Overview of the Energy Supply Portfolio

J.W. Tester

Sustainable Energy

10.391J, 22.811J, ESD166J, …

Textbook readings: chapter 9, sections 7.1-7.2,and 8.1-8.3 plus important background in Chapters 1- 4 and 6

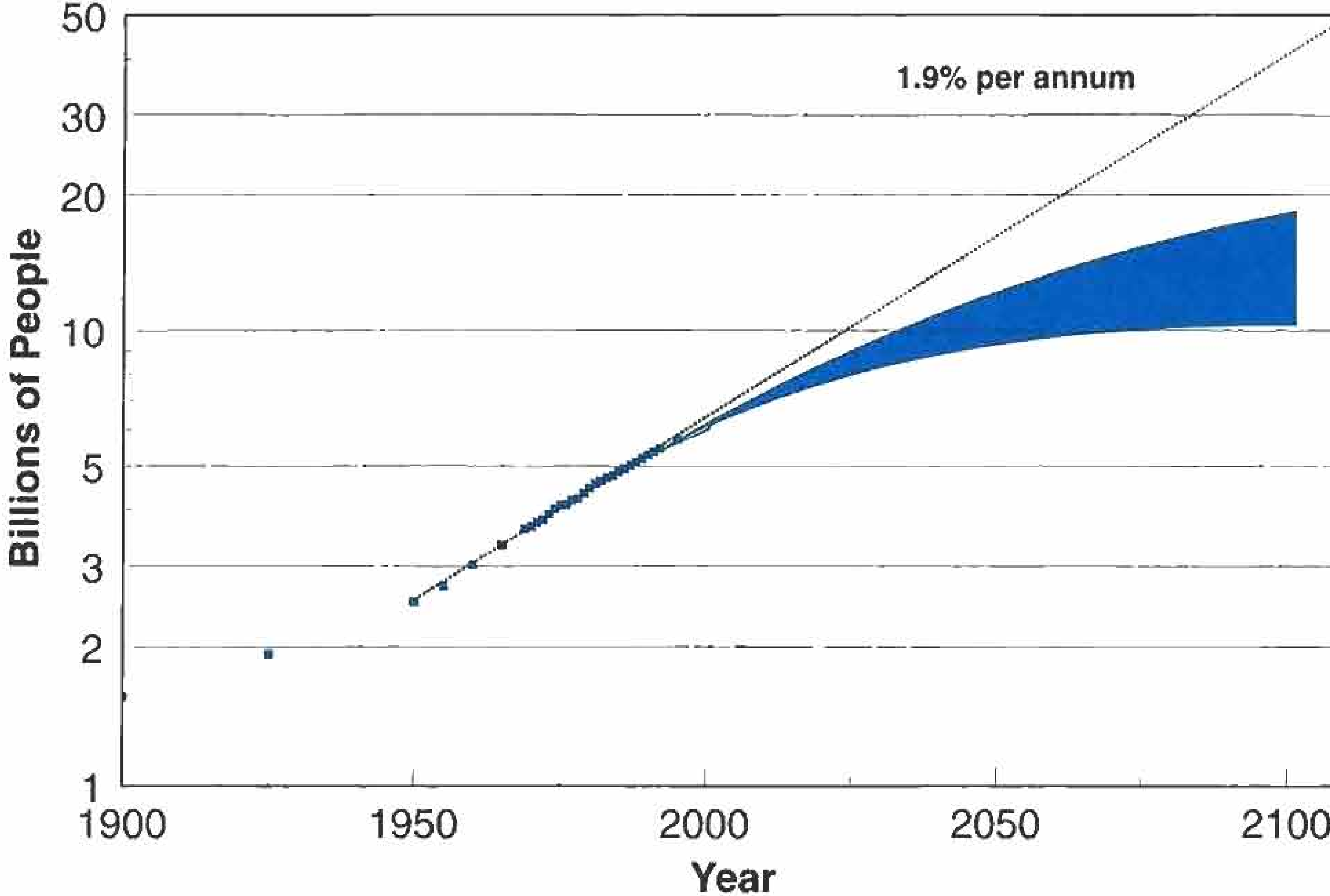
Overview of Our Energy Supply Portfolio

- Review of the current and projected demand for energy
- End-use energy forms and conversions
- Energy sources
- Scaling energy flows and prices on a common basis
- Energy chains and interconnectedness
- A portfolio of options
- Desirable characteristics addressing sustainability
- General energy resource characterization
  - Renewable versus depletable resources
  - Hubbert depletion curve for mineral resources
  - Uncertainities regarding discovery and technology
- Role of energy storage

