Modeling Agricultural Systems

Projecting the High Plains' Ecological Future

The Religion of Reductionism

The Religion of Reductionism

Origin frustration borne of complexity

Dogma the whole is the sum of the parts

Prophets applied scientists and engineers

Doctrine simplify, simplify, simplify

Method divide and conquer

Destiny fragmented understanding

Heartaches yearning for holism
guilt concerning illicit assumptions

- Clean Water Act objective: restore the *physical, chemical* and *biological* integrity of the nation's water
- Conspicuously avoided: *ecological* integrity

WHY?

- Market economics
  - (Sort of) efficient risk integrator
  - Visible, concrete impact
  - Broad and fuzzy
  - Pathologies both systemic (structural) and acute
  - Things look both similar and different at different scales
- Ecology
  - (Sort of) efficient risk integrator
  - Visible, concrete impact
  - Broad and fuzzy
  - Pathologies both systemic (structural) and acute
  - Things look both similar and different at different scales

What Constitutes a Systems Approach to AFOs?

- Engineers: "*Draw a circle!*"
- Animal scientists: "*Consider the animal as well as its waste streams!*"
- Crop scientists: "*Consider the cropping regime as well as the animals and their waste streams*"
- Economists and producers: "*What about the costs and benefits?*"
- Administrators: "*Make it multidisciplinary!*"

Translation: "A system is complete when it includes my piece."

What Constitutes a Systems Approach to AFOs?

- "A system is complete when it includes my piece;" OR,
- "A system is complete when its synthesis generates the necessary information in the right context with adequate certainty."

Some Truisms

- All models are wrong.
- Some models are useful.
- Assumptions facilitate solutions.
- Assumptions limit generality.
- Narrow models are more useful than general models.
- General models are more useful than narrow models.
- Modern technology is built on linear models.

Real (Interesting) Problems Defy Conventional, Linear Solutions

- Feedback is often helpful.
- Nonlinearity is terribly inconvenient.
- Feedback spawns nonlinearity.

Where does that leave us?

Ecology...

- …includes biology, physics, chemistry etc.
- …includes (geo)politics
- … includes (global) markets
- … includes weather
- … includes neighborhoods and species
- … thumbs its nose at administrative boundaries

Modeling, Schmodeling

- How would you propose to develop a useful concept of sustainable agriculture without recourse to modeling?

Toward a Black-Gold Standard

Hard Decisions Now,
Harder Decisions Later

Ground Rules

- Your servant is neither an economist, an ecologist, a physicist nor a political theorist
- Nor has he ever had a strictly original thought
- His job is to make you
  - Question your scientific assumptions;
  - Think in *systems* in addition to *processes*;
  - Get angry, but get along;
  - Synthesize and synergize;
  - Any one or more of the above

Pitch the Cynicism

- Our mission concerns both science and politics
- Let's keep 'em separate as long as we can
  - Science: diagnose challenges, offer solutions
  - Politics: select from the suite of options/solutions
- Let's not be deterred by:
  - Fear of "guilt by association" with politically unpopular ideas, their proponents or their implications
  - Disputes over minutiae (that means YOU, pointy-heads!)

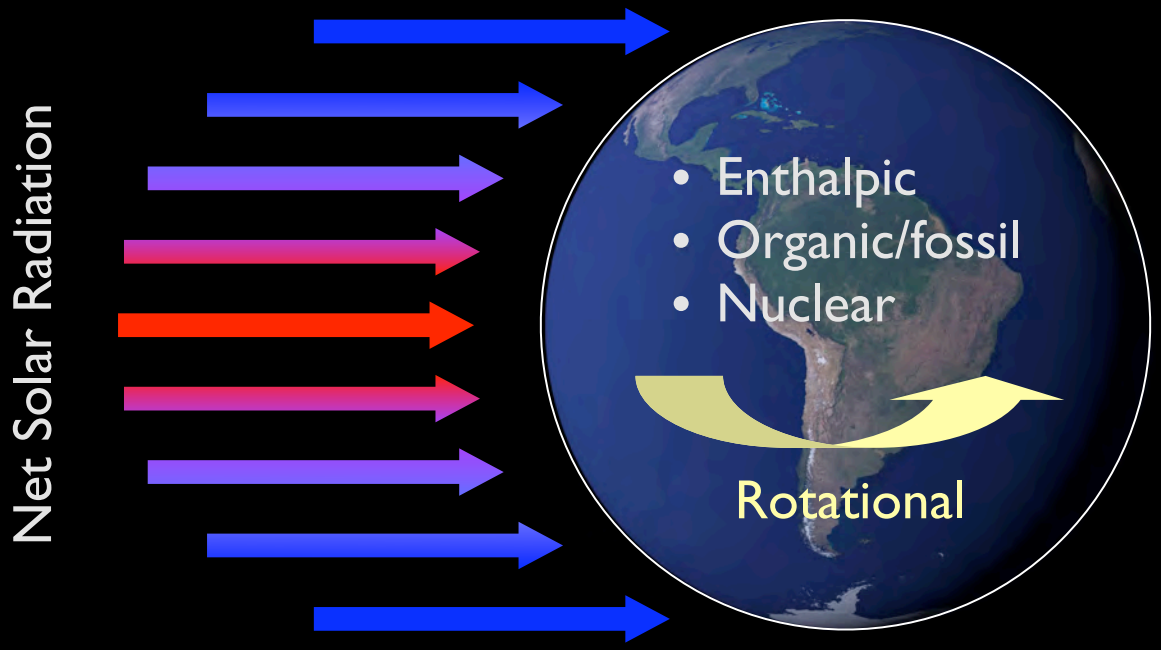
The Objective

An American beef industry that is compatible with long-term, global, sustainability principles grounded in credible, consensus-based science, economic freedom and geopolitical security

My Assumptions

- As scientists, we are governed by inviolate, scientific laws
- As citizens, we are influenced by our individual political convictions
  - Content
  - Intensity
- Globalization has global consequences
- Uniquely human capacities (e. g., technology, history) impose a cumulative *ecological trajectory*

