The Role of Energy Efficiency: Roadmap to Sustainable Manufacturing

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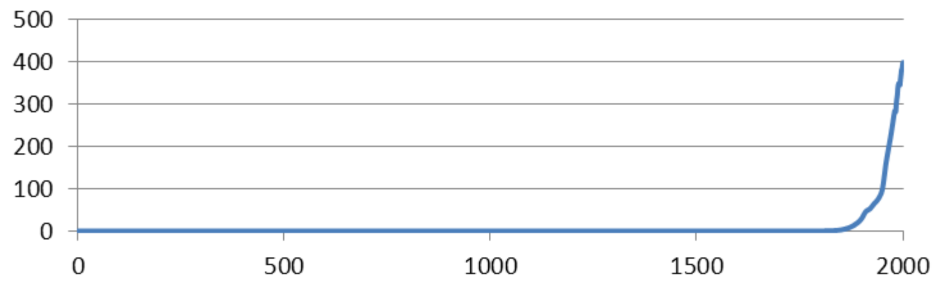
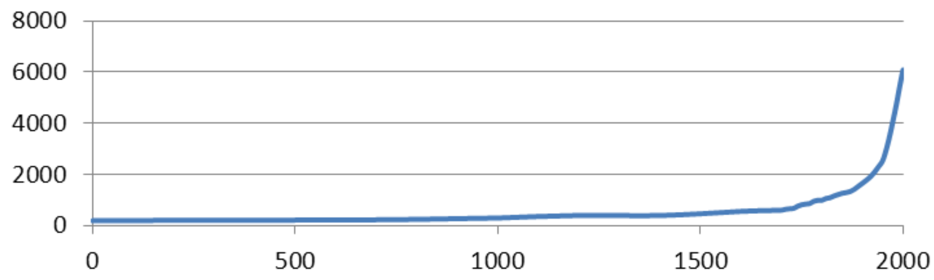
UNIVERSITY of DAYTON 1850-2000

What on Earth Are These?

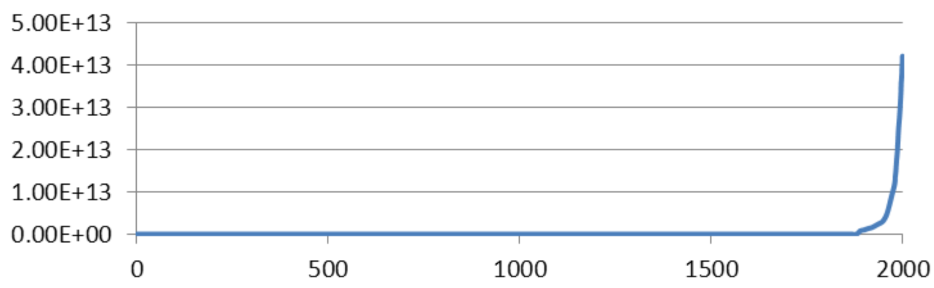
World
Energy Use



World
Population



World
Gross
Income



Converting Heat to Work

Since pre-history we knew how to:

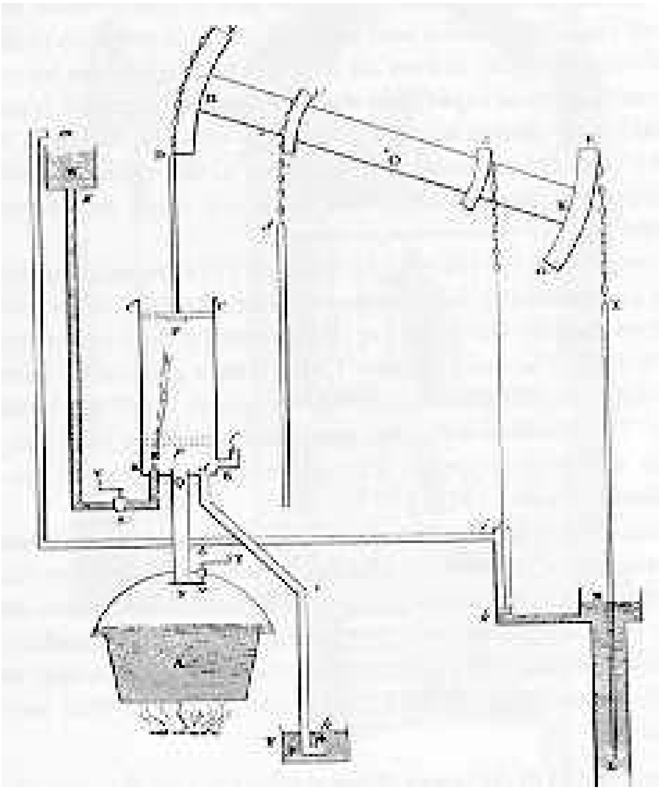
Work → Heat

Industrial Revolution to:

Work ← Heat

Newcomen's Steam Engine

~1712



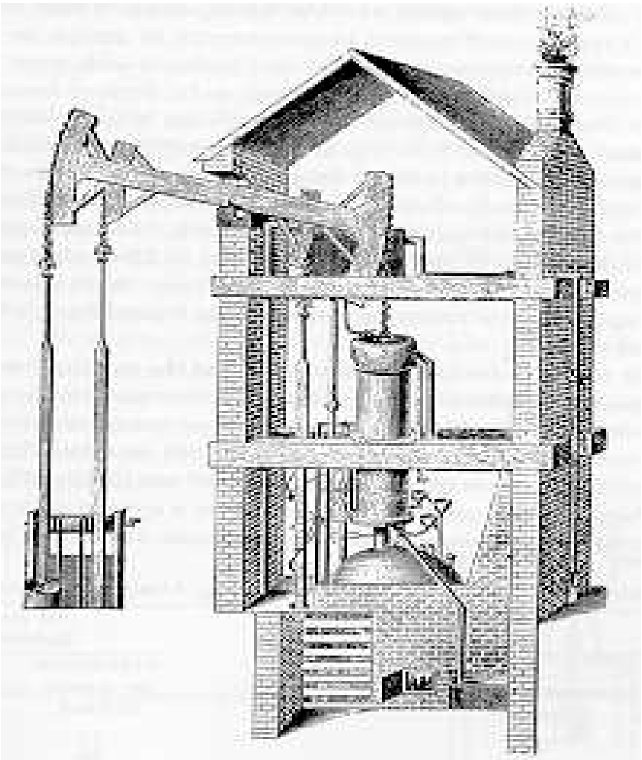
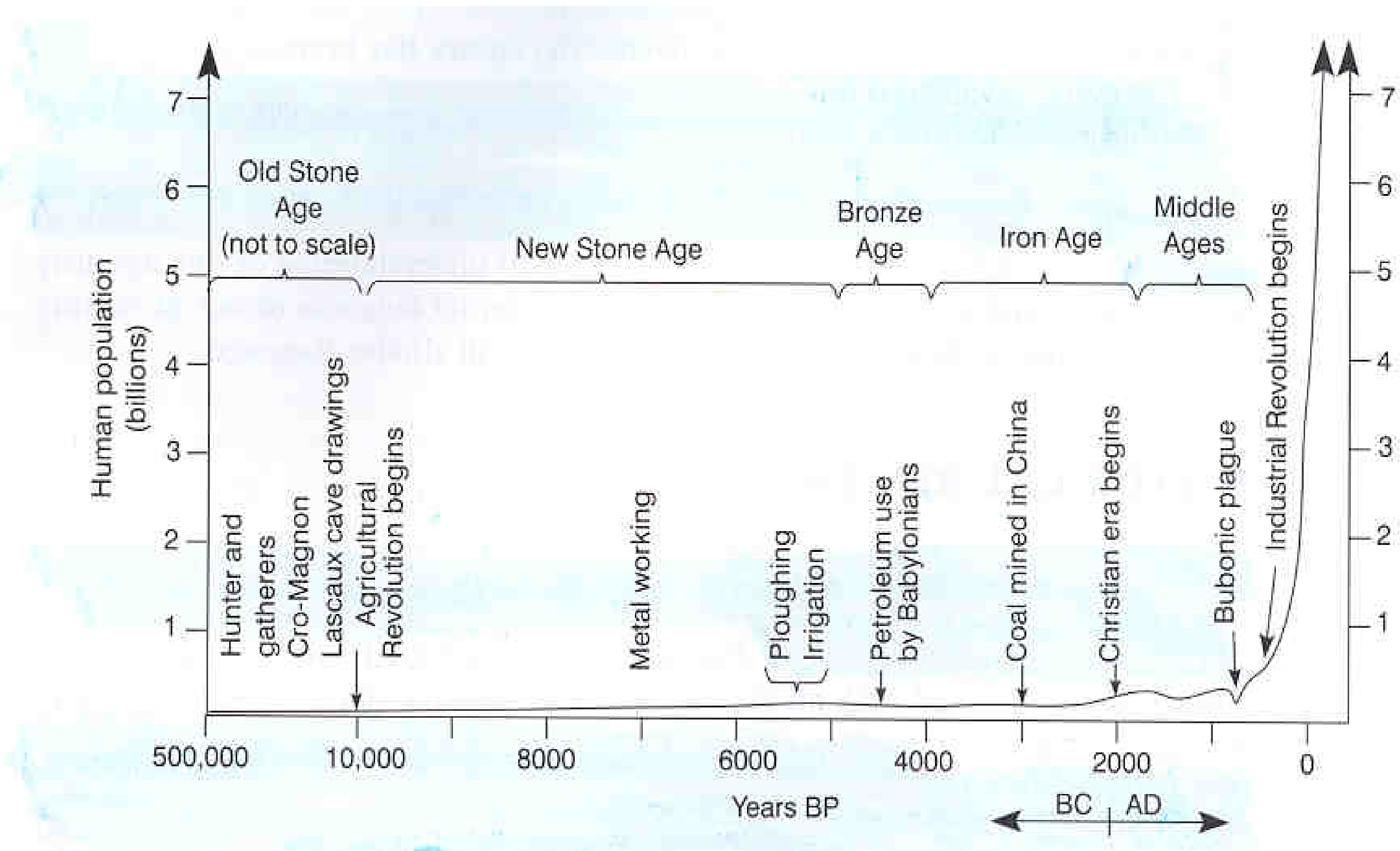


Fig. 129. Newcomen engine, 1732.

