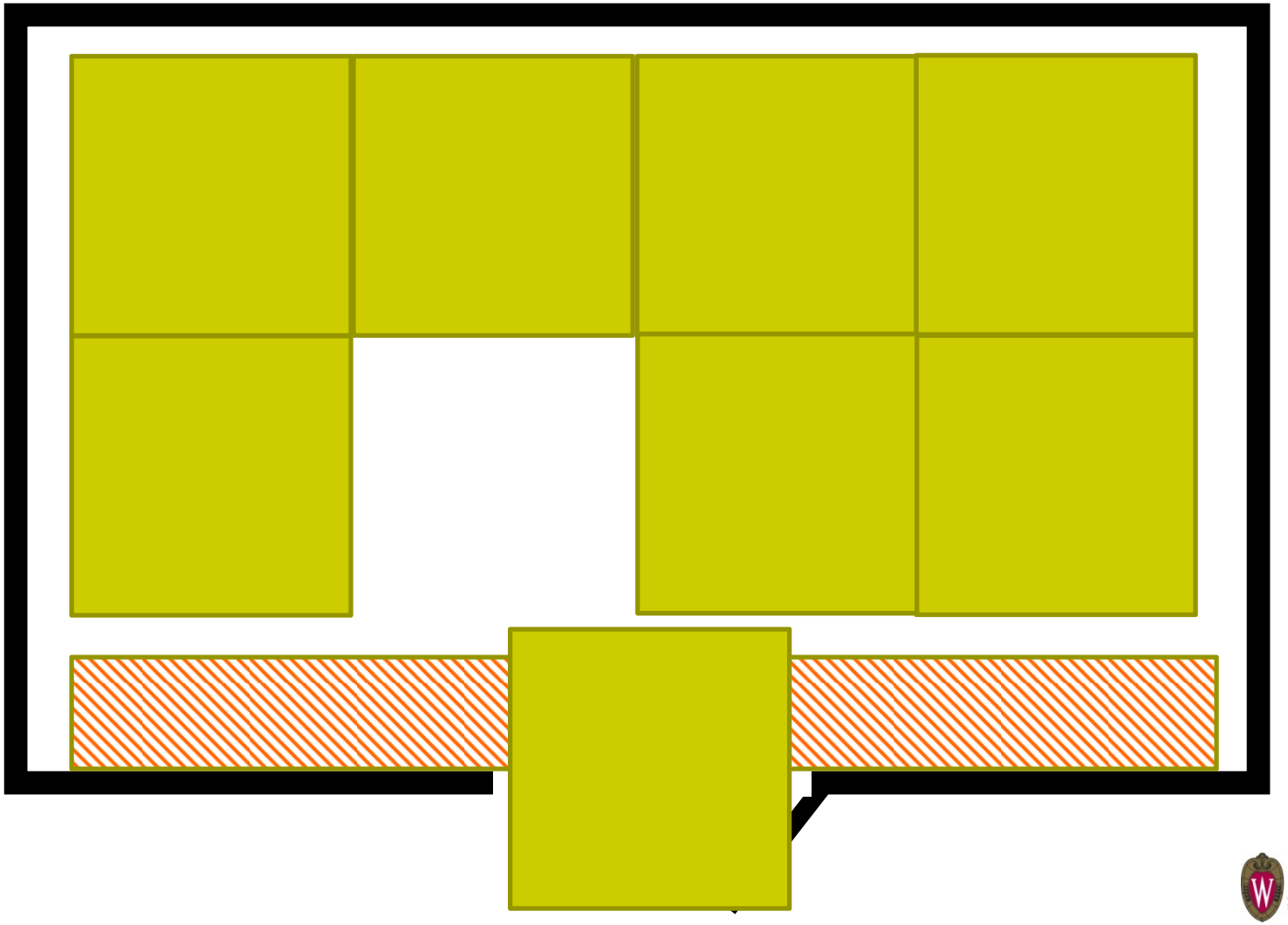


Rules of Thumb

- 2.5 to 3 cu. ft. of cooler volume per bushel
  - 1.24 cu ft / bushel – 50% utilization
- 4-6” between side walls and containers
- 8-10” between end walls and containers
- 12-18” between of overhead space