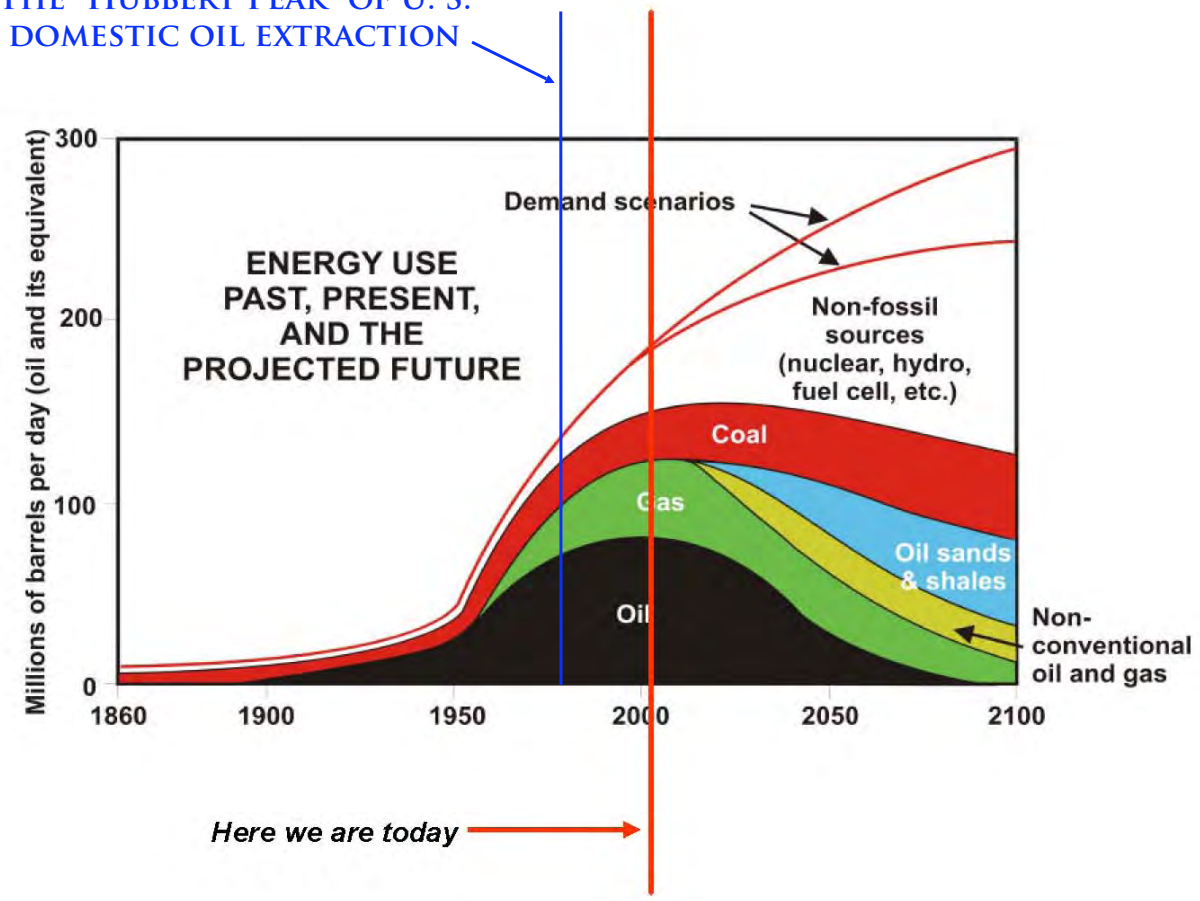
Sources of Primary Energy in the Ecosphere



Exogenic Input Flows

Internal Stocks

The "Hubbert Peak" of U. S. domestic oil extraction



3)
2003)

A Couple of Truisms

- Domestic extraction of [ ] ought to cease when one barrel of it is required to extract one barrel of it from its most accessible reservoir
- Extraction of fossil fuels – among other things it accomplishes, and whatever the ecological implications might be – moves energy and carbon from the *lithosphere* to the *ecosphere*

A Sustainability Conjecture

No terrestrial ecosystem can be considered sustainable if it must be subsidized indefinitely by non-renewable energy