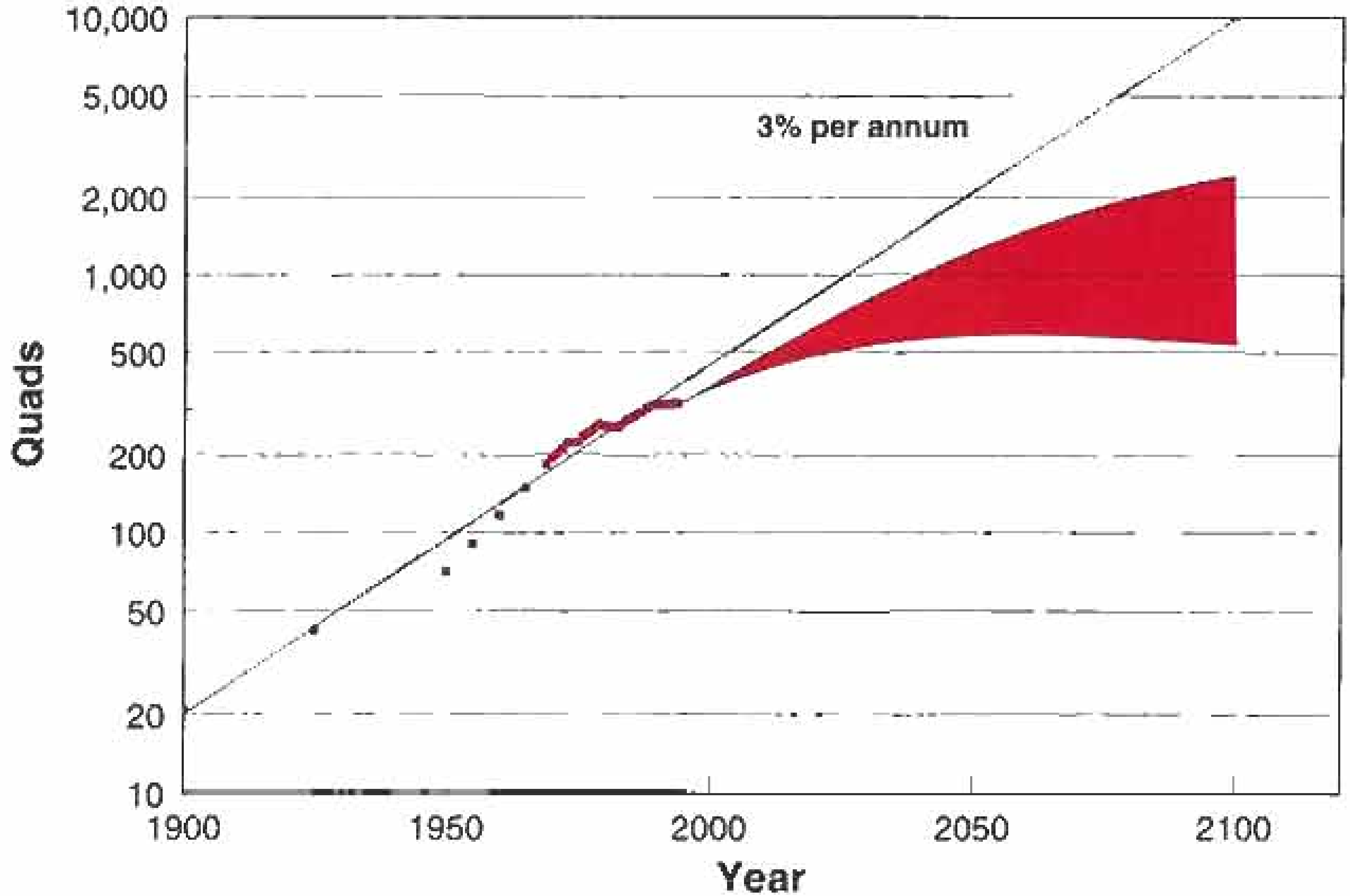
21^{st} Century Energy-Related Megatrends

- ❑ Increases in population lead to increasing demand for energy – significantly in LDCs, some in DCs
- ❑ Interest in developing indigenous energy resources grows
- ❑ Environmental and health concerns increase on all scales from local to global
- ❑ Increased electrification
- ❑ Infrastructure security concerns increase

Worldwide Population Growth



Worldwide Energy Consumption



Fundamental Global Issues
Dealing with reality

❑ population	6,000,000,000
❑ land area	58,000,000 sq miles
❑ population density	100+ people/sq mile
❑ annual energy consumption	400 Quads
- oil equivalent	72,000,000,000 bbl
- coal equivalent	14,400,000,000 tonnes
❑ registered car and trucks	700,000,0000
❑ electric generating capacity	3,000,000 MWe
❑ annual steel production	650,000,000 tonnes
❑ annual aluminum production	20,000,000 tonnes
❑ annual cement production	1,500,000,000 tonnes

Progressing toward an asymptotic world ?