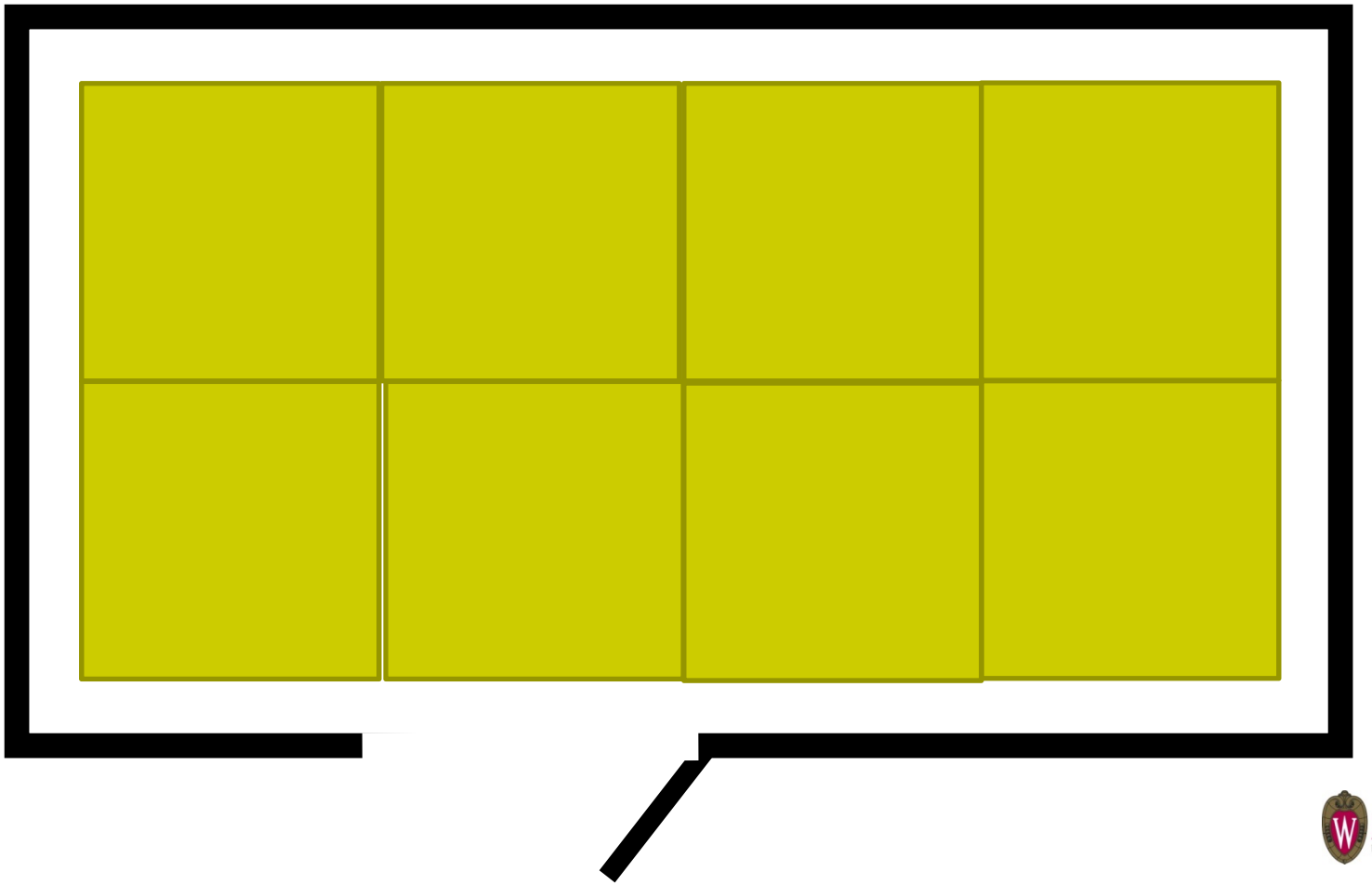
Layout Issues

- Wide or length in-efficient for container size
- Door location doesn't allow maximum number of containers