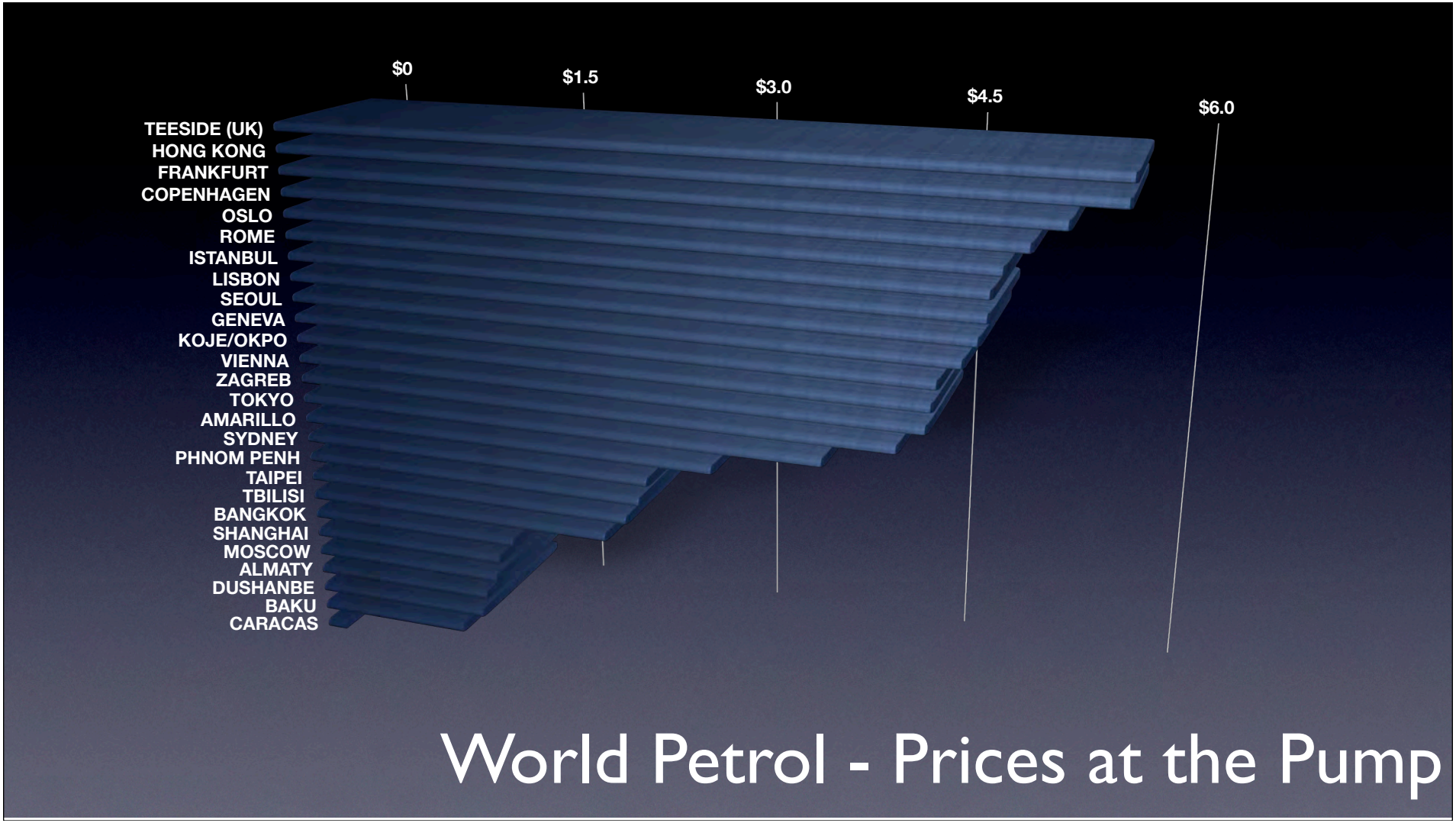
3 Degrees of Sustainability

- "Weak" sustainability - total natural capital remains intact without regard to how it is partitioned
- "Strong" sustainability - species of natural capital are maintained w/o substituting human capital
- "Absurdly strong" sustainability - no depletion of any species of natural capital is permitted

Robert Goodland, "The concept of environmental sustainability," *Ann Rev Ecol Sys* 26(1995):15-16.

Substitutes and Complements

- "Substitution" replaces a natural form of capital with one or more man-made forms of capital of [ostensibly] equal value
  - Example: EtOH, gasoline
- "Complements" do not substitute for one another but cannot be fully used without one another, usually at some optimum ratio
  - Example: Nitrogen, phosphorus and water



World Petrol - Prices at the Pump

Why Energy, and Not Matter?

- Both matter and energy are conserved
- There is no "mass sink" equivalent to the inevitable increase in system entropy
- We can conceivably recycle matter *ad infinitum*…
- …given an inexhaustible source of available energy to do so
- Irreversible processes are the norm: energy is conserved, but *its*

Example #1

- Recommendation: *Build an advanced weapon to bring the war to a rapid close and save American lives*
- Application: *^{235}U enrichment at K-25/Y-12 in Oak Ridge, TN, 1942-1945*
- Marginal Energy Costs:

–Mechanical energy to transport, pulverize ore; compress UF_6

–Thermal energy to accelerate isotope diffusion

Example #2

- Recommendation: *Increase N&P use efficiency by increasing feed digestibility and nutrient availability*
- Application: *Steam-flake grain*
- Marginal Energy Costs:

–*Thermal energy to generate steam and pressure*

–*Fluid energy to pump water, transport grain*

Example #3

- Recommendation: *Reduce volatile-solids loading to lagoons to reduce odorant emissions*
- Application: *Solid-liquid separation via settling basins*
- Marginal Energy Costs:

–Mechanical energy to mine concrete aggregates, excavate basins

–Thermal energy to manufacture cement

Example #4

- Recommendation: *Increase break-even distance for hauling manure profitably as a phosphorus source, and reduce weed and pathogen viability to reduce pesticide use*

- Application: *On-farm composting*

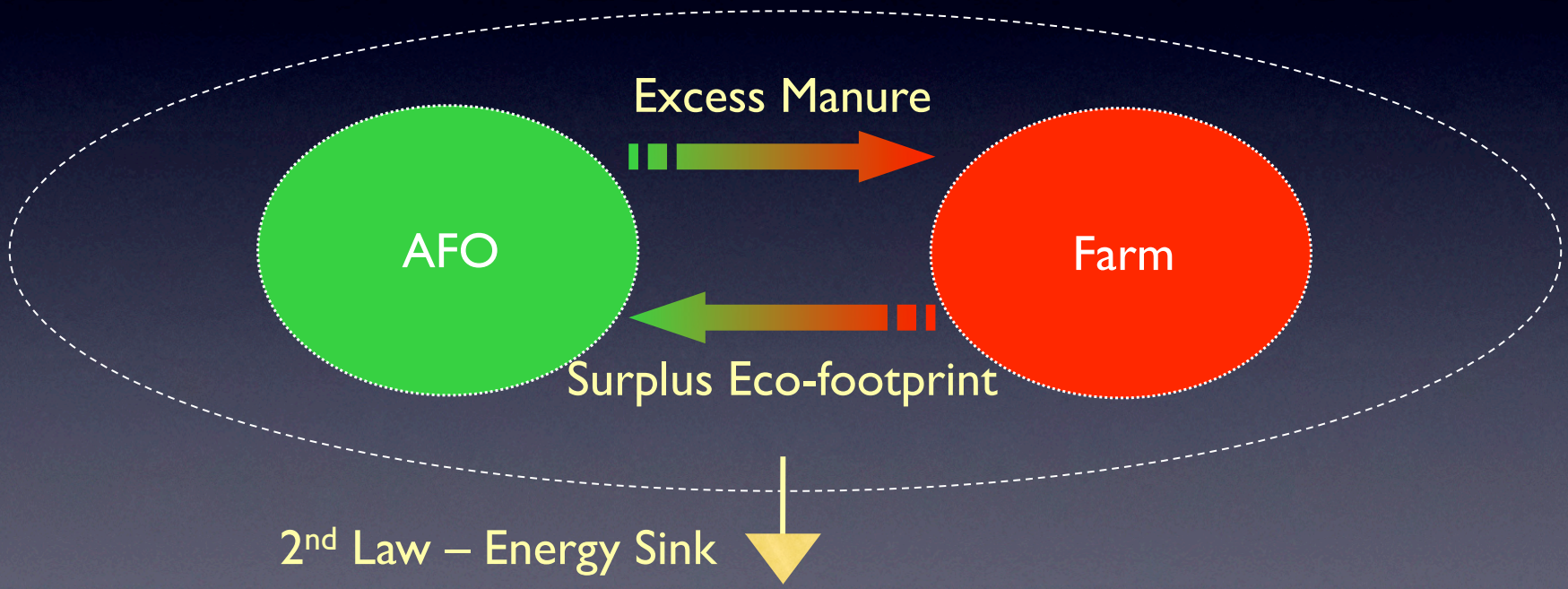
- Marginal Energy Costs:

–Mechanical energy to handle manure, turn compost

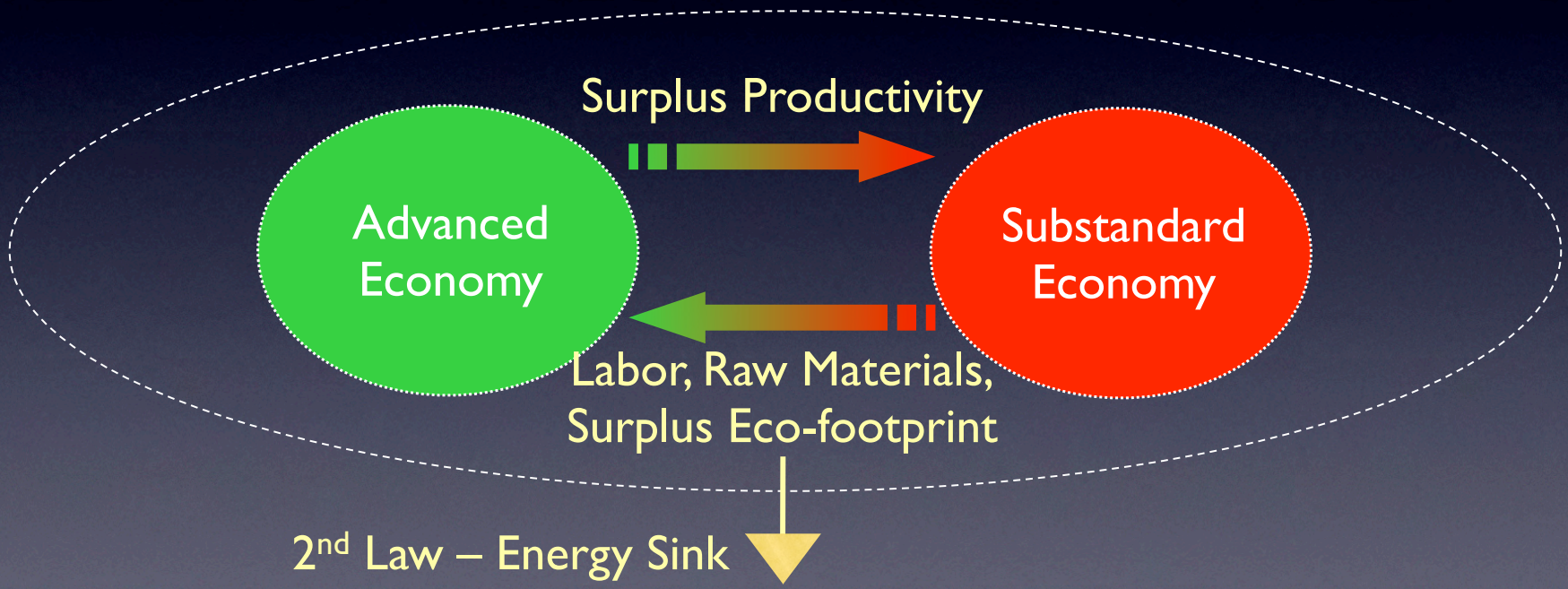
–Biological energy to increase pile temperature, evaporate water, oxidize organic matter to CO_2, NH_3 and trace gases

–You get the idea by now

Trade Couples Ecosystems



Globalization Couples Distant Ecosystems



Two Different Accounting Techniques

"We cannot manage what we cannot measure"

Ecological Footprint

(W. Rees et al.)

The *per capita* area of ecologically productive land and/or ocean needed to sustain an ecosystem continuously by...

- ...providing all of the material and energy resources that it requires; *and*
- ...safely assimilating all of the wastes that it generates
- Does it exceed the EP area available?

Emergy: Embedded Energy

(H.T. Odum et al.)

The available energy having an arbitrary reference quality (e. g., solar radiation) previously required – directly and indirectly – to make a product or service

- Normalizes available energy to common units ("emjoules")
- Accounts for transformations among energy types differing in their ability to do useful work

A Corollary or Two

No ecosystem can be considered sustainable if its aggregated ecological footprint exceeds the ecologically productive area of the earth…

…we are part of that ecosystem!

Ecological Footprint of a Cattle Feedyard

How is it Affected by Water Use?

Motivation

- "Sustainability" is ultimately both an *ecological* and an *economic* question
- Water resources play a key role in both the *ecology* and the *economy* of the High Plains
- Linking *ecology* and the *economy* has always been a vexing challenge…
- …How does one trade environmental benefits in one medium (e.

Where We're Going

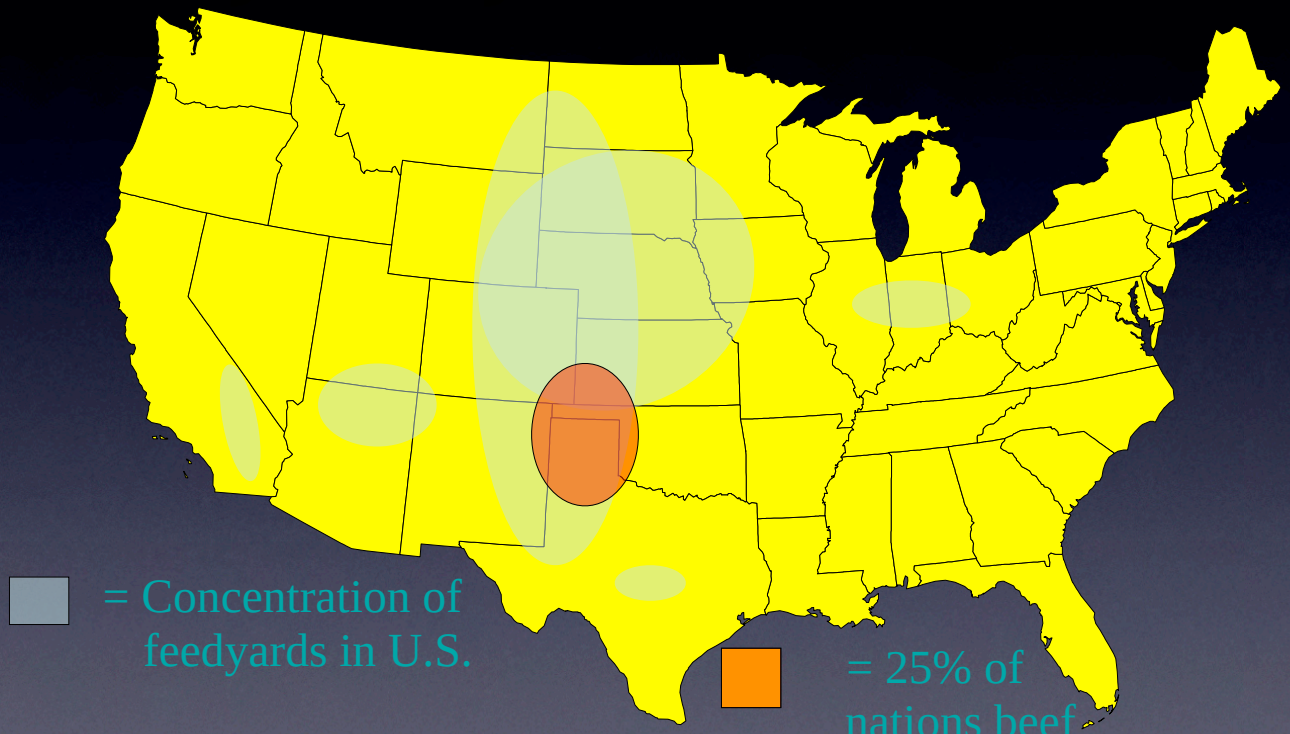
- What is the water-use intensity of the feedyard industry?
- What are some benchmark values for a typical cattle feedyard?