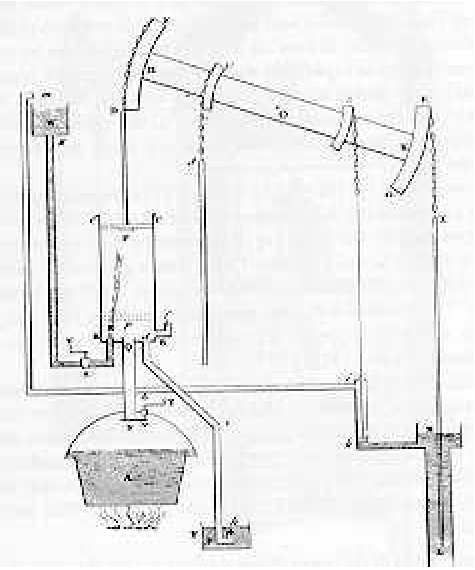
Energy Revolution Creates Modern World

Most Important Event in Human History



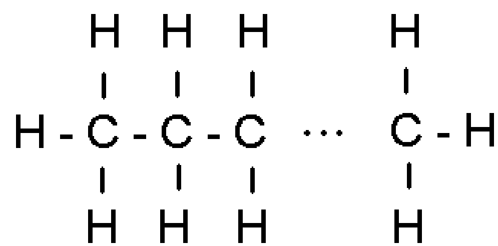
We've Come a Long Way…

- Newcomen's steam engine: 0.5%
- Watt's steam engine: 1%
- Gasoline engines: 30%
- Coal Rankine cycles: 35%
- Turbines: 40%
- Diesel engines: 50%
- Combined-cycle turbine/Rankine engines: 60%



But Energy Conversion Largely Unchanged…

1. Use hydrocarbon fossil fuels

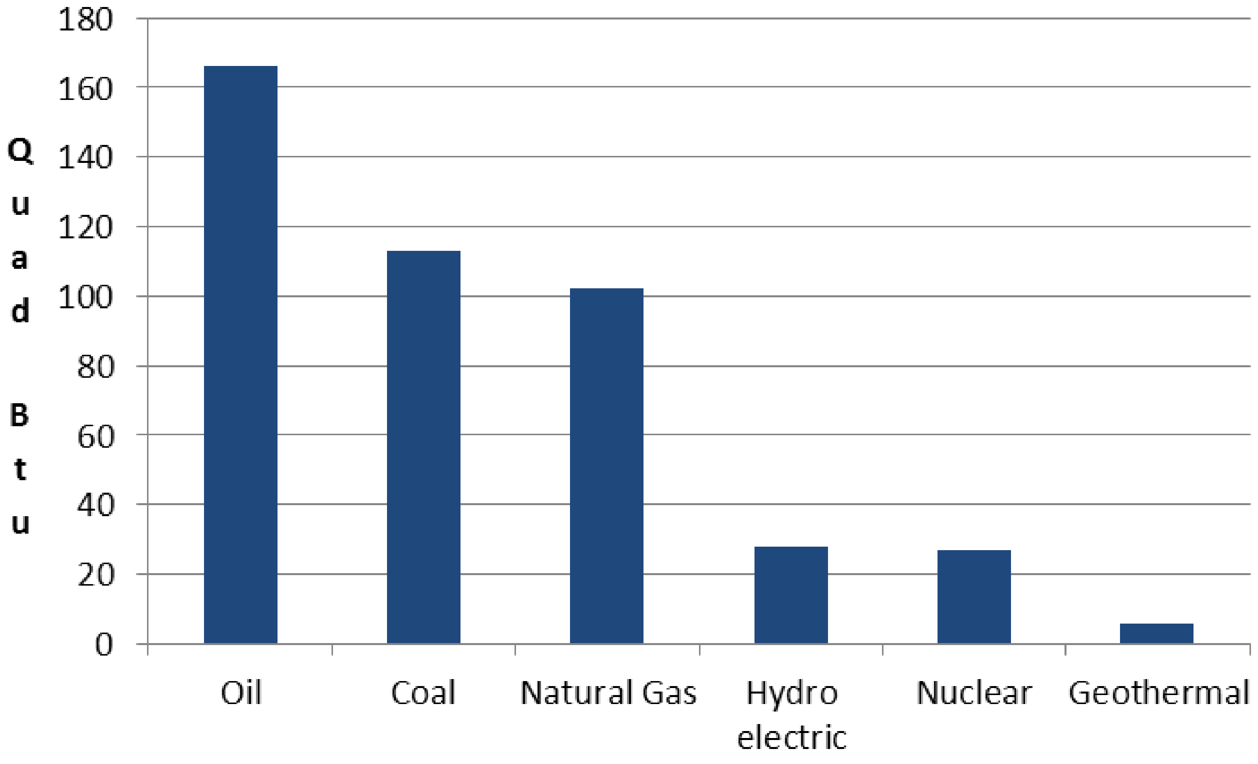


2. Employ combustion to release heat

$$CH_4+2(O_2 + 3.76\ N_2)=CO_2+2H_20+(NOx+SOx+\ldots)$$

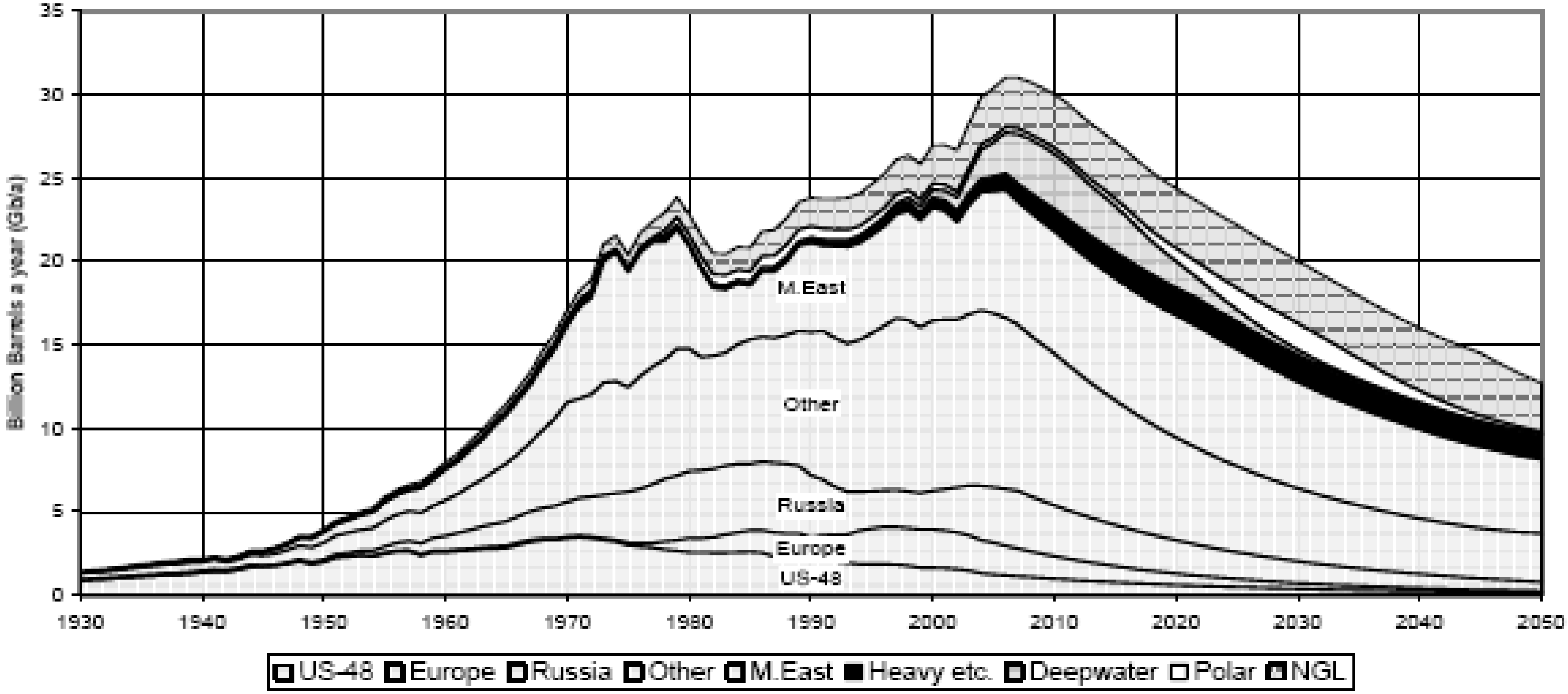
3. Convert heat to work via thermal expansion

84% Of World Energy From Fossil Fuels

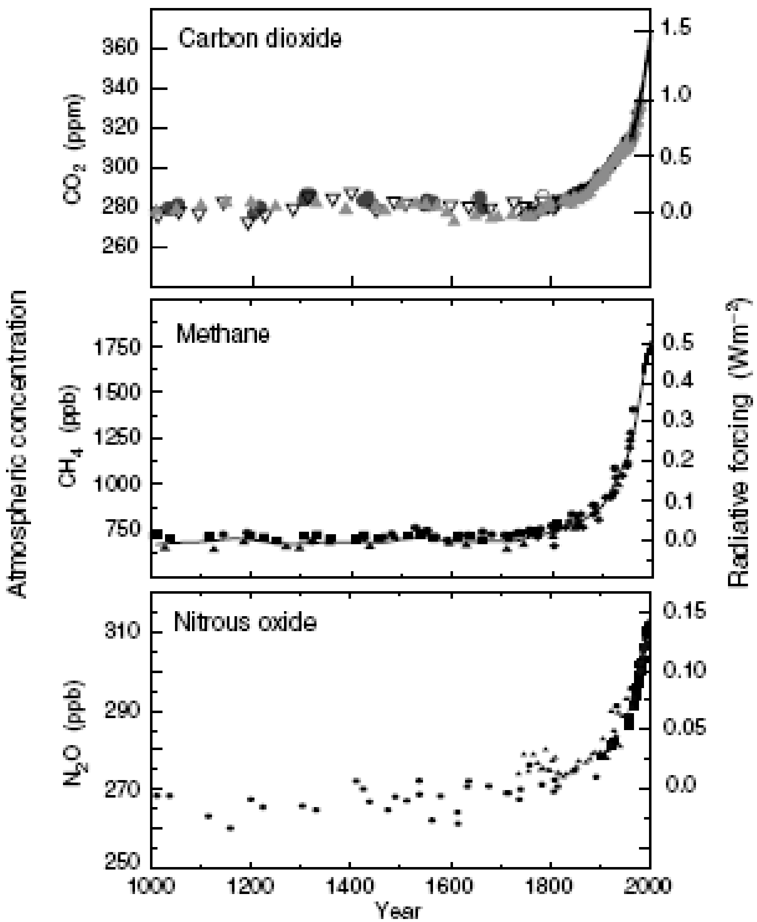


- In U.S. 86% from non-renewable fossil fuels
- Source: U.S. D.O.E. Annual Energy Review 2005

Resource Constraints: World Oil Peak

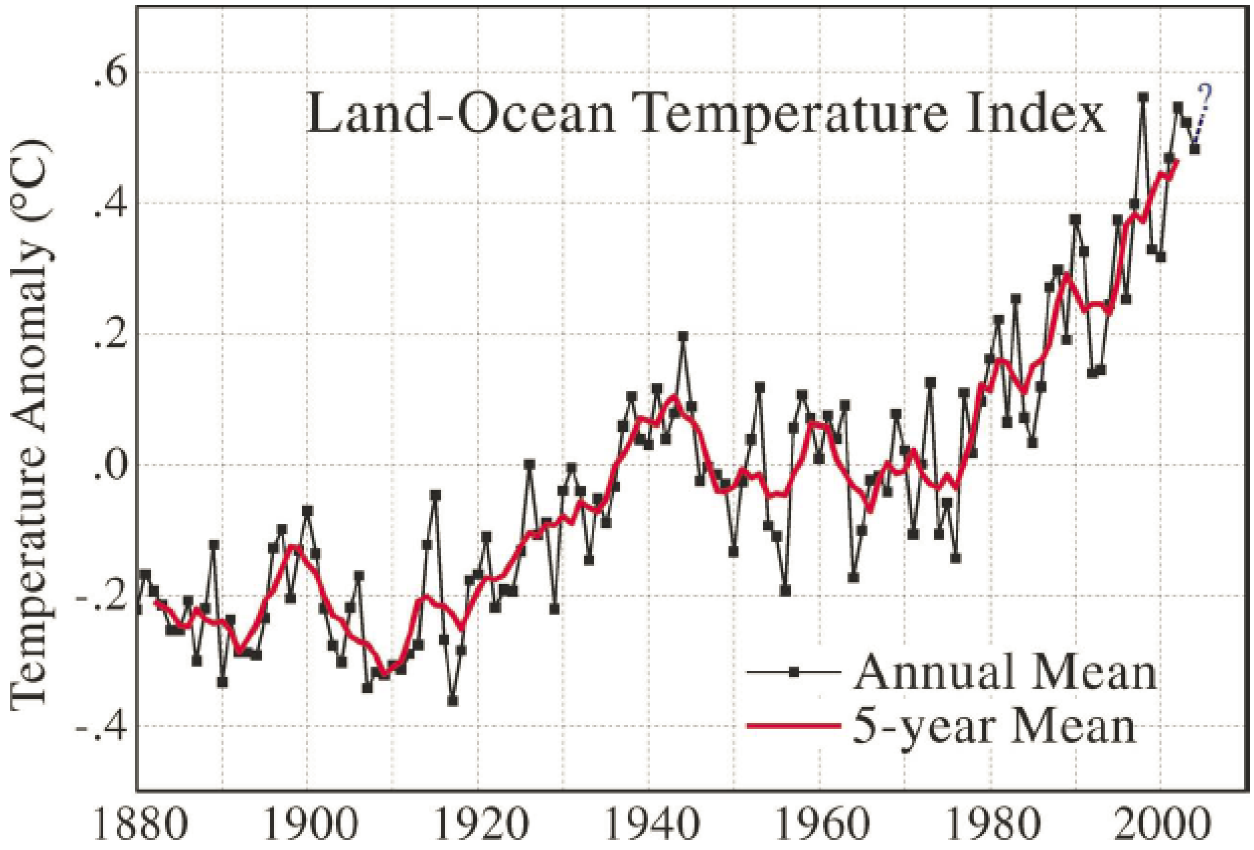


Greenhouse Gas Trends



Intergovernmental Panel
on Climate Change, 2001,
“Summary for Policymakers”