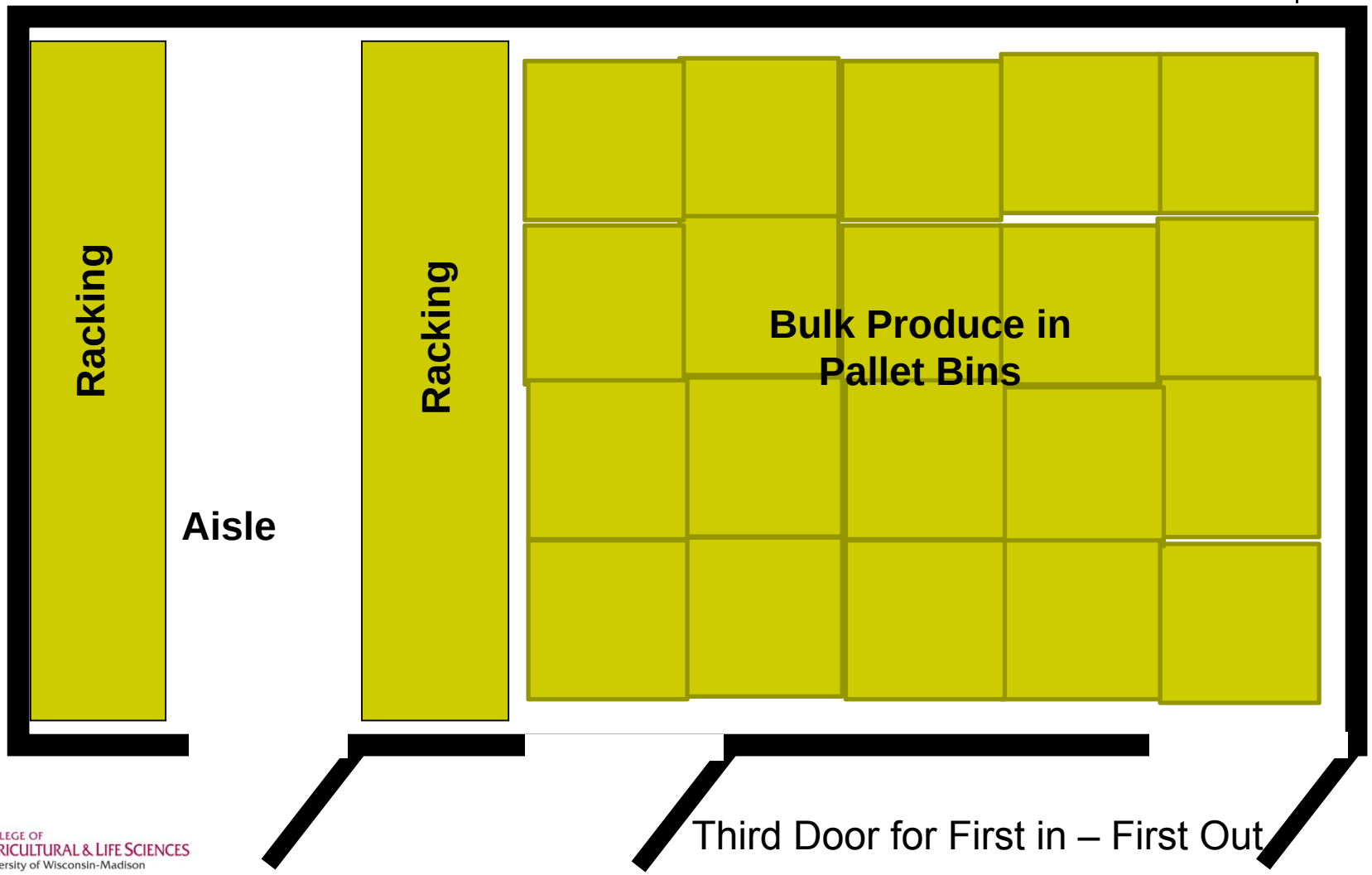
Layout Issues

- Door location / sized for bins
- Allows last bin to go straight in.