- Population - 6+ billion growing to 10 to15+ billion
- Total primary energy –
  400 quads growing to 2000+ quads annually
  73 billion growing to 365+ billion bbl of oil/yr
- Per capita energy per year –
  10 BOE/yr-person growing to 25 BOE/yr-person
- Number of cars and trucks -
  750 million now growing to 5 + billion
- MW electric generating capacity -
  3.5 million MWe now growing to 15+ million MWe

Other Fundamental Global Issues

- Carbon emissions may be affecting climate
- Health concerns over other emissions are growing
- Global fossil energy resources are not uniformly distributed

The Big Energy Questions

- Can we satisfactorily reduce emissions and remediate wastes residing in our water and air basins?
- Can we offset changes being introduced by our consumption of fossil fuels?
- Can we significantly reduce our dependence on imported oil?
- Can nuclear, renewable, and other non-fossil energy resources be deployed quickly enough to make a difference?

U.S. energy goals are focused maintaining a secure energy supply

" We need to inoculate ourselves against the risks of a disrupted energy supply due to deliverability constraints or price instabilities. Therefore, having a robust set of alternative sources of indigenous energy will provide such protection and increase our energy security"

J.W. Tester – testimony at a joint USDOE/DOI hearing in Washington DC, November 2001

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Some policy makers might interpret this goal as a quest for sustainable energy!!

U.S. energy goals are not currently focused on carbon management!

- Increase homeland security – requires increased energy infrastructure security
- Reduce dependence on imported oil
- Increase energy system performance
  - more efficient per unit of output
  - more robust -- flexible, reliable and durable
  - more distributed
  - lower environmental impacts -- cleaner
  - lower cost.

Green is becoming a favorite color

- green power
- green chemistry
- green buildings
- green schools
- green electrons

New performance paradigms are emerging

- zero emissions power plant
- zero emissions chemical plant
- zero (net) energy building
- zero emissions vehicle (ZEV)

Practical implementation of new performance standards requires full life cycle accounting (LCA)

End use energy forms

- Thermal
- Electrical
- Electromagnetic
- Chemical
  - fuels for transportation
  - fuels for industrial processes
- Electrochemical
- Mechanical (KE or PE) for power

Primary Energy Sources

- Nuclear fission and fusion
- Solar radiation
- Chemical reactions, e.g. combustion of fossil and biomass fuels
- Gravitational forces, planetary motion, and friction

Energy conversions and equivalences

1 BTU = 1055 Joules or J = 778 ft-lbs = 252 cal
1 watt or W = 1 J/s = 3.41 BTU/hr
1 horsepower or hp = 550 ft-lbs/s = 746 W
1 kWh = 3.61 million J = 3413 BTU

1 quad = 10^{15} BTU
1 exaJoule = 10^{18} J = 4 days of US energy use

1 burning match = 1000 J

Energy density scaling

1 bbl oil = 42 gallons = 5.6 x 10^6 BTU = 5.9 x10^9 J

1 bbl hot water cooled by 100 deg C =
8900 BTU = 9.4 million J = 0.00159 bbl of oil

1 bbl of cold water raised 100 feet high
contains about 42 BTU = .00000753 bbl of oil

Energy rate scaling

- food - ---------------------------------- 250 kcal/candy bar
- average daily requirement ---------- 2000-3000 kcal/day = 100 W
- human heart -------------------------------- 2 W
- running -- 500 W
- 1 horsepower ---------------------------------- 750 W
- 747 jet plane ---------------------------------- 250 MW
- automobile ------------------------------------ 100 kW
- space shuttle (with boosters) ----------------------- 1 (14)GW
- Typical electric generating plant ---------- 1000 MW
- 1 wind turbine ---------------------------------- 1-3 MW
- laptop computer ---------------------------- 10 W
- cell phone ------------------------------------- 2 W

US energy consumption per year -----------
100,000,000,000,000,000,000 J or 3.5 TW
Worldwide energy consumption per year ------
400,000,000,000,000,000,000 J or 15 TW

Our terawatt (TW) society

US energy consumption per year -----------
100,000,000,000,000,000,000 J = 100 Quads

Worldwide energy consumption per year ------
400,000,000,000,000,000,000,000 J = 400 Quads