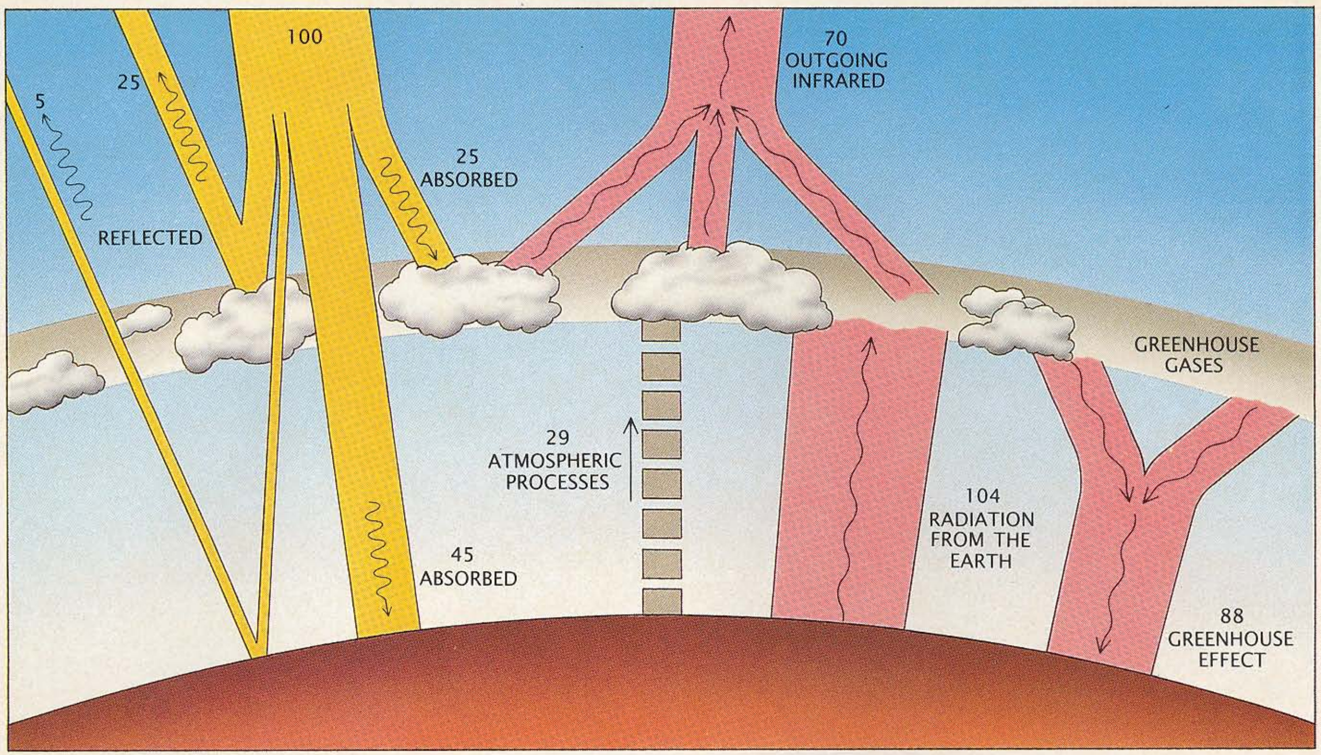
Coincident Global Warming



Global mean surface temperature change based on surface air measurements over land and SSTs over ocean

Hansen, J., "Is There Still Time to Avoid Dangerous Anthropogenic Interference with Global Climate?", American Geophysical Union, 2005.

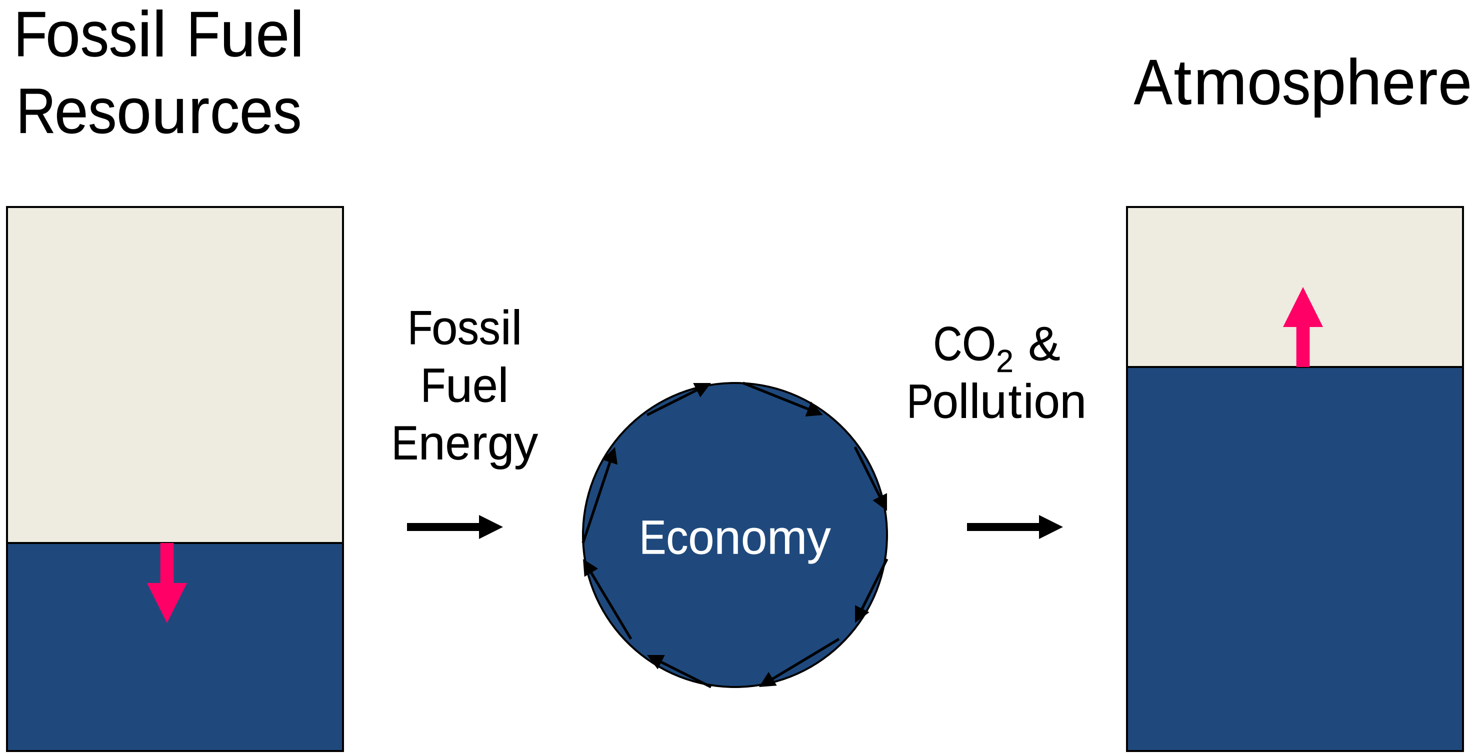
Mechanism Well Understood



HEAT TRAPPING in the atmosphere dominates the earth's energy balance. Some 30 percent of incoming solar energy is reflected (*left*), either from clouds and particles in the atmosphere or from the earth's surface; the remaining 70 percent is absorbed. The absorbed energy is reemitted at infrared wavelengths by the atmosphere (which is also heated by updrafts and cloud formation) and by the surface. Because most of the surface radiation is trapped by clouds and greenhouse gases and returned to the earth, the surface is currently about 33 degrees Celsius warmer than it would be without the trapping.

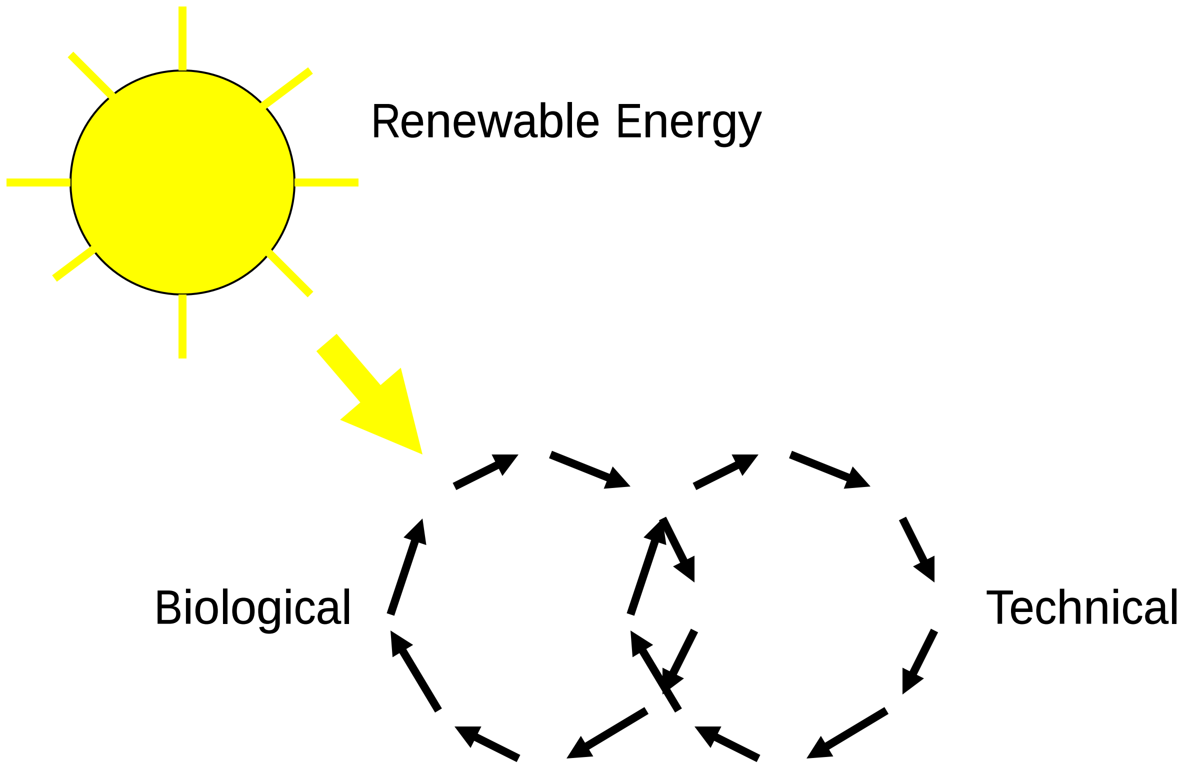
"Changing Climate", Stephen Schneider, Scientific American, 10/1989