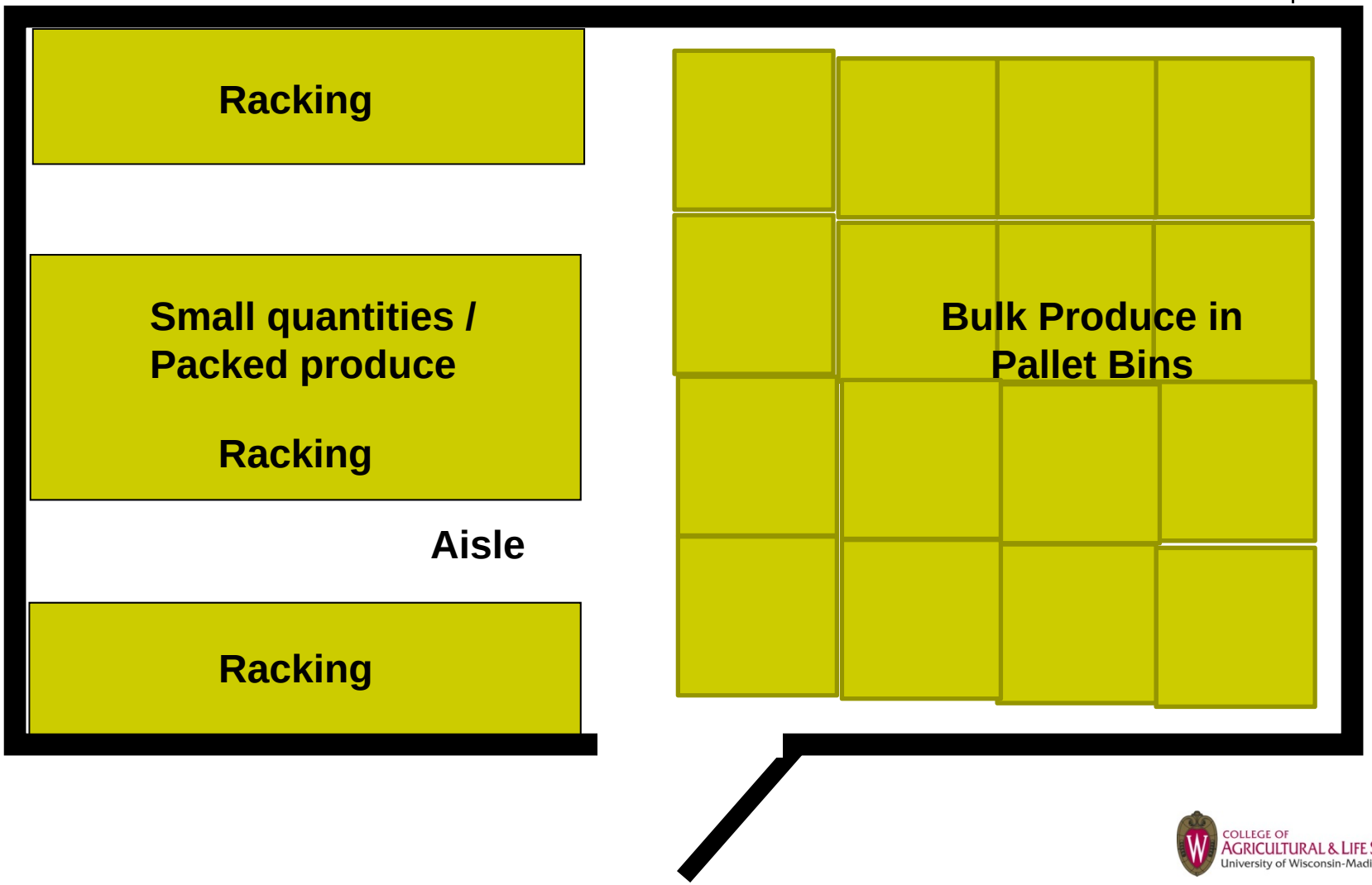
Layout for accessibility

- Add doors to reduce aisle space inside cooler
- Small goods and Bulk area



Layout for accessibility

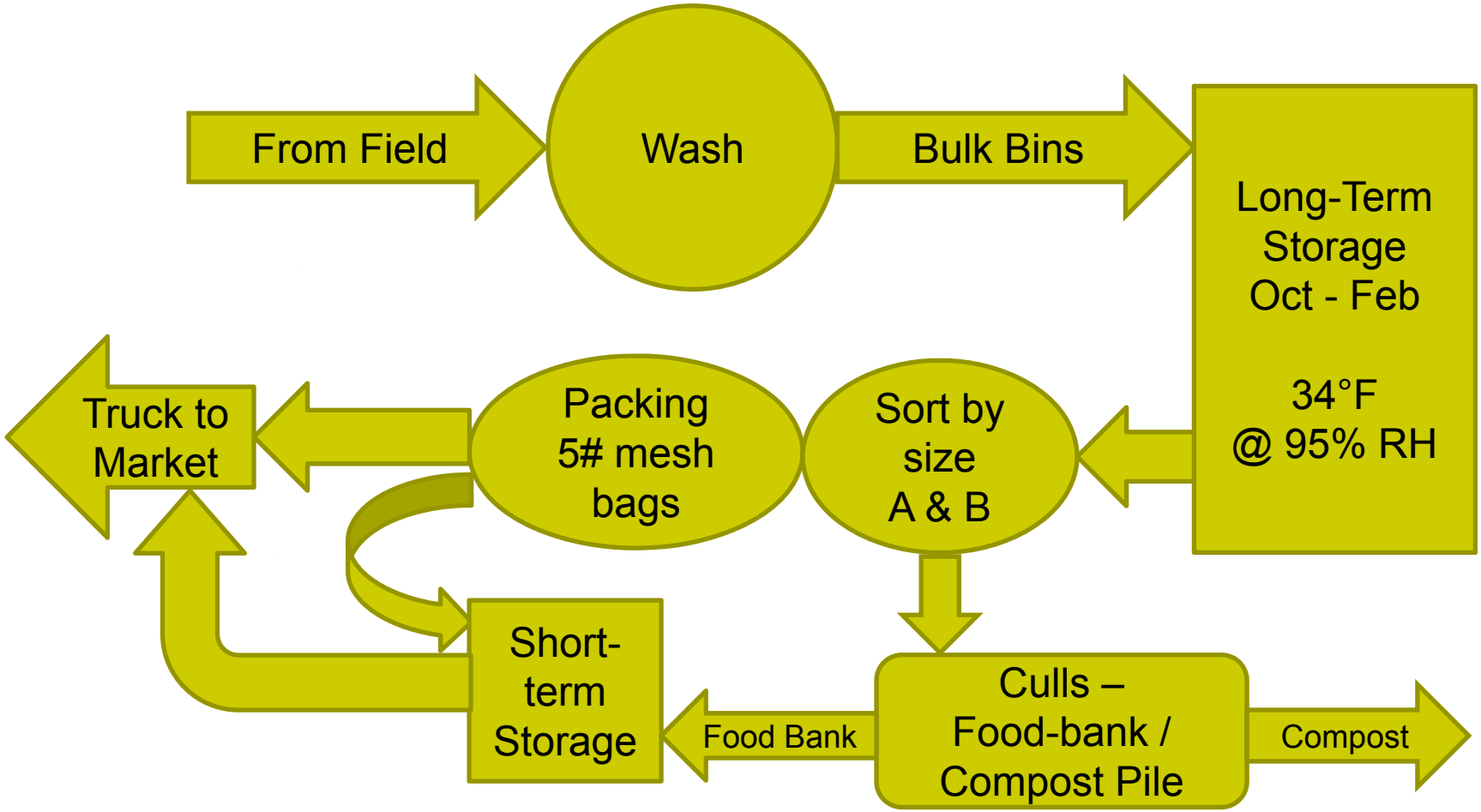
- Small quantities / fragile goods / packed produces