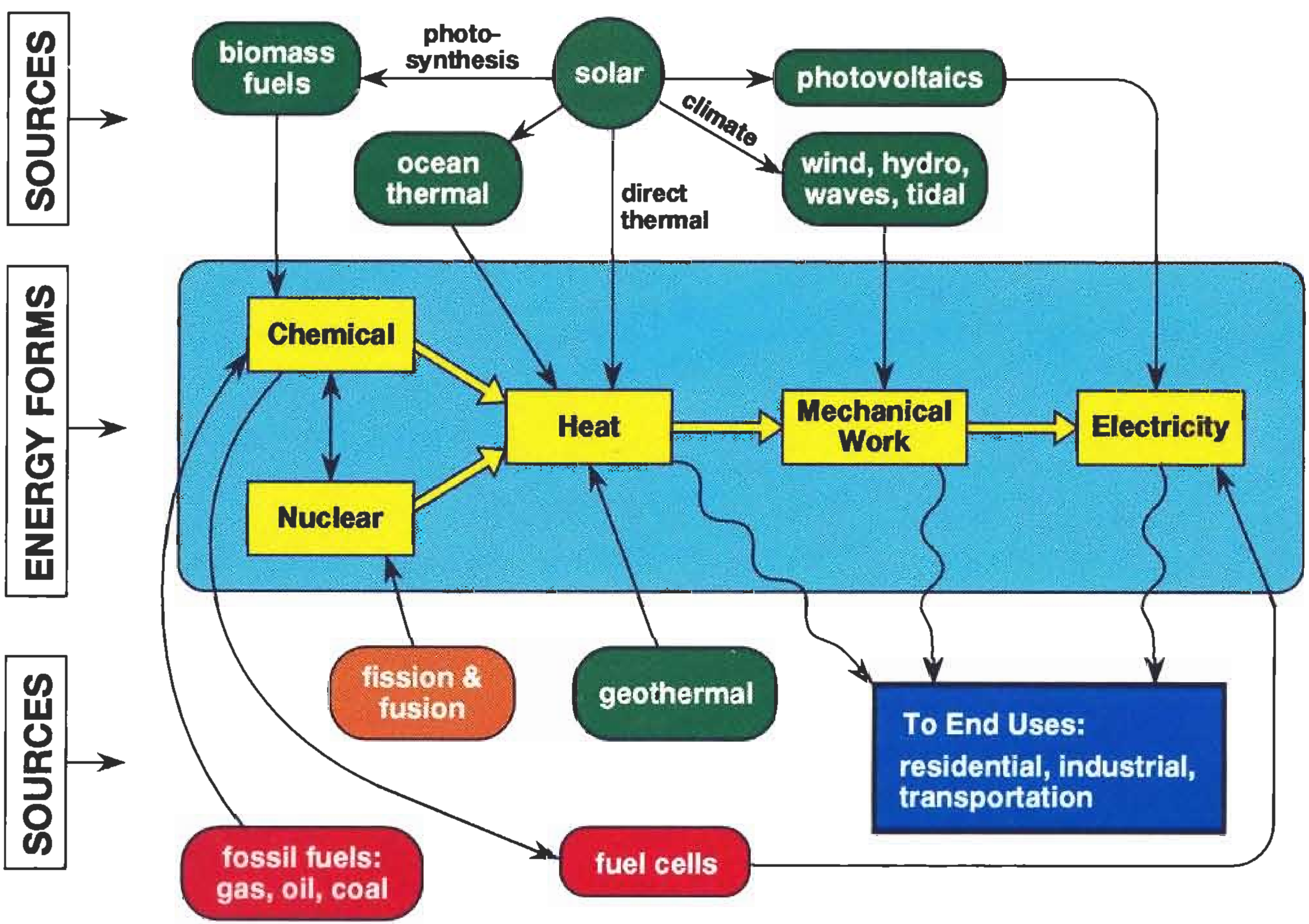
Sustainable Energy Technology Characteristics

- **Non-depletable** on a short time scale
- **Low impacts on natural resources --** land, water, etc., across process life cycle
- **Accessible and well distributed** – available close to demand
- **Emissions free** – no NO_x, SO_x, CO_2, particulates, etc.
- **Scalable** – from 1 kW to 1000 MW (t or e)
- **Dispatchable** - for base load, peaking, and distributed needs
- **Robust** - simple, reliable, durable and safe to operate
- **Flexible** - applications for electricity, heat, and cogen
- **Competitive economically**

Energy Supply Options

- Earth based energy
  - conventional fossil fuels (coal, oil, natural gas)
  - unconventional fossil fuels (oil shale, tar sands)
  - nuclear fission – uranium, etc.
  - hydropower (also from solar)
  - geothermal heat
- Ocean based energy
  - tidal
  - waves
- Solar based energy
  - solar thermal
  - photovoltaics
  - wind
  - biomass