Water-Use Intensity of Cattle Feedyards

Special Thanks to:

Drs. John Sweeten and David Parker

The Fed Cattle Industry in the United States

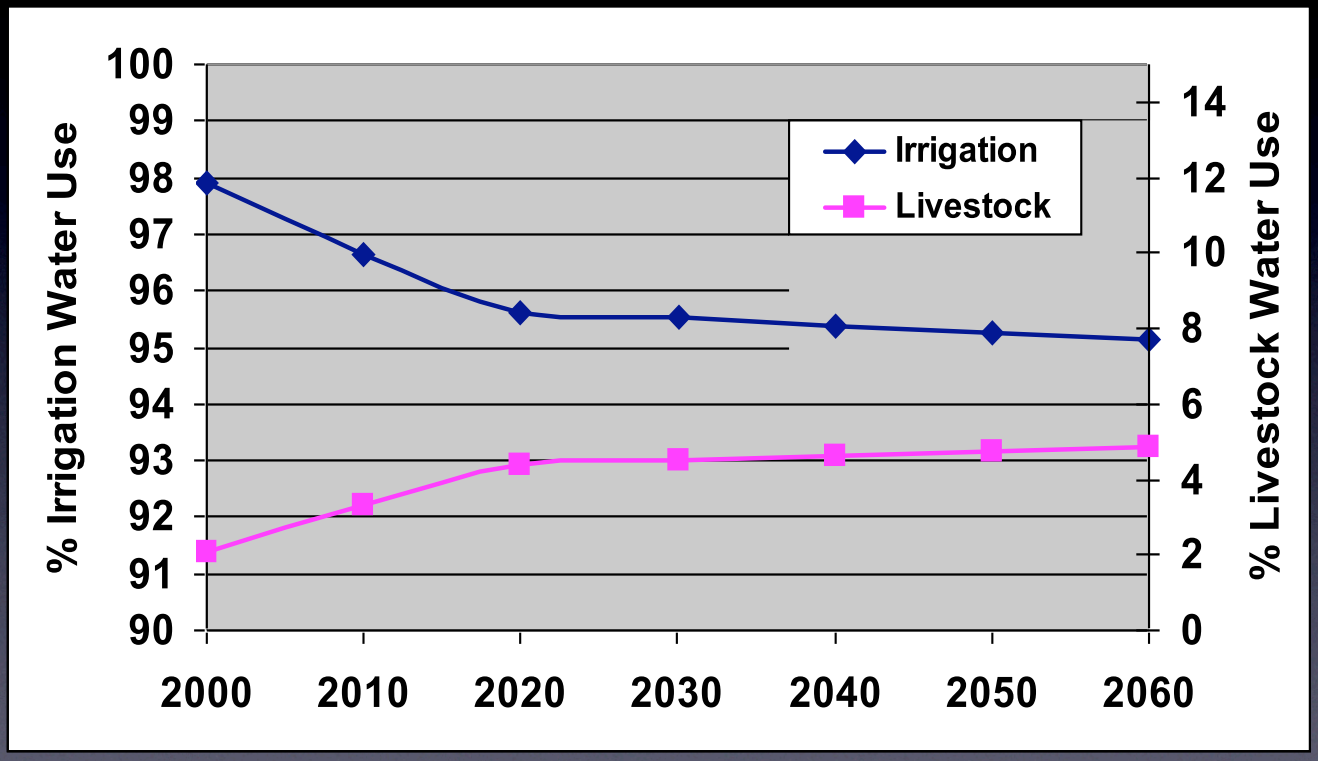


The Fed Cattle Industry in the United States

- The trend to fewer, larger feedyards continues
- Nearly 60% of cattle are marketed from about 200 feedyards
- The number of cattle marketed from yards with fewer than 1,000 head has declined to under 3 million
- Average capacity in Texas High Plains: 40,000+

Irrigation vs. Livestock

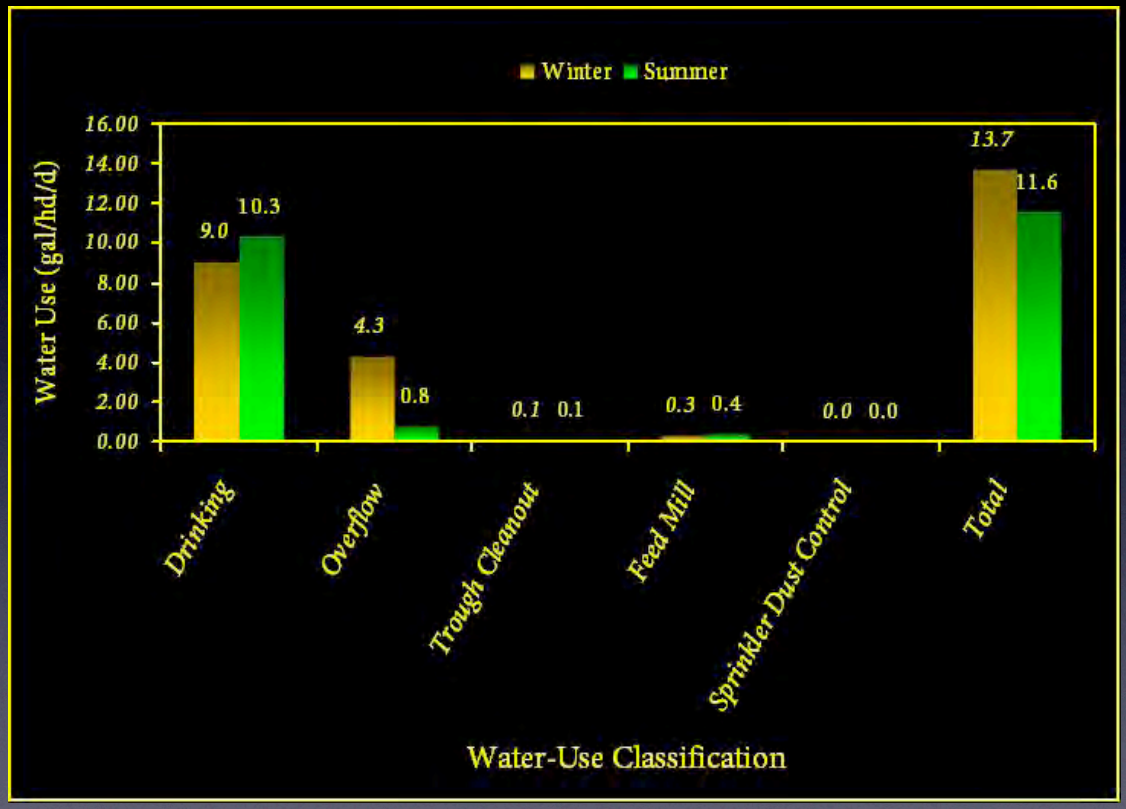
(expressed as % of gross agricultural water use)