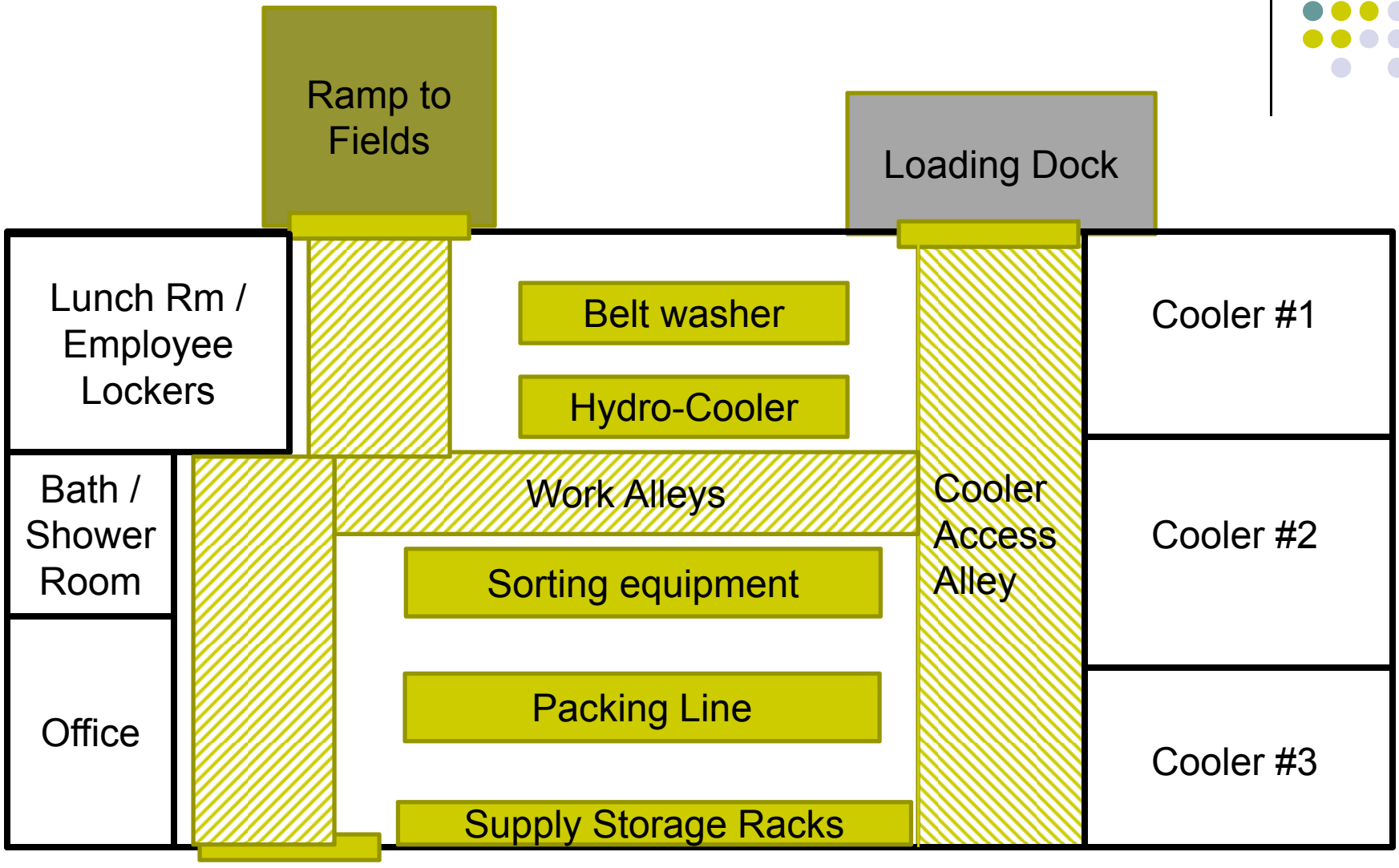
Planning!!!