ENERGY SOURCES AND CONVERSION PROCESSES

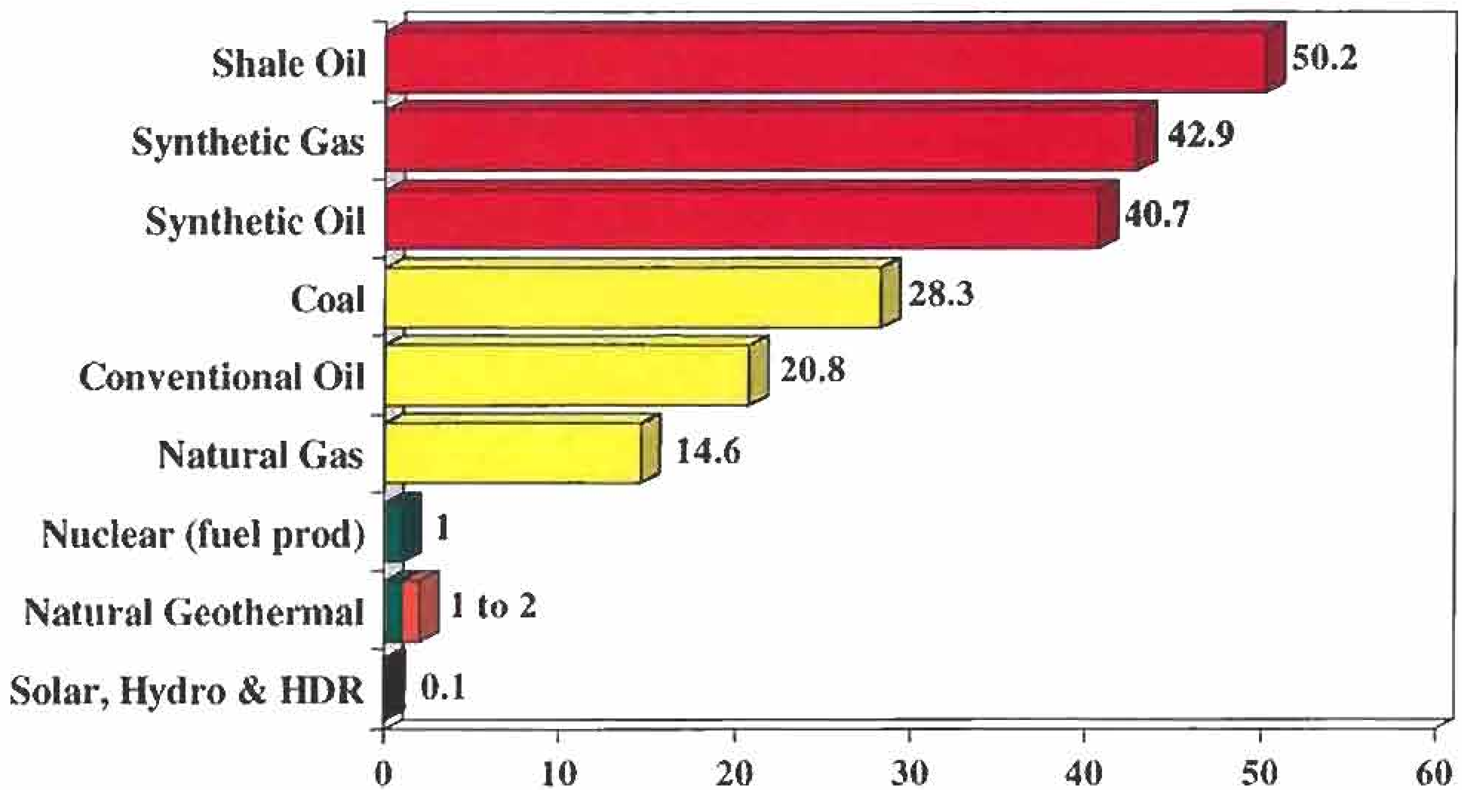


21st Century US Energy Supply Options
Quality Assessment Matrix

Resource Type

Attribute (scale of -10 to +10)	Oil	Gas	Coal	Oil Shale	Fission	Fusion	Solar	Wind	Hydro	Biomass	HDR
1. Resource Size											
2. Resource Grade											
3. Continuous Supply Capability											
4. Storage Needs											
5. End Use Adaptability											
6. Gaseous Emissions											
7. Particulate Emissions											
8. Solid & Liquid Wastes											
9. Land Use											
10. Life Cycle Impact											
11. Adaptable to 1-100 MW Sizes											
12. System Complexity											
13. Safety Concerns											
14. Use of Strategic Materials											
15. Transferable Technology											
16. Economic Projections											
17. State of Development											
18. R&D Needs (Time and $)											
Total Quality Index Σ (1-18)											

Millions of Tons of Carbon (as CO_2) Emitted per Quad



MIT Energy Lab, 1997

Pacala and Socolow of Princeton have proposed a program to reduce CO2 emisions by 1 billion metric tons per year – or 25 billion tons over the 50-year period.