Texas Panhandle Regional Water Planning Group, 2003

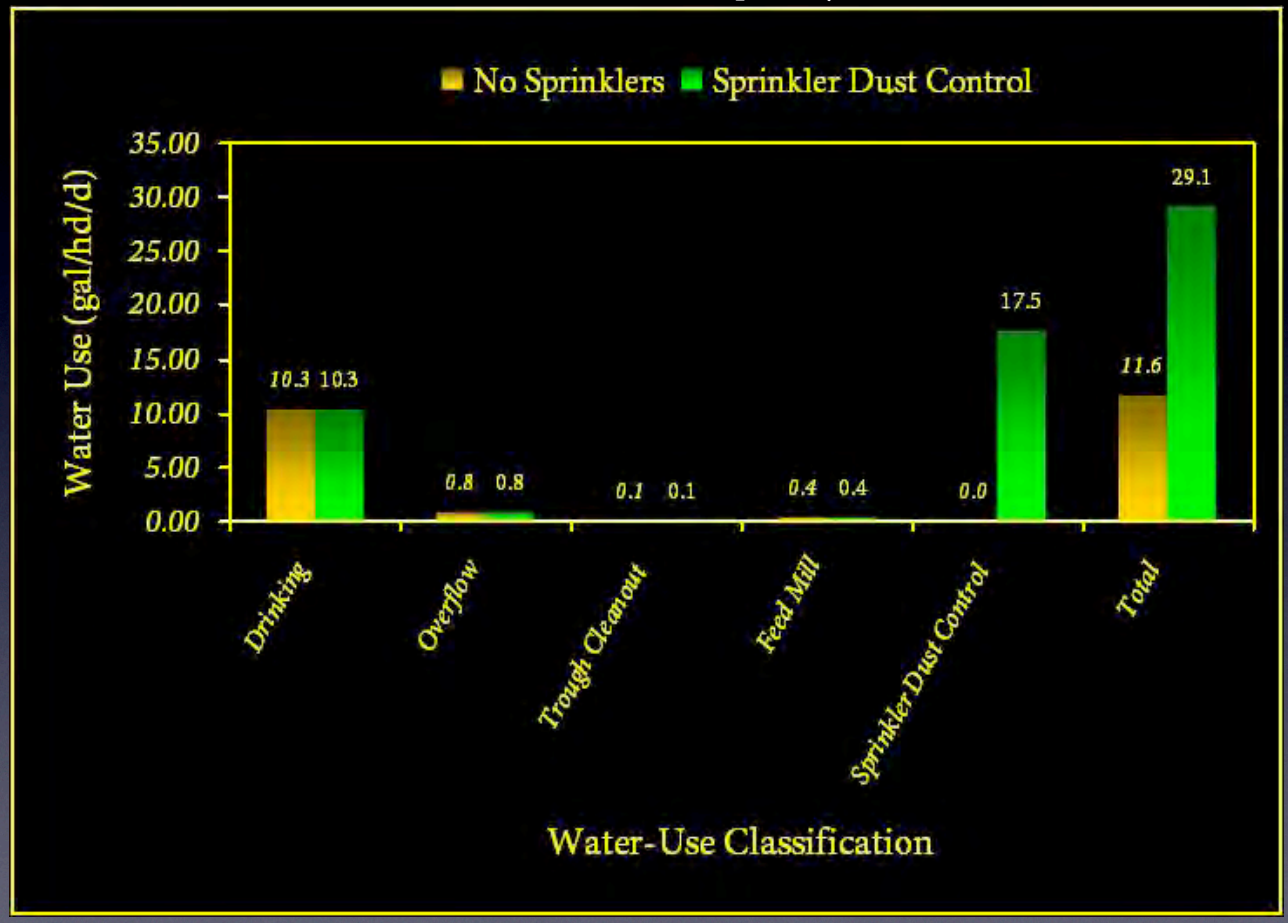
Seasonal Water Use

(excludes dust control; adapted from Parker et al., 2000)



Sprinkler Dust Control vs. Gross Water Use

Summertime, 3/16" per day



Reducing Feedyard Water Use

- *More efficient* water troughs
- *Electric* tank heaters for existing troughs
- Repair water trough leaks at threaded standpipe
- *Collect & reuse* overflow water for :
  - Water treatment/reuse system—*filtration/chlorination*
  - *Irrigation*, with or without effluent blend
  - Dust control, pens and/or roads
  - Feedmill

The "Rebound Effect"

(Is *more efficient* necessarily *better*?)

- Decline of the High Plains Aquifer has accelerated despite irrigation regimes that approach or exceed 95% application efficiency (Marek, 2005; Allen, 2006)
- American farms have doubled their energy efficiency since 1978…still, due to more advanced processing, U.S. agriculture uses at least ten calories of fossil energy for every calorie of food energy produced (Miranowski, 2004; [acb] Lovins, 2005)
- My new 4THz iMac still takes 4 minutes to boot up
- We plow efficiency savings back into the enterprise to maximize profit instead of reducing net inputs