- Space requirements
- Material Flow
  - Access to processing area
- Material Handling
- Utility needs
  - Water
  - Electricity
  - Drains
  - Temperature
- Labor
- Future Expansion

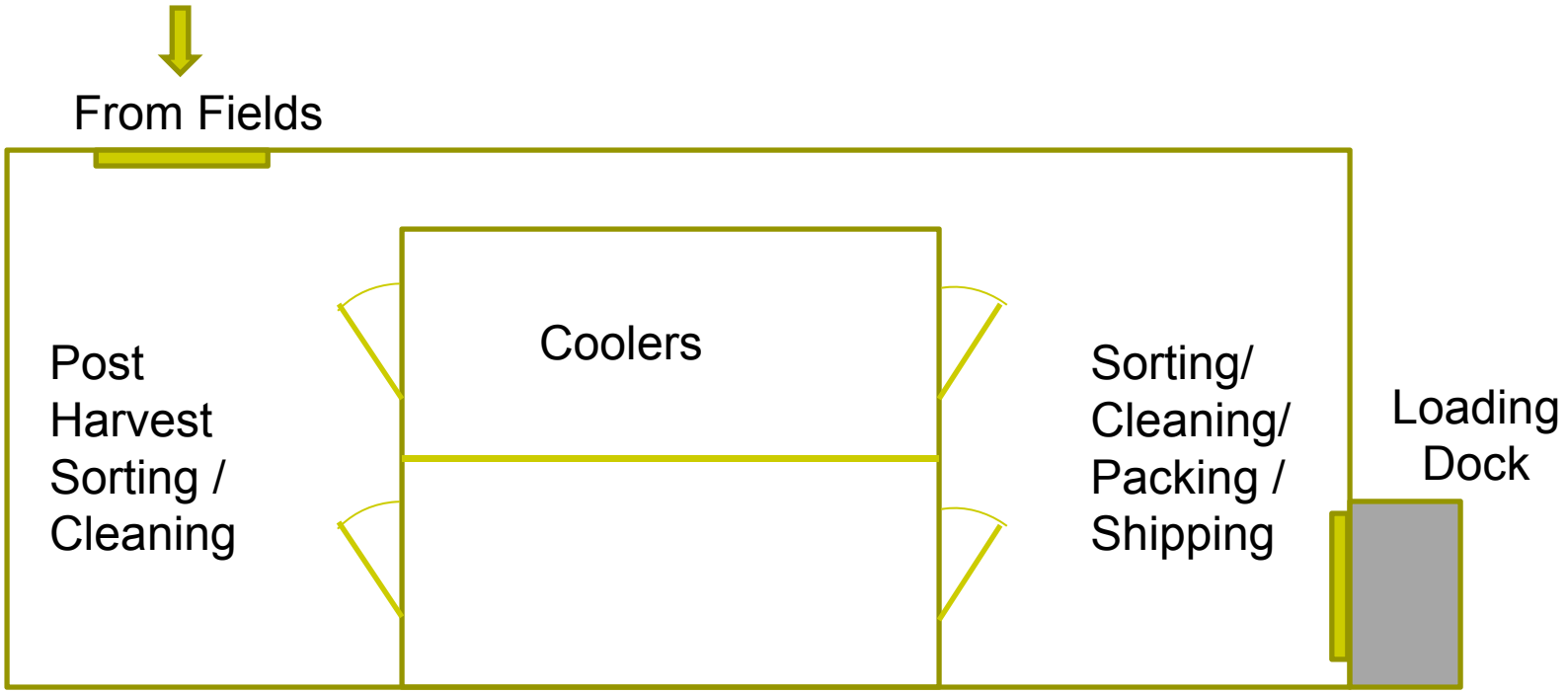
Flow Charts – by crop



Building Layout



Packing House Layout



Economics of Storage Crops

Factors to consider:

- Cost to build and operate storage units
- Facilities and capacity to move, wash and pack heavy, bulky items during the winter
- Shrink (spoilage and grading)
- Labor costs (benefits)
- Markets and Pricing
- Risk and rewards