Proposed 15 different programs - any seven of which could achieve the goal:

1. Efficient vehicles - increase fuel economy from 30 to 60 mpg for 2 billion vehicles.
2. Reduce use of vehicles - Improve urban design to reduce miles driven from 10,000 to 5,000 miles per year for 2 billion vehicles.
3. Efficient buildings - reduce energy consumption by 25%.
4. Improve efficiency of coal plants from today's 40% to 60%.
5. Replace 1,400 gigawatts of coal power plants with natural gas.
6. Capture and store carbon emitted from 800 gigawatts of new coal plants
7. Capture and reuse hydrogen created by #6 above.
8. Capture and store carbon from coal to synfuels conversion at 30 million barrels per day.
9. Displace 700 gigawatts of coal power with nuclear.
10. Add 2 million 1 megawatt windmills (50 times current capacity).
11. Displace 2,000 gigawatts of coal with solar power (700 times current capacity)
12. Produce hydrogen fuel from 4 million 1 Megawatt windmills
13. Use biomass to make fuel to displace oil (100 times current capacity)
14. Stop de-forestation and re-establish 300 million hectares of new tree plantations
15. Conservation tillage - Apply to all crop land (10 times current usage.)

(see August 13, 2004 issue of Science)

Fossil and Nuclear Options

- **Fossil** – oil and gas resources are depletable and maldistributed worldwide and carbon sequestration will be costly and not a permanent solution
- **Fissile** – no carbon emissions but wastes, proliferation and safety remain as dominant public acceptance issues
- **Fusion** – technology not ready with uncertain costs and performance

Renewable energy technologies have high sustainability index scores

- Solar
- Wind
- Biomass
- Geothermal
- Hydro

Renewable energy technologies have high sustainability index scores

- ❑ Solar
- ❑ Wind
- ❑ Biomass
- ❑ Geothermal
- ❑ Hydro

But, costs relative to fossil fuels remain high

Where do we go from here ?

Photos depicting various fuel sources removed for copyright reasons.