Linear Model of Production

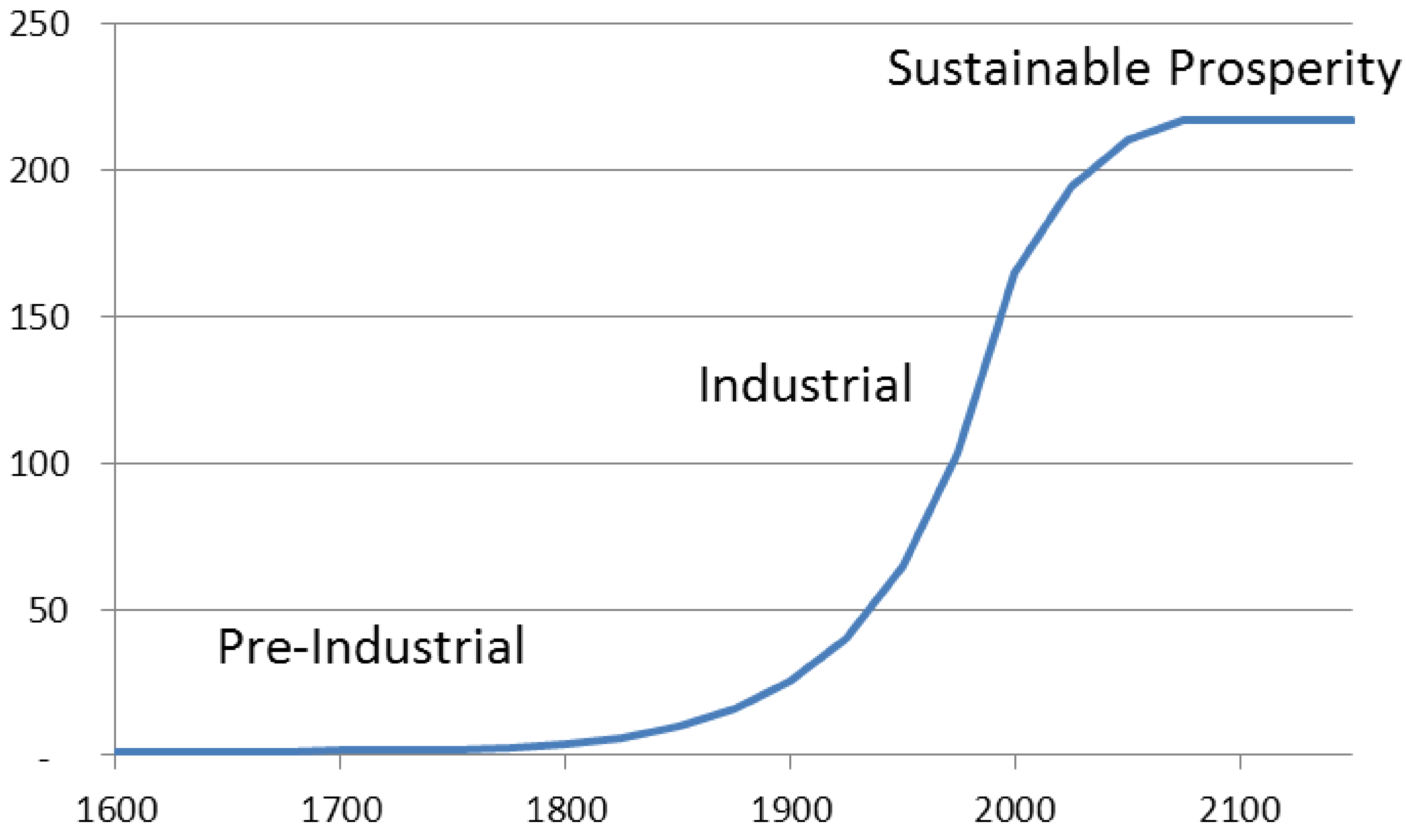


Running Out of Energy Resources While Atmosphere Filling Up

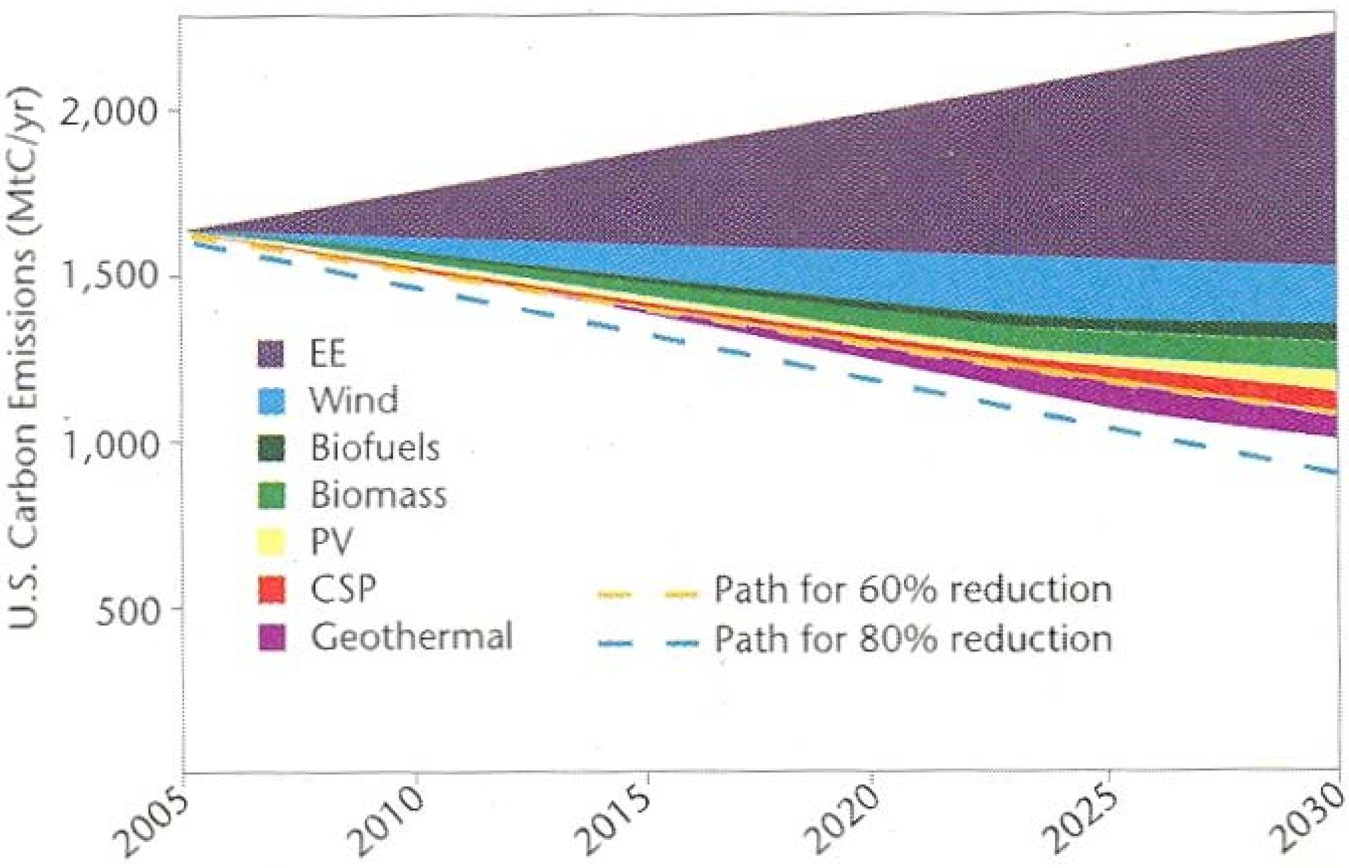
Ecological Model of Production



Our Challenge: Sustainable Prosperity



US CO_2 Stabilization Scenario



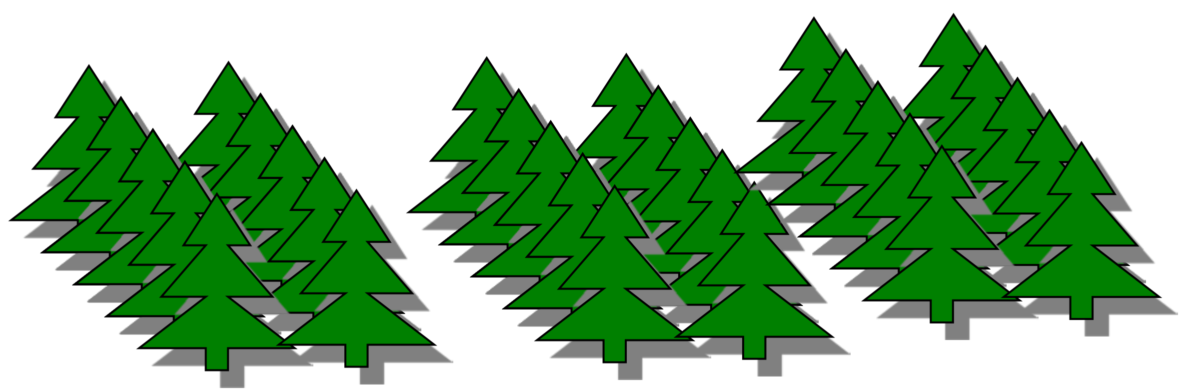
Kutscher, C., “Tackling Climate Change in the US”, Solar Today, March, 2007

Manufacturing: Large Efficiency Gains Possible

- Manufacturers make money, making it easier to spend money
- Energy costs are only 2% of gross income
- Technologies improve faster than obsolete factories replaced
- Manufacturing is inherently inefficient

Manufacturing Efficiency??

- 1 kg paper requires 100 kg of resources
- 1 liter OJ requires 1,000 liters of water
- 1 semiconductor chip generates 100,000 times its mass in waste
- US industry mines, burns, pumps, disposes of **4 M lb** of material per family per year



Mechanisms of Improved Energy Efficiency

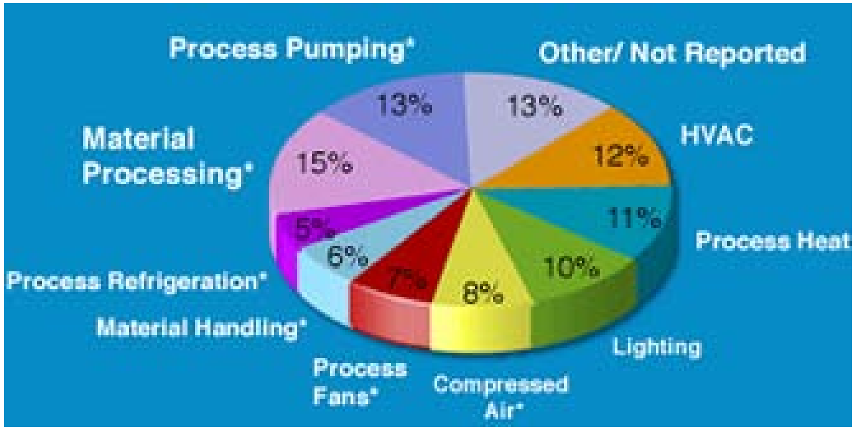
- New technologies (lights, VSDs, fuel cells, …)
- New processes (biological engineering, …)
- New controls (local feedback, nn, fl,…)
- Material substitution and reduction (near net shape, dematerialization, remanufacturing,…)

Integrated Approach to Energy Efficiency

Integrated Systems + Principles Approach

Energy Systems

- Lighting
- Motor drive
- Fluid flow
- Compressed air
- Steam and hot water
- Process heating
- Process cooling
- Heating, ventilating and air conditioning
- Cogeneration



Principles of Energy Efficiency

- Apply Inside Out Analysis
- Maximize Control Efficiency
- Maximize Counter-flow
- Avoid Mixing
- Match Energy Source to End Use
- Consider Theoretical Minimum Energy Use
- Consider Whole System
- Consider Whole Time Frame