Storage Facility Capital Cost

- Multiple units may be needed if you plan to store different products
  - Cold and moist (root crops)
  - Cold and dry (onions, garlic)
  - Cool and dry (squash, swt potato)
- **12 x 12 cooler:**

  $8,000-$9000 (new)
  $4,000-$6,000 (used)
- **20 x 30 cooler:**

  $20,000-$24,000 (new)
  $12,000-$14,000 (used)

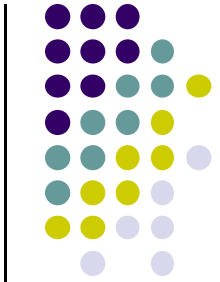
Costs and Pricing

- Higher Costs -Winter storage and sales
  - Add at least 20% more costs (growers' estimates)
  - Additional handling of product.
- Charge more at winter markets,
  - Achieving positive cash flow

  during a normally dead time of year.
- Electric costs to run cooler:
  - $2 to $4 per day.
  - Supplemental heating required
    - Storage units in unheated building/outside

Utility Cost Estimates

Madison, WI (12’ x 12’ x 9’)



	---------- Heating ----------			---------- Refrigeration ----------			Circulating Fans and Lights		Electric cost by Month
	Heating (Btu/mo)	kWh/mo	Heat cost	Cooling (Btu/mo)	kWh/mo	Cooling Cost	kWh	Cost	$USD
January	220606	68	$7	935570	110	$11	269	27	$45
February	107586	33	$3	998719	117	$12	243	24	$39
March	0	0	$0	1396363	164	$16	269	27	$43
April	0	0	$0	1888260	222	$22	260	26	$48
May	0	0	$0	2487550	293	$29	269	27	$56
June	0	0	$0	2768388	326	$33	260	26	$59
July	0	0	$0	2930126	345	$34	269	27	$61
August	0	0	$0	2821733	332	$33	269	27	$60
September	0	0	$0	2491730	293	$29	260	26	$55
October	0	0	$0	2310927	272	$27	269	27	$54
November	0	0	$0	1538737	181	$18	260	26	$44
December	115122	36	$4	1090925	128	$13	269	27	$43
Yearly heat loss	443313	137	$14	23659027	2783	$278	3,169	$317	

Est. Yearly Electric Use	6089	kWh
Est. Yearly Electric Cost	$609	

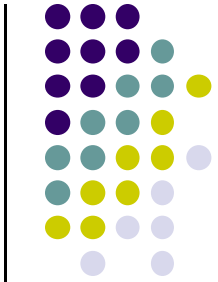
Shrinkage and Labor Costs

- Shrinkage
  - Squash and onions - 20 to 30% - spoil
  - Root crops - 3 to 10% - culls
  - Cabbage - 10 to 40% - storage disease
- Labor
  - Few hours / week – Owner/operator
  - Part-time / full-time – larger farm

Storage Crop Case Studies

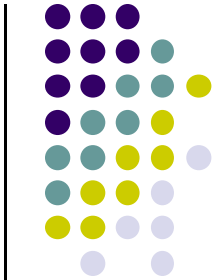
	Farm A	Farm B	Farm C	Farm D
Cubic Feet of Storage Space	812	6,000	17,374	22,400
Crops	Roots, Alliums, Squash, Cabbage, Sweet Potatoes	Roots, Alliums, Squash, Cabbage	Roots, Cabbage, Alliums, Squash, Sweet Potatoes	Cabbage, Carrots, Butternut
Winter Labor	Owner (2-4 hrs / wk)	Owner + 1 part-time (30 hrs / wk	Owner + 5.5 (80-90 hrs / wk)	Owner + 8 (280 hrs / wk)
Markets	**CSA** (Direct Wholesale)	**Direct Wholesale** CSA and (f. mkts)	**Direct Wholesale** Distributor & (CSA)	**Direct Wholesale** (CSA)
Gross Sales	$14,400	$85,000	$136,000	$250,000
Gross / cubic ft	$18	$14	$8	$11

Farm Storage Facility Loan Program



- Low interest financing
  - Fixed rate for 2.000% - 7yr, 2.625% - 10yr , 2.875% - 12 yr
  - Up to $500,000
  - 15% down
- Build or upgrade storage and handling facility
  - New cold storage (Used equipment not eligible)
  - Framed structure or prefabricated permanently installed
  - Permanently affix equipment – refrigeration system, lighting, controls
  - Useful life of 15 years or more
- Administered by Farm Service Agency
  - **http://www.fsa.usda.gov/FSA/webapp?area=home&subject=prsu&topic=flp-fp**