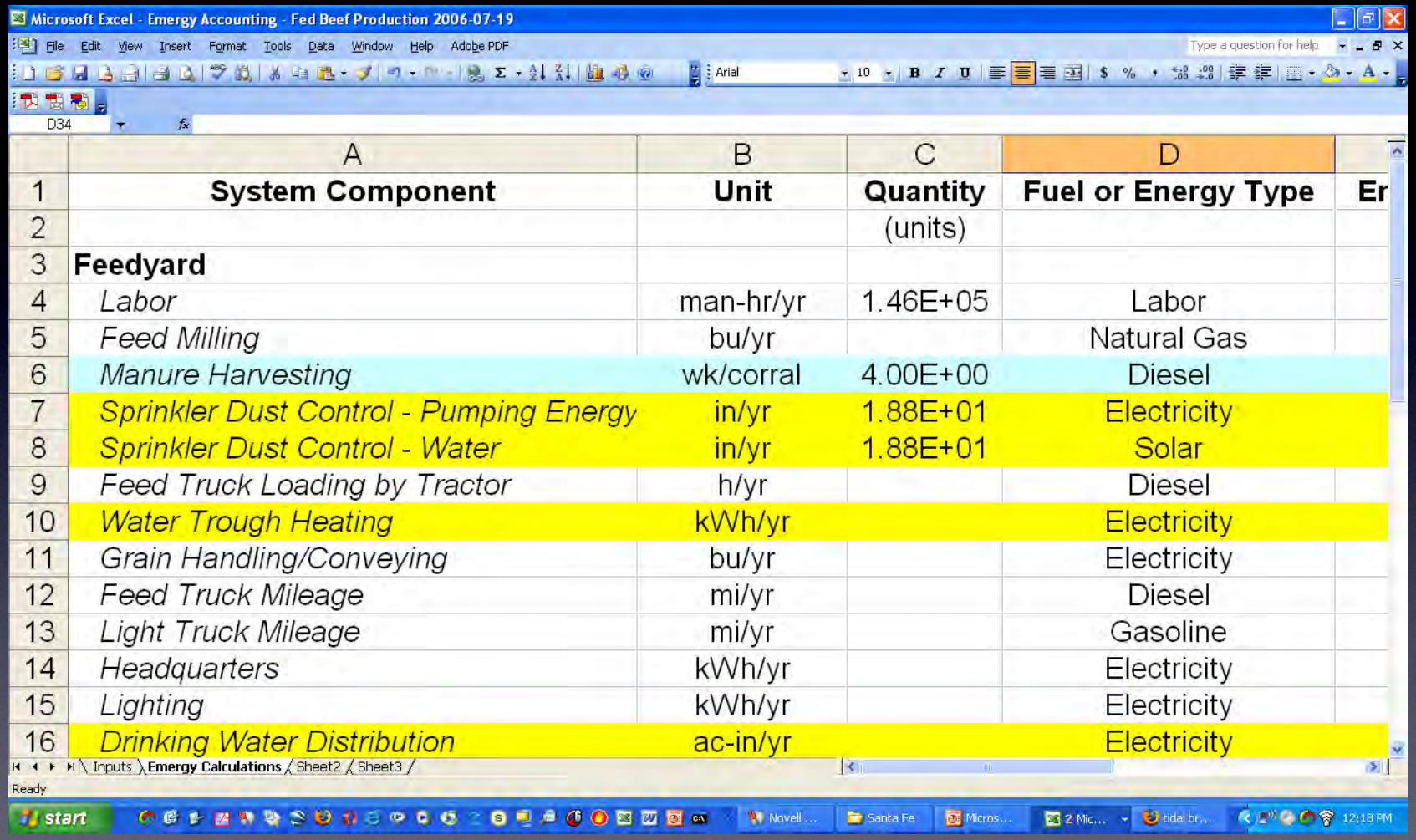
Reducing Feedyard Water Use

- *More efficient* water troughs (CE)
- *Electric* tank heaters for existing troughs (EE)
- *Repair* water trough leaks at threaded standpipe (LE)
- *Collect* & *reuse* overflow water for :
  - Water treatment/reuse system—*filtration/chlorination (EE)*
  - *Irrigation*, with or without effluent blend (EE)
  - etc., etc.

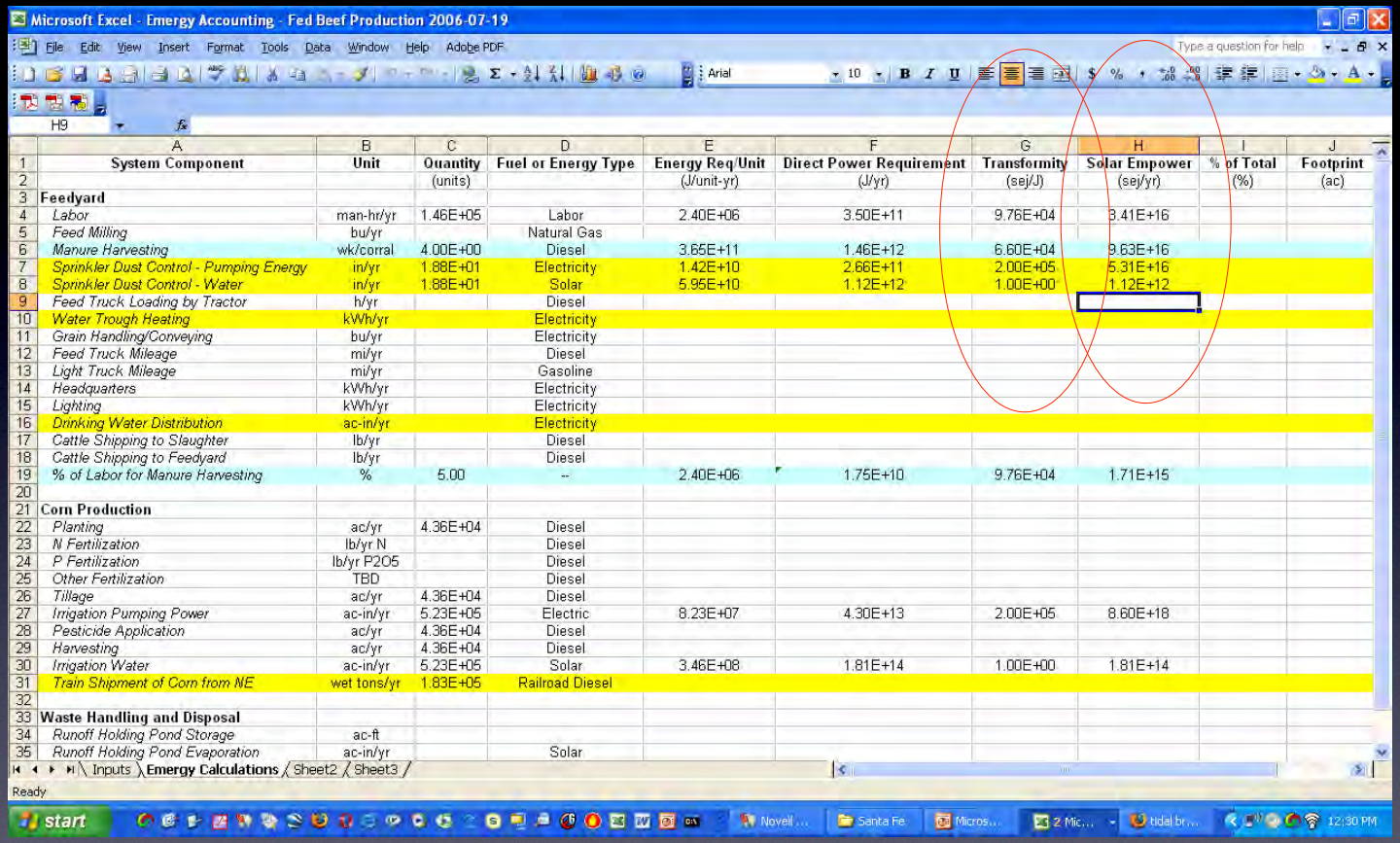
Ecological Footprints and

As we approach the limits of our easy access to energy, the defining economic currency will be dominated by availability of energy units rather than by an artificial currency, be that gold or dollars.