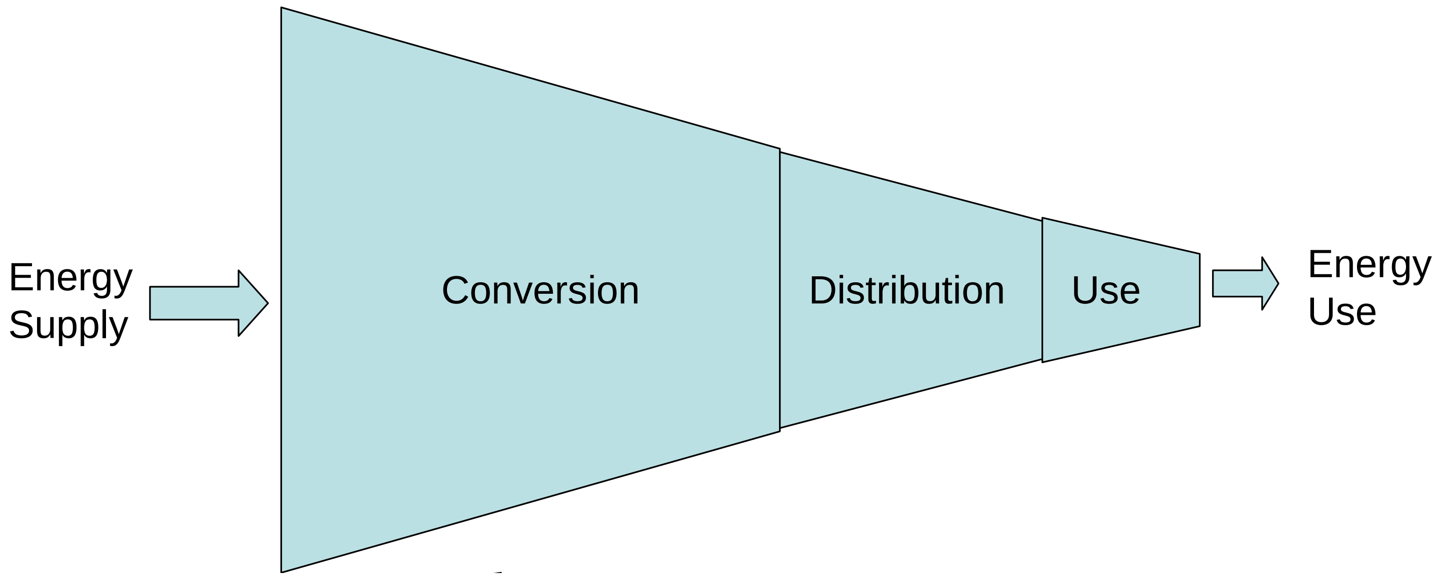
Integrated Systems + Principles Approach

- Integrated systems + principles approach (ISPA) =
  Systems approach + Principles of energy efficiency

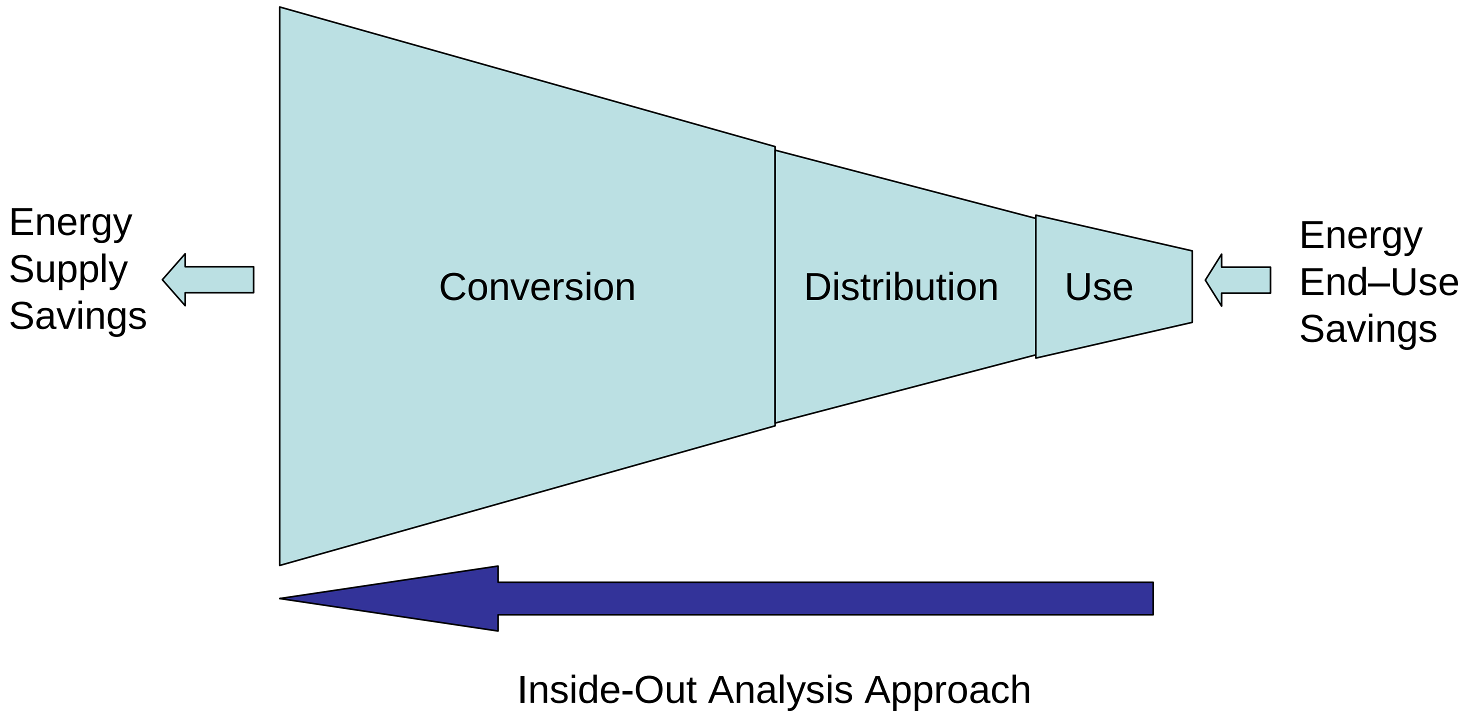
	Electrical	Lighting	Motors	Fluid Flow	Comp Air	Steam	Proc Heat	Proc Cool	HVAC	CHP
Inside Out										
Control Efficiency										
Counter-flow										
Avoid Mixing										
Match Source Energy to End Use										
Theoretical Minimum Energy Use										
Whole-system, Whole-time Frame Analysis										

- ISPA is both effective and thorough.

1. Inside-out Approach



Inside-out Approach



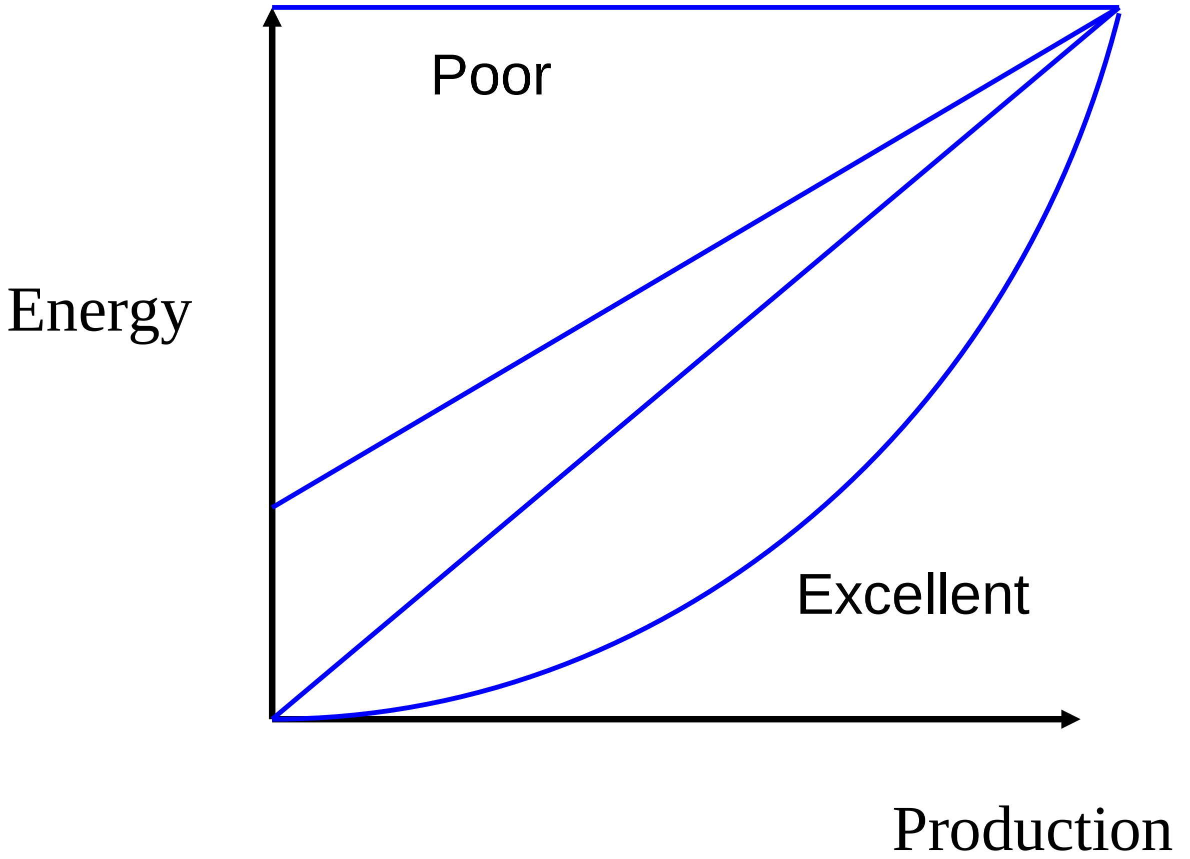
Inside-out Amplifies Savings

Reduce pipe friction: Savings =	1.00 kWh
Pump 70% eff: Savings =	1.43 kWh
Drive 95% eff: Savings =	1.50 kWh
Motor 90% eff: Savings =	1.67 kWh
T&D 91% eff: Savings =	1.83 kWh
Powerplant 33% eff: Savings =	5.55 kWh