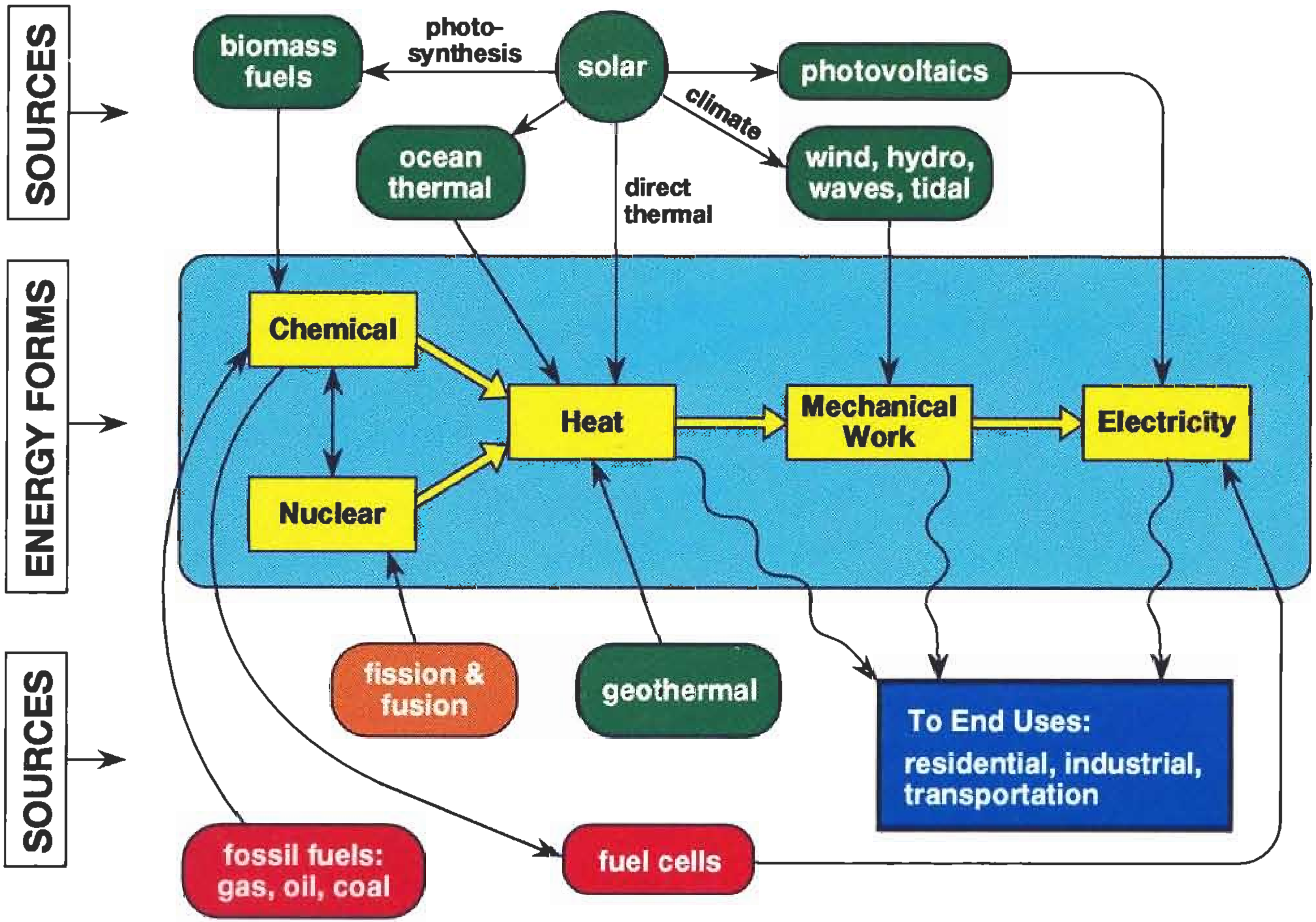
Playing by the rules

- The 1st and 2nd Laws of thermodynamics are relevant
- Heat and electric power are not the same
- Conversion efficiency does not have a single definition
- All parts of the system must work – fuel supply, fuel and energy converters, control and monitoring sub systems, and the interconnection if required