Summary



- Harvest quality produce
- Cool it
- Store at optimal Temperature & Humidity
- Storage compatibility?
- Prevent chill injury
  - Environmental Controllers
  - Heat in cooler for winter storage
- Monitor produce quality while in storage
- Market within normal storage period
- Sanitize container and facility
- Plan before building

References

- The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks, USDA-ARS, Agricultural Handbook Number 66, 2004. http://www.ba.ars.usda.gov/hb66/contents.html
- Postharvest Handling of Horticultural Crops – factsheets North Carolina Cooperative Extension, http://www.ces.ncsu.edu/hil/post-index.html
- Post harvest publications, Biological and Agricultural Engineering, North Carolina State University. http://www.bae.ncsu.edu/programs/extension/publicat/postharv/
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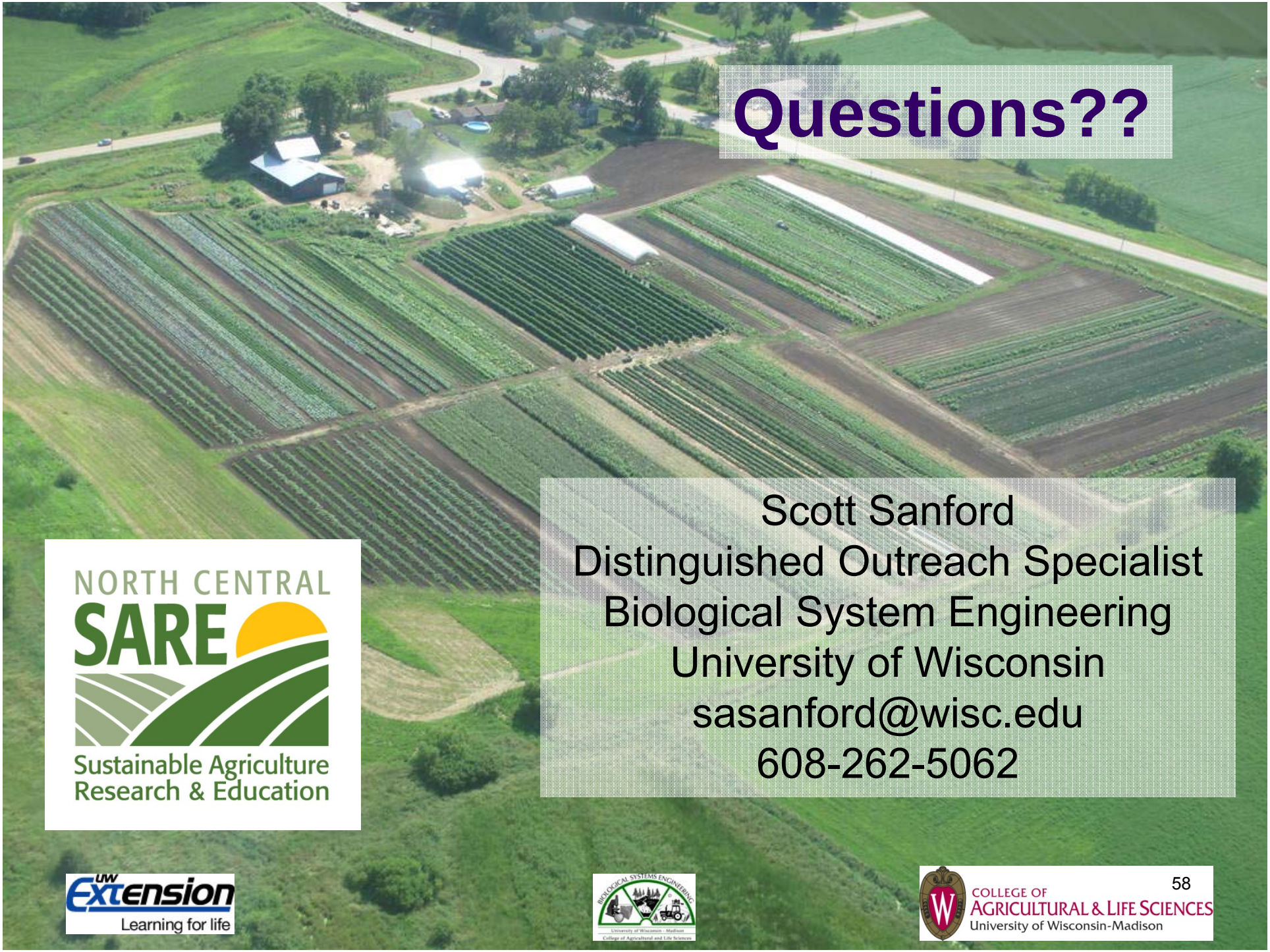

Questions??

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