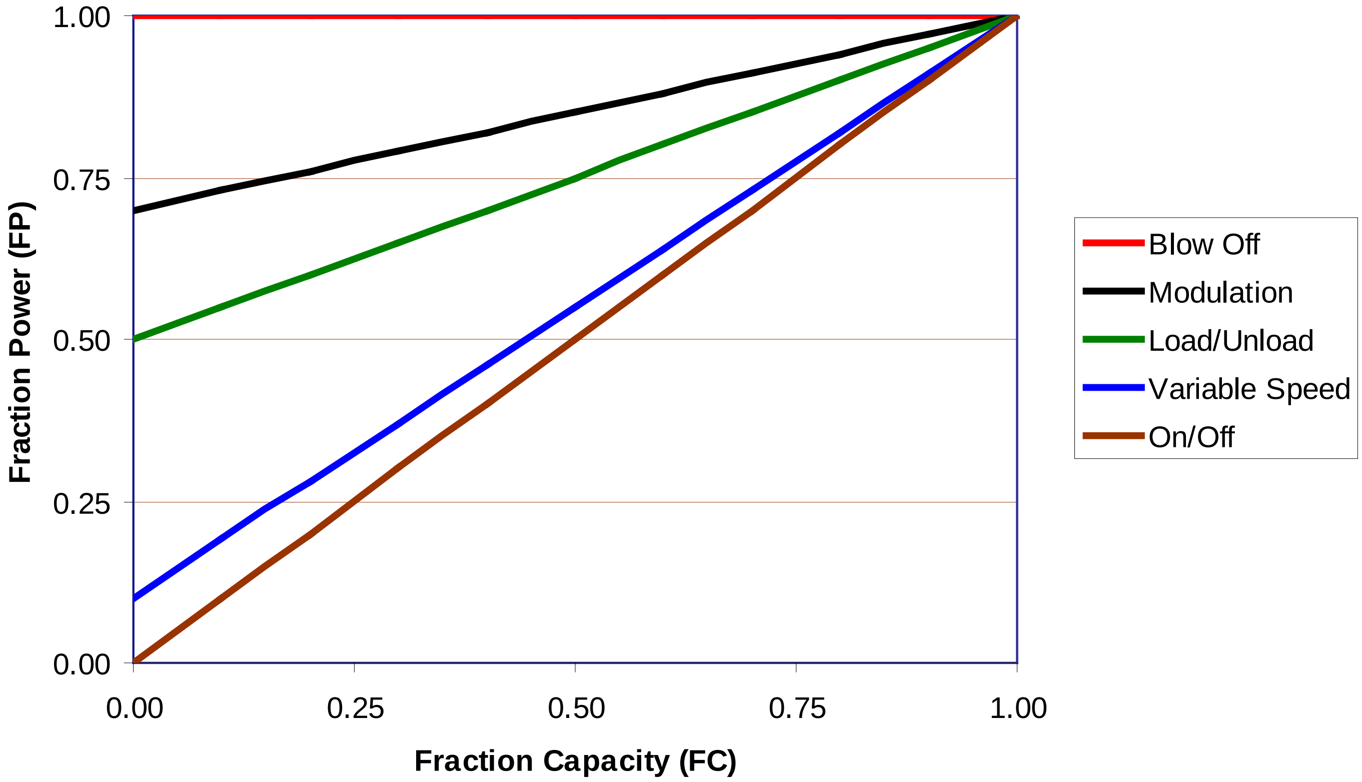
2. Maximize Control Efficiency

- Systems designed for peak load, but operate at part load
- System efficiency generally changes at part load
- Recognize and modify systems with poor part-load (control) efficiency

Control Efficiency

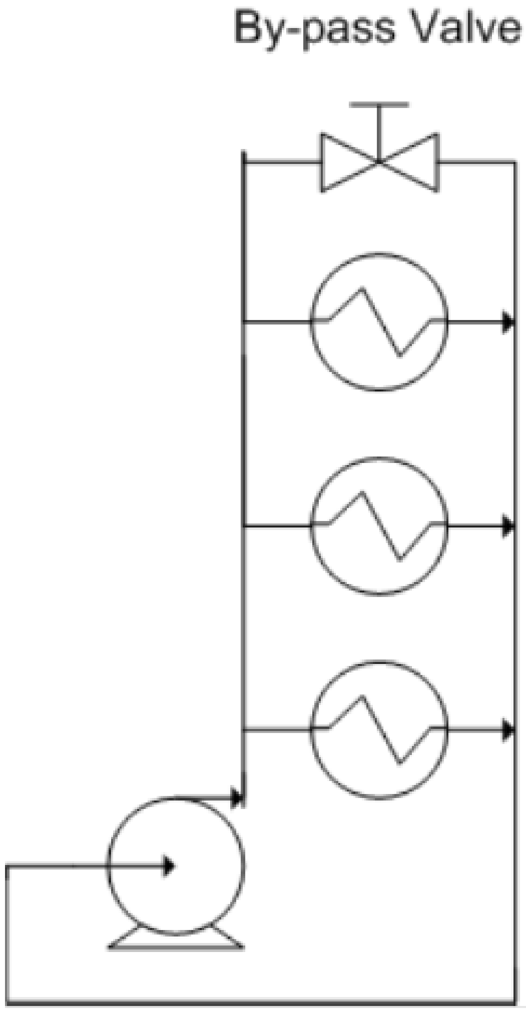


Air Compressor Control

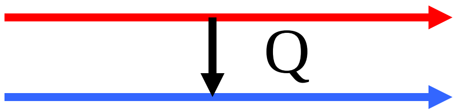


$$FP = FP_0 + FC\,(1 - FP_0)$$

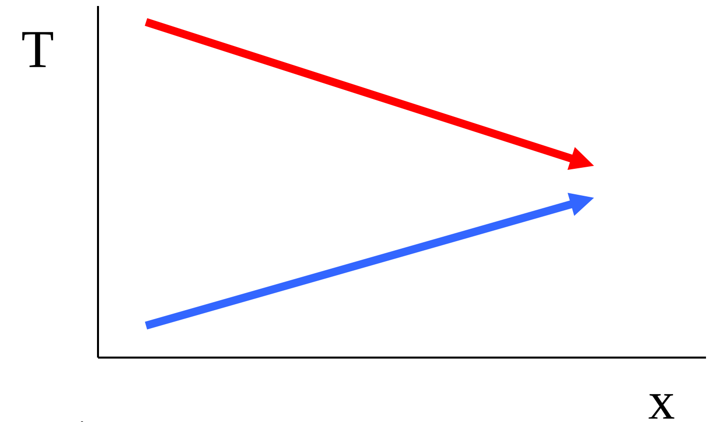
Pump System Control

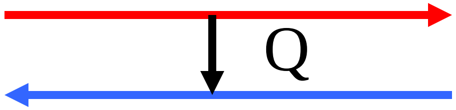


3. Maximize Counter-flow

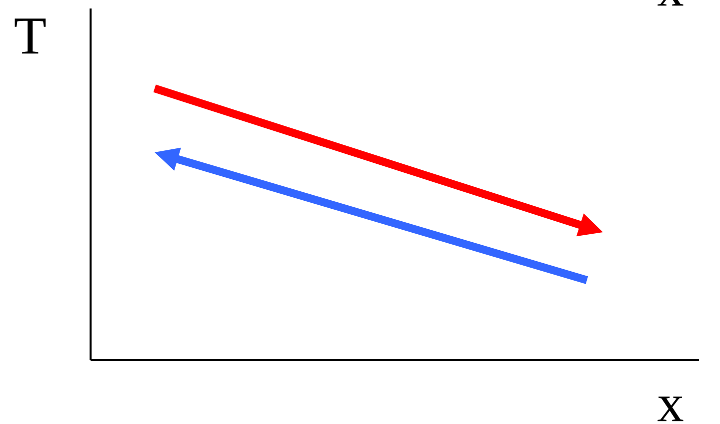


Parallel Flow





Counter Flow

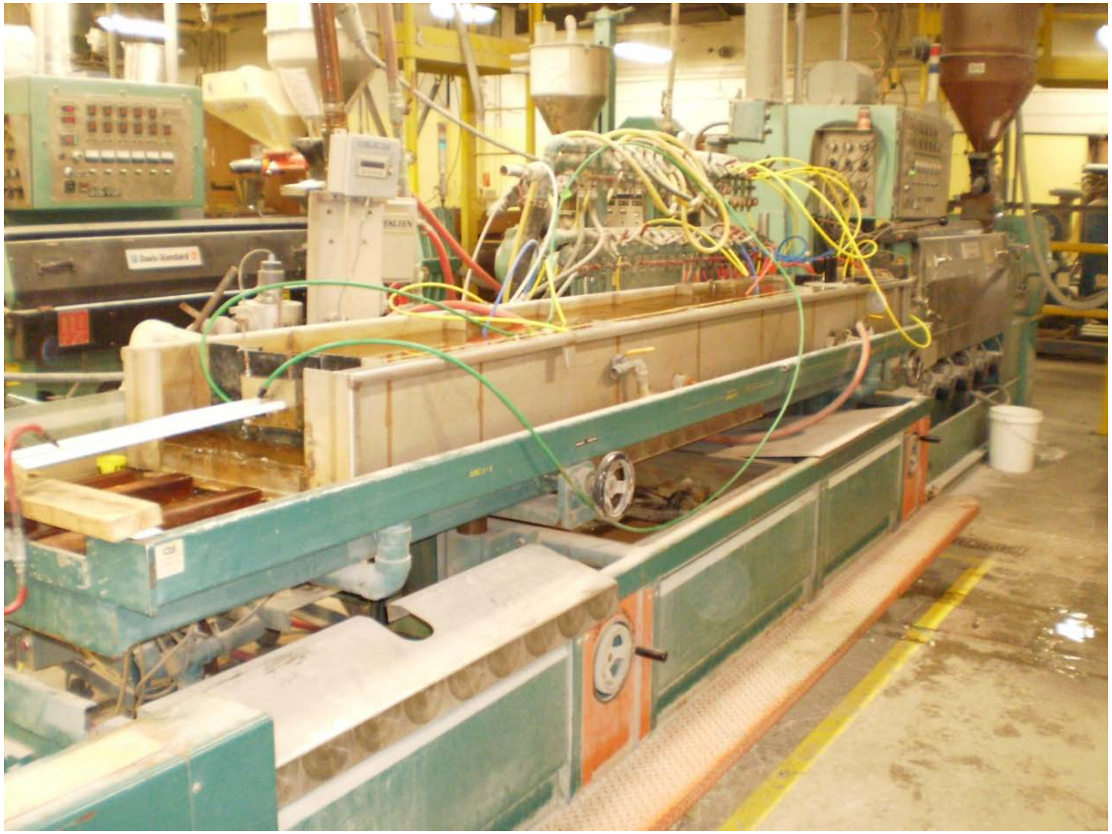


Counter-flow Furnace Pre-heats Charge

Reverb Furnace Efficiency = 25% Stack Furnace Efficiency = 44%

(Eppich and Nuranjo, 2007)

Counter-Flow Cooling



Counter flow enables 50 F to 70 F water saves 10x

4. Avoid Mixing

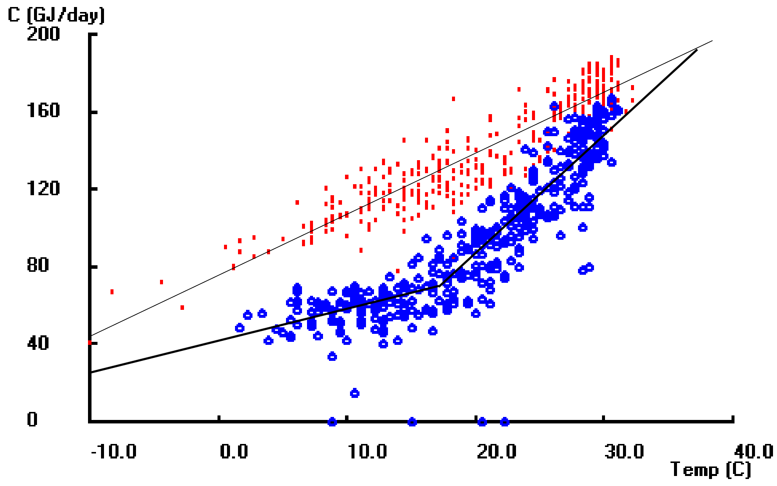
- Availability analysis…

  Useful work destroyed with mixing

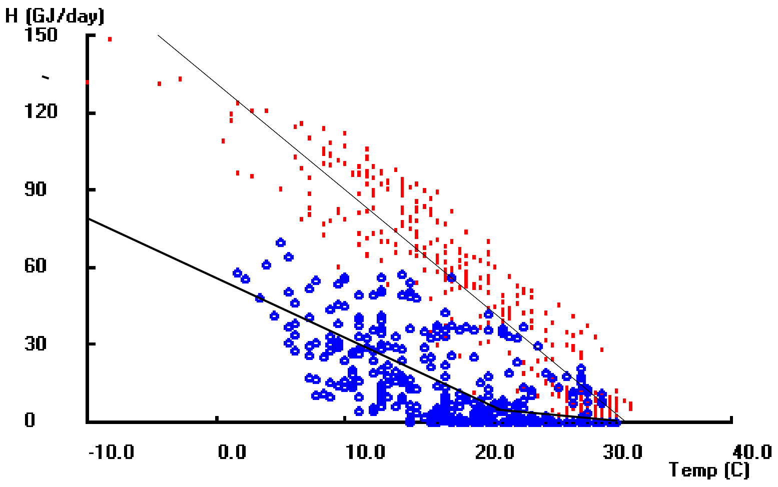
- Examples
  - CAV/VAV air handlers
  - Separate hot and cold wells