Paul Weisz (2004)



	A	B	C	D	
1	**System Component**	**Unit**	**Quantity**	**Fuel or Energy Type**	**Er**
2			(units)		
3	**Feedyard**				
4	*Labor*	man-hr/yr	1.46E+05	Labor	
5	*Feed Milling*	bu/yr		Natural Gas	
6	*Manure Harvesting*	wk/corral	4.00E+00	Diesel	
7	*Sprinkler Dust Control - Pumping Energy*	in/yr	1.88E+01	Electricity	
8	*Sprinkler Dust Control - Water*	in/yr	1.88E+01	Solar	
9	*Feed Truck Loading by Tractor*	h/yr		Diesel	
10	*Water Trough Heating*	kWh/yr		Electricity	
11	*Grain Handling/Conveying*	bu/yr		Electricity	
12	*Feed Truck Mileage*	mi/yr		Diesel	
13	*Light Truck Mileage*	mi/yr		Gasoline	
14	*Headquarters*	kWh/yr		Electricity	
15	*Lighting*	kWh/yr		Electricity	
16	*Drinking Water Distribution*	ac-in/yr		Electricity	



Microsoft Excel - Emergy Accounting - Fed Beef Production 2006-07-19

File Edit View Insert Format Tools Data Window Help Adobe PDF

H9

	A	B	C	D	E	F	G	H	I	J
1	System Component	Unit	Quantity	Fuel or Energy Type	Energy Req/Unit	Direct Power Requirement	Transformity	Solar Empower	% of Total	Footprint
2			(units)		(J/unit-yr)	(J/yr)	(sej/J)	(sej/yr)	(%)	(ac)
3	**Feedyard**									
4	*Labor*	man-hr/yr	1.46E+05	Labor	2.40E+06	3.50E+11	9.76E+04	3.41E+16		
5	*Feed Milling*	bu/yr		Natural Gas						
6	*Manure Harvesting*	wk/corral	4.00E+00	Diesel	3.65E+11	1.46E+12	6.60E+04	9.63E+16		
7	*Sprinkler Dust Control - Pumping Energy*	in/yr	1.88E+01	Electricity	1.42E+10	2.66E+11	2.00E+05	5.31E+16		
8	*Sprinkler Dust Control - Water*	in/yr	1.88E+01	Solar	5.95E+10	1.12E+12	1.00E+00	1.12E+12		
9	*Feed Truck Loading by Tractor*	h/yr		Diesel						
10	*Water Trough Heating*	kWh/yr		Electricity						
11	*Grain Handling/Conveying*	bu/yr		Electricity						
12	*Feed Truck Mileage*	mi/yr		Diesel						
13	*Light Truck Mileage*	mi/yr		Gasoline						
14	*Headquarters*	kWh/yr		Electricity						
15	*Lighting*	kWh/yr		Electricity						
16	*Drinking Water Distribution*	ac-in/yr		Electricity						
17	*Cattle Shipping to Slaughter*	lb/yr		Diesel						
18	*Cattle Shipping to Feedyard*	lb/yr		Diesel						
19	*% of Labor for Manure Harvesting*	%	5.00	--	2.40E+06	1.75E+10	9.76E+04	1.71E+15		
20										
21	**Corn Production**									
22	*Planting*	ac/yr	4.36E+04	Diesel						
23	*N Fertilization*	lb/yr N		Diesel						
24	*P Fertilization*	lb/yr P2O5		Diesel						
25	*Other Fertilization*	TBD		Diesel						
26	*Tillage*	ac/yr	4.36E+04	Diesel						
27	*Irrigation Pumping Power*	ac-in/yr	5.23E+05	Electric	8.23E+07	4.30E+13	2.00E+05	8.60E+18		
28	*Pesticide Application*	ac/yr	4.36E+04	Diesel						
29	*Harvesting*	ac/yr	4.36E+04	Diesel						
30	*Irrigation Water*	ac-in/yr	5.23E+05	Solar	3.46E+08	1.81E+14	1.00E+00	1.81E+14		
31	*Train Shipment of Corn from NE*	wet tons/yr	1.83E+05	Railroad Diesel						
32										
33	**Waste Handling and Disposal**									
34	*Runoff Holding Pond Storage*	ac-ft								
35	*Runoff Holding Pond Evaporation*	ac-in/yr		Solar						

Inputs | Emergy Calculations | Sheet2 | Sheet3

Ready

start 12:30 PM

Emergy of Feedyard Water Use

- Groundwater (GW) used for sprinkler dust control in the Texas Panhandle represents 50-80% more emergy than cattle drinking water (solar distillation basis)
- Pumping GW for sprinkler dust control represents 47,000 times the emergy content of the water itself
- Manure harvesting carries ~85% more emergy (in labor and diesel) than sprinkler dust control
- Corn grown locally to satisfy a feedyard's grain requirements carries 100 times the emergy *in irrigation alone* than the water pumped for cattle drinking

A Reminder

- We can probably design/engineer systems to accomplish ecological sustainability to an arbitrary degree of reliability
- But *can we afford it* at current levels of energy use?
- What about at *future* levels?

A Sustainability Conjecture

No terrestrial ecosystem of can be considered sustainable if it must be subsidized indefinitely by non-renewable energy

Future Directions

- One need not accept all of Rees' and Odum's extrapolations in order to adopt their analytical perspectives
- We are seeing today a rapid lurch toward a more plausible linkage between energy scarcity and market prices
- Can we use emergy synthesis to evaluate the sustainability of our AFO technologies (water use, feeding regimes, nutrient flows, biofuels)?

Researchable Questions

- A ton of NH_3 in the tank vs. a ton in the air?
- Embodied ___ in hormonal implants; what are their *net* ___ effects?
- How does one assign LCA "currency" value to microbes, odors, biodiversity and other nonlinear stressors and ecological services?
- Biofuels, hydrogen etc.; net fuel value "FOB" AFO?