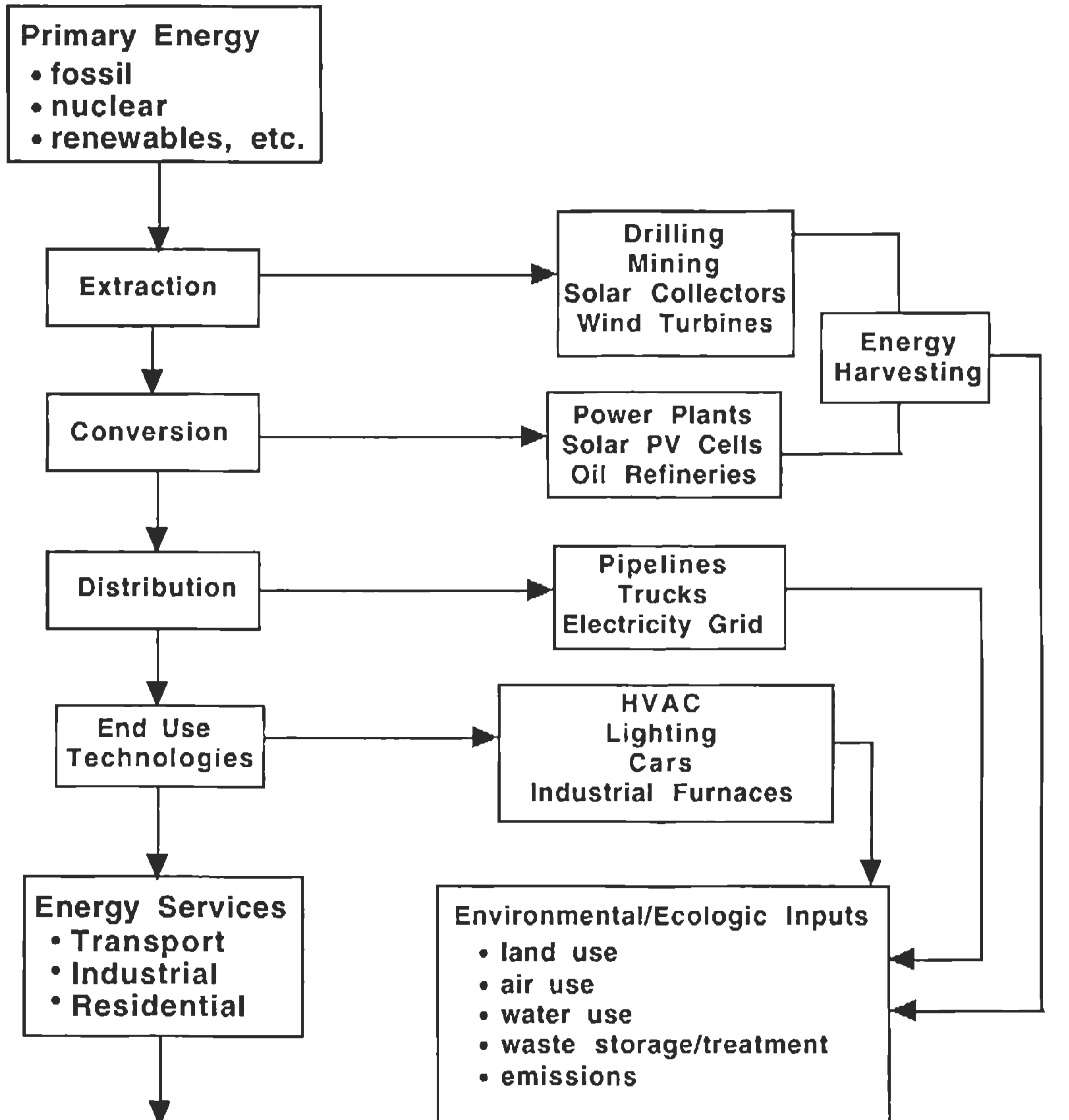
Seek collateral,win-win opportunities

1. Combined heat and power to increase resource utilization efficiency
2. Integrated high efficiency building designs
3. Hybrid energy use with distributed generation
4. Manufacturing processes that use less materials and energy

ENERGY SOURCES AND CONVERSION PROCESSES



Energy System Components



Energy chains – a connected path of steps from “cradle to grave” (LCA)

1. Locating a source – solar, fossil, geothermal, nuclear
2. Recovery and/or capture
3. Storage of a depletable resource, or storage due to the intermittency of a renewable energy supply
4. Conversion, upgrading, refining, etc.
5. Storage as a refined product
6. Transmission and distribution
7. Use and reuse
8. Dissipation as degraded energy an/or wastes

Overall LCA efficiency is the product of the efficiency of each step

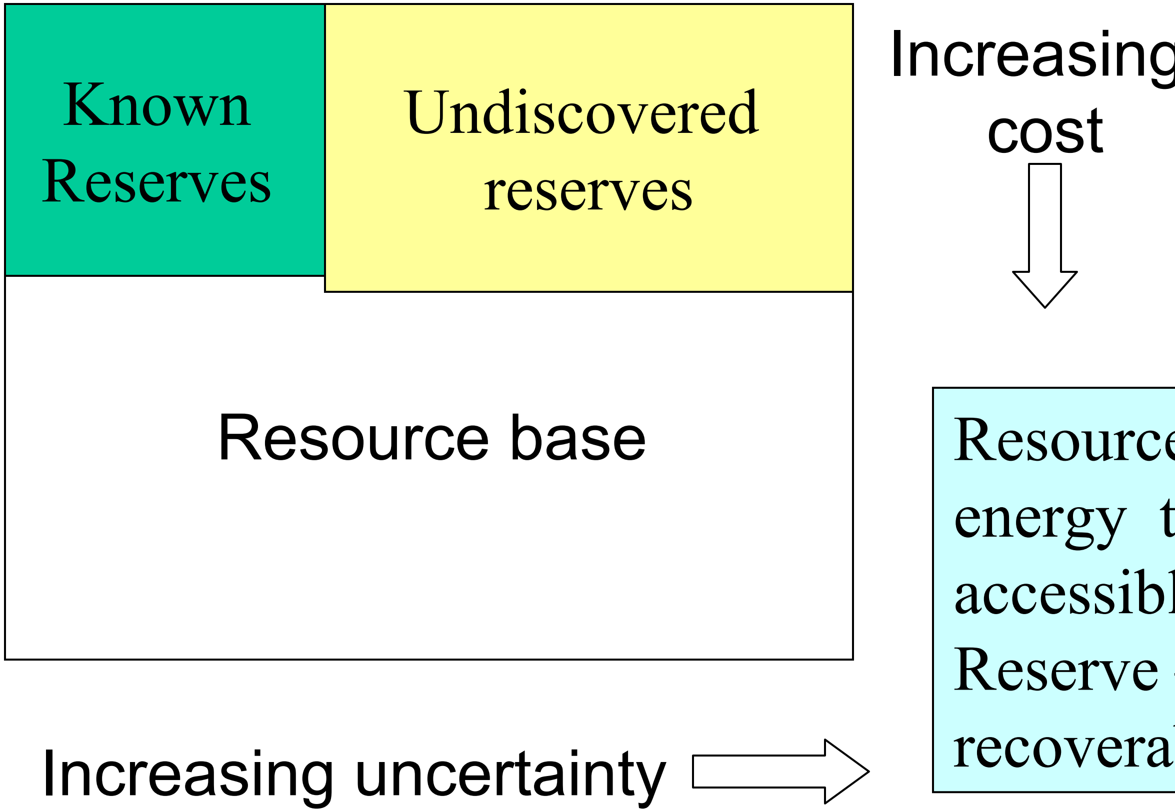
Resource Assessment

Global energy resources are not uniformly distributed and vary widely in quality!!!

- ❑ Characterization inadequate for developed countries and very poor for developing countries
- ❑ Energy resource bases and energy reserves are not the same
- ❑ New technology enhancements exist to significantly improve resolution and quantification of assessments
- ❑ Resource assessment is under-valued and under-supported nationally and internationally

Quantifying Resource Quality