HVAC Applications

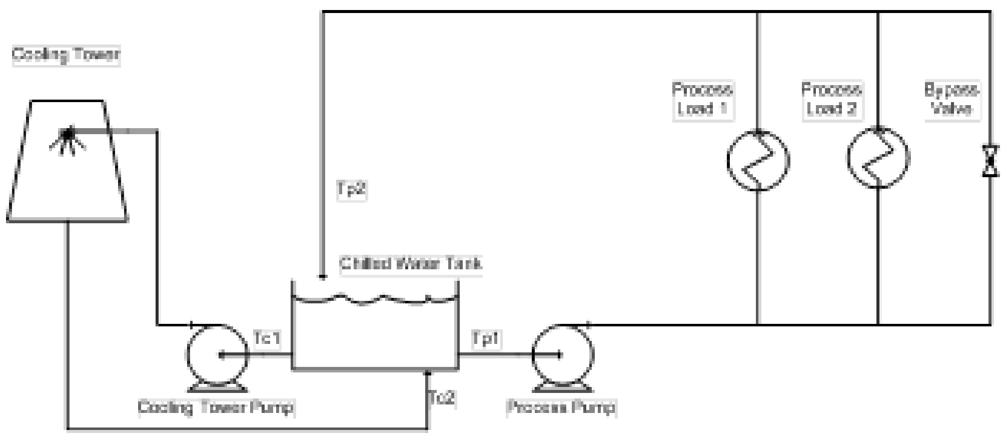
Cooling Energy Use

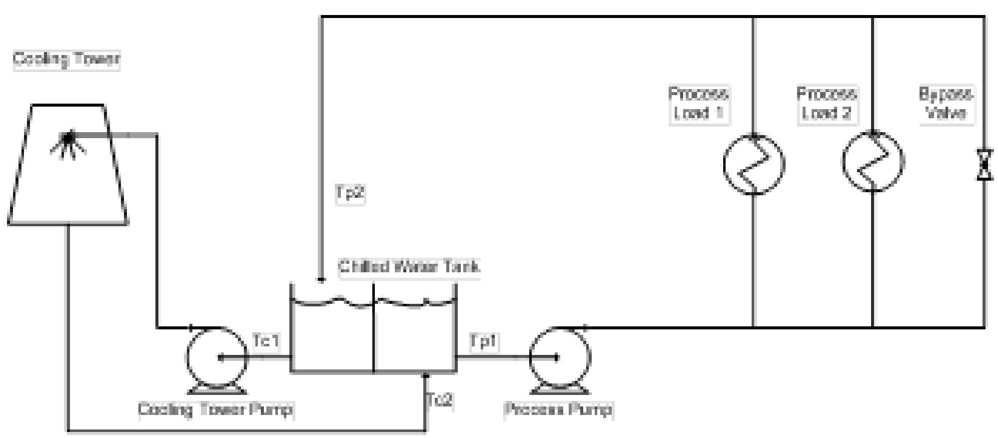


Heating Energy Use



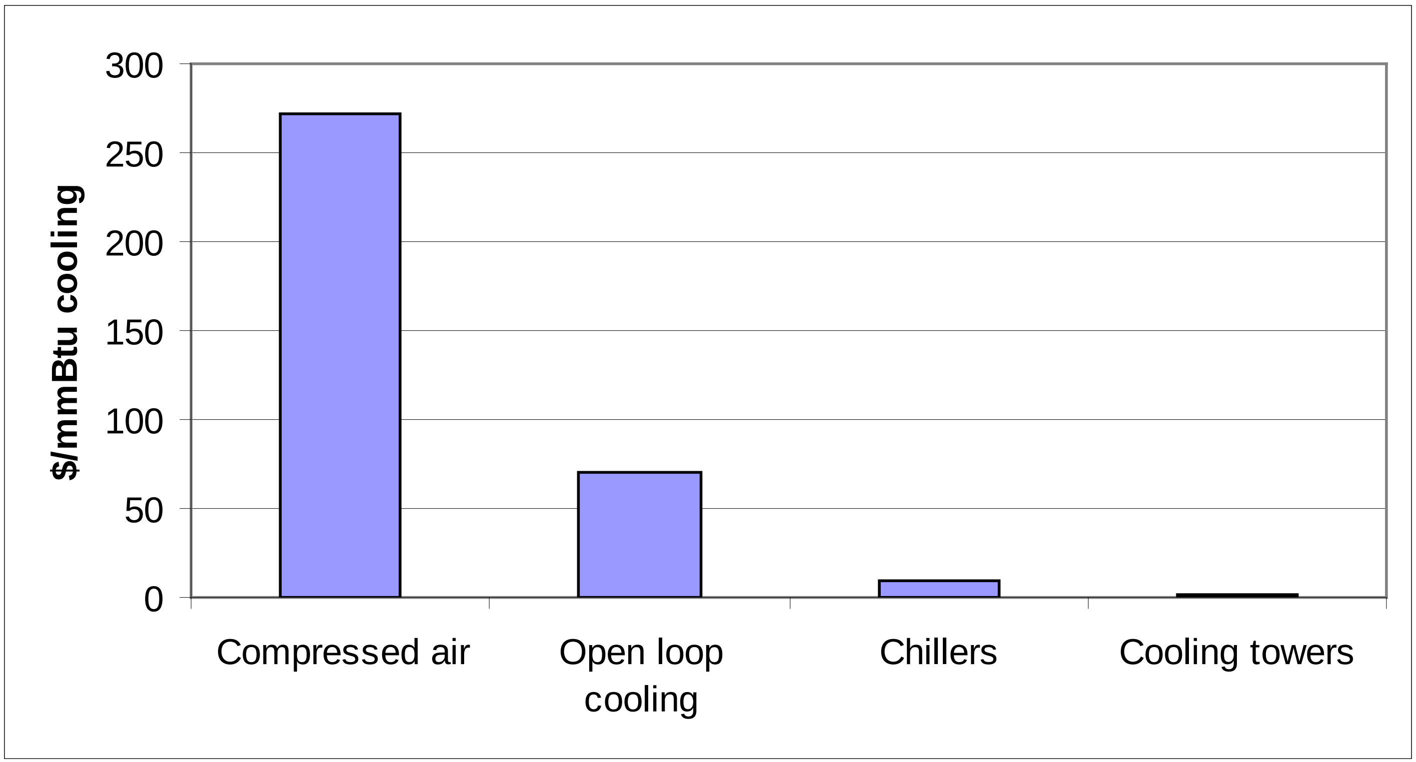
Cooling Applications





Separate tank into hot and cold sides

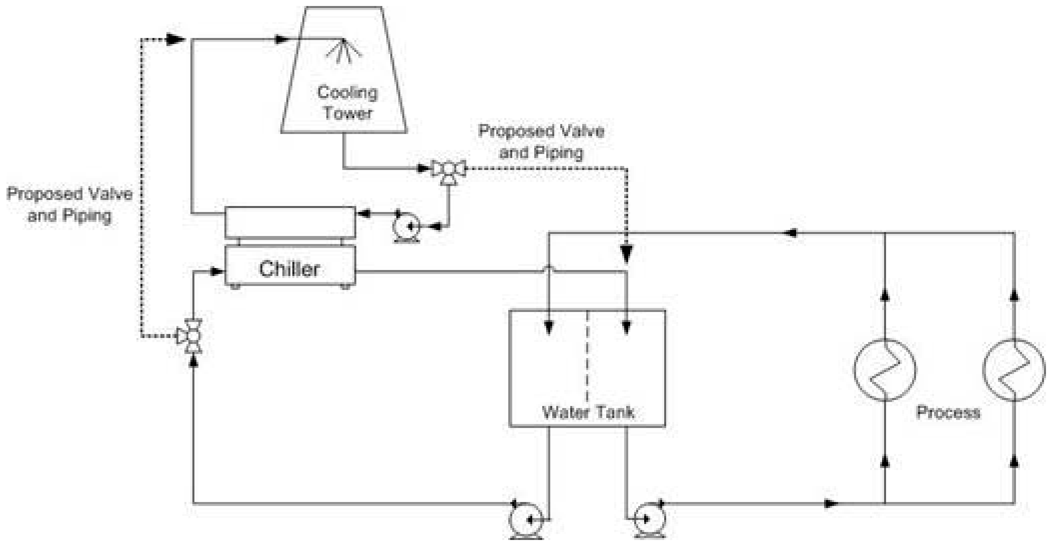
5. Match Energy Source and End Use



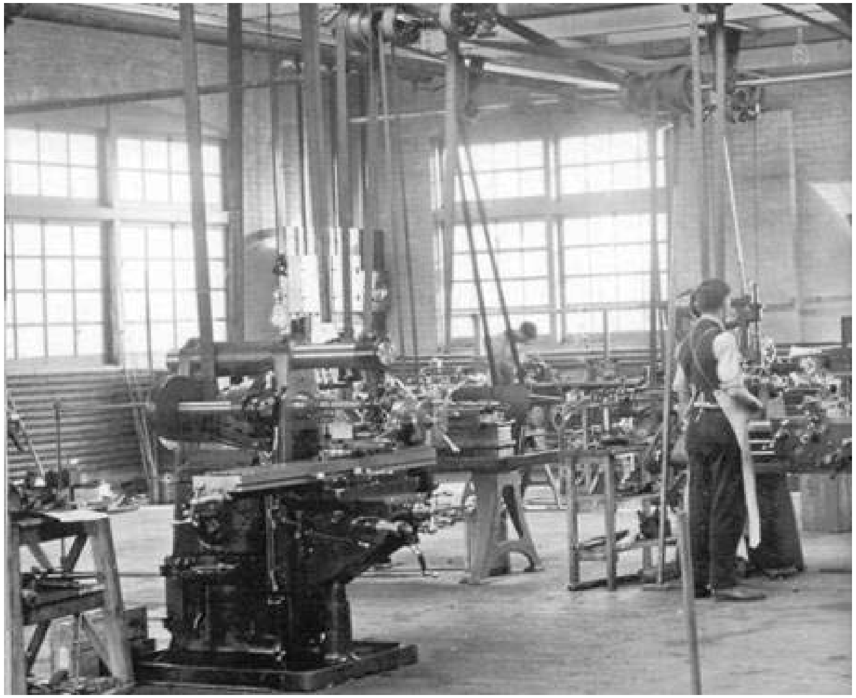
Use Cooling Tower When Possible

Fraction of year cooling tower can deliver water at Tc (Assume Tr = 10 F in Dayton OH)

Tc (F)	Twb (F)	Fyr (%)
75	65	72%
70	57	61%
65	50	53%
60	42	40%



Natural Lighting: Eyes See Best in Sunlight



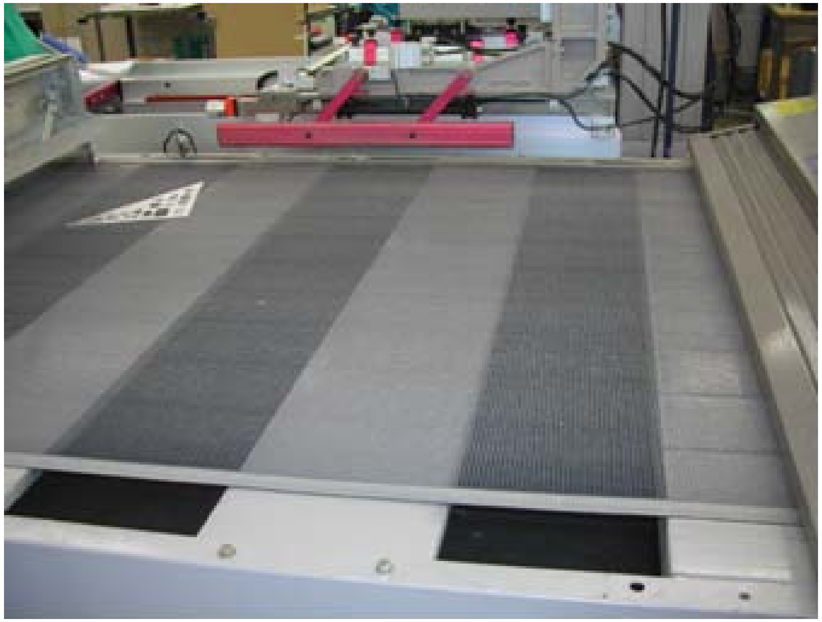
6. Theoretical Minimum Energy Use

Industrial Process Aluminum	Theoretical Minimum Energy Requirement (kWh (10[9])/year)	Total US Gross Energy Required (kWh (10[9])/year)	Theoretical Minimum Energy % of Actual	Authors
Alumina Refining	0.56	16.24	3.4%	
Anodes Production	9.77	21.86	44.7%	
Aluminum Smelting	22.41	116.36	19.3%	
Primary Casting	1.23	4.56	27.0%	
Secondary Casting	1.15	9.64	11.9%	
Rolling	1.76	6.66	26.4%	
Extrusion	0.75	2.59	29.0%	
Shape Casting	0.84	6.63	12.7%	
Total Aluminum Shape Casting	38.47	184.54	20.8%	Choate & Green
Steel	GJ/ton product	GJ/ton product		
Liquid Hot Metal	9.8	13.5	72.6%	
Liquid Steel (BOF)	7.9	11	71.8%	
Liquid Steel (EAF)	1.3	2.25	57.8%	
Hot Rolling Flat	0.03	2.2	1.4%	
Cold Rolling Flat	0.03	1.2	2.5%	Fruehan, et al.
Ammonia				
Ammonia Steam Reforming	21.6	35.5	60.8%	Worrell, et al.

Choate and Green (2003), Fruehan, et al. (2000), and Worrell, et al. (2000)

- 2.5% of primary energy used to provide energy services Ayers (1989)

TME: Parts on UV Curing Oven



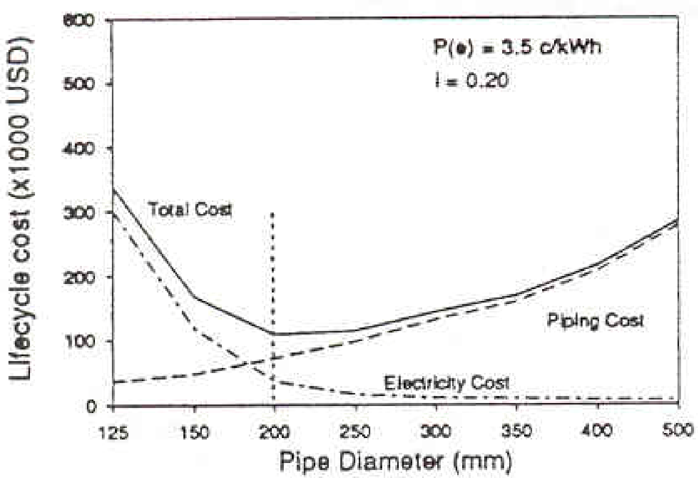
End Use	% Total
Light hitting conveyor belt	99.23%
Light hitting non-inked part	0.58%
Non-UV light hitting inked part	0.05%
UV light hitting inked part	0.14%
Total	**100%**

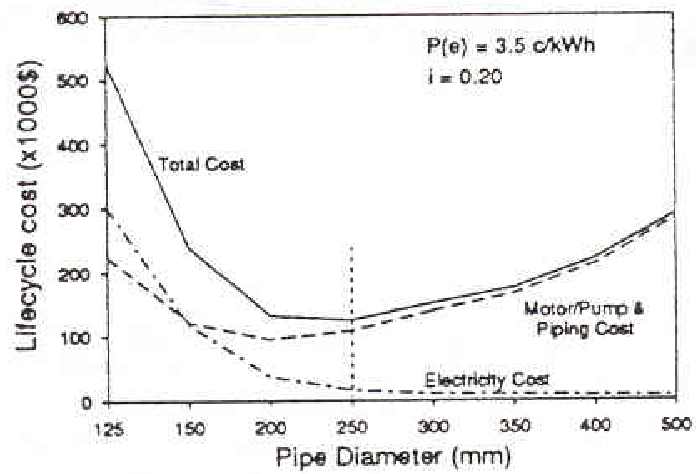
Slowed belt, shut of excess lamps, saved 50%

7. Whole-System Design

- Design heuristic derived from natural evolution
- Nothing evolves in a vacuum, only as part of a system
- No optimum tree, fan, …
- Evolutionary perspective: ‘optimum’ synonymous with ‘perfectly integrated’
- Optimize whole system, not components
- Design for whole time frame, next generation

Whole System Pumping
"Optimum Pipe Diameter"





- D_{opt} = 200 mm when Tot Cost = NPV(Energy)+Pipe
- D_{opt} = 250 mm when Cost= NPV(Energy)+Pipe+Pump
- $Energy_{250} = Energy_{200} / 2$

8. Whole-Time Frame Analysis:
“Efficiency Gap”

- “Numerous studies conclude 20% to 40% energy savings could be implemented cost effectively, but aren’t…..”

- Discrepancy between economic and actual savings potential called “efficiency gap”.

- Puzzled economists for decades: “I can’t believe they leave that much change lying on the table.”

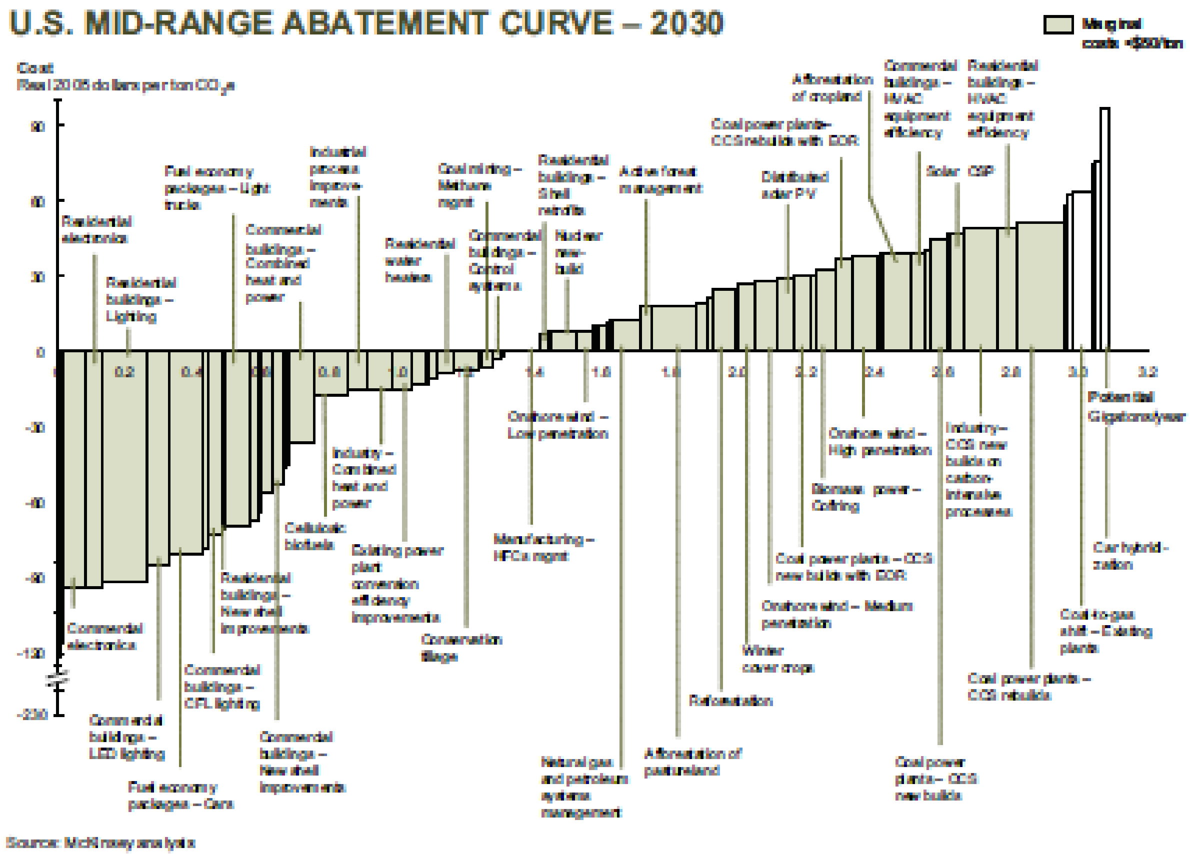
Whole Time Frame Accounting:
"Don't Eat Your Seed Corn"

- SP = 2 years (10 year life) is ROI = 49%
- SP = 5 years (10 year life) is ROI = 15%
- SP = 10 years (20 year life) is ROI = 8%

Integrated Systems and Principles Approach

– Global, applied to all manufacturing processes
– Can be taught and mastered in programs dedicated to energy efficency
– Build an ethic of energy/environmental awareness: “Rather do 100 kaizans that save 1 second each than 1 kaizan that saves 100 seconds.”

Leveraging Energy Efficiency to Pay for Renewable Energy

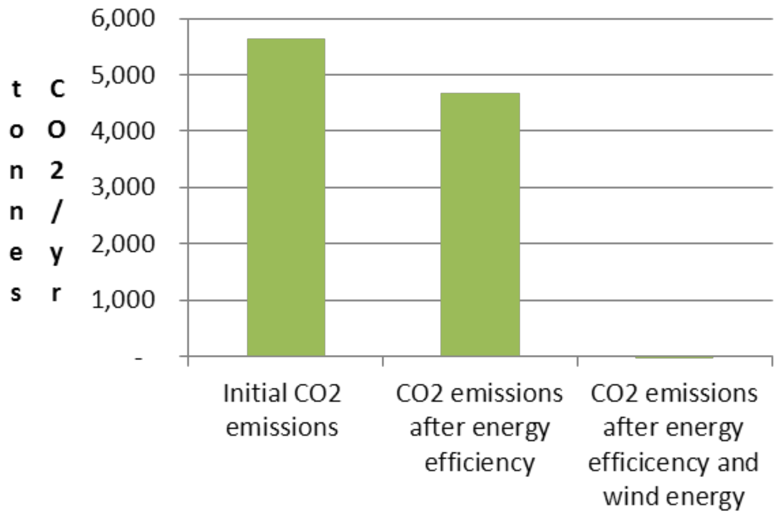


Reduce CO_2 by 20% at “Negative Cost”

Source: McKinsey and Company, December 2007

Eliminating Plant CO_2 Emissions at Zero Additional Cost

- CO_2 emissions = 5,642 t/yr
- ISPA savings
  = 17% at 2-year payback
- CO_2 emissions after ISPA
  = 4,683 t/yr
- Annualized ISPA savings
  = $78,000 /yr
- If ISPA invested in RECs at $0.015 /kWh, CO_2 savings = 4,746 t/yr
- Net zero CO_2 emissions at zero net cost



Conclusion

- Net-zero energy buildings
  - Solar array won't fit on roof of standard energy efficient house
  - Solar array easily fits on roof of energy efficient house
- Energy efficiency is essential to renewable energy
- Energy efficiency savings can drive renewable energy
- Can't wait for leadership from industry: "I want a faster horse!"

Thank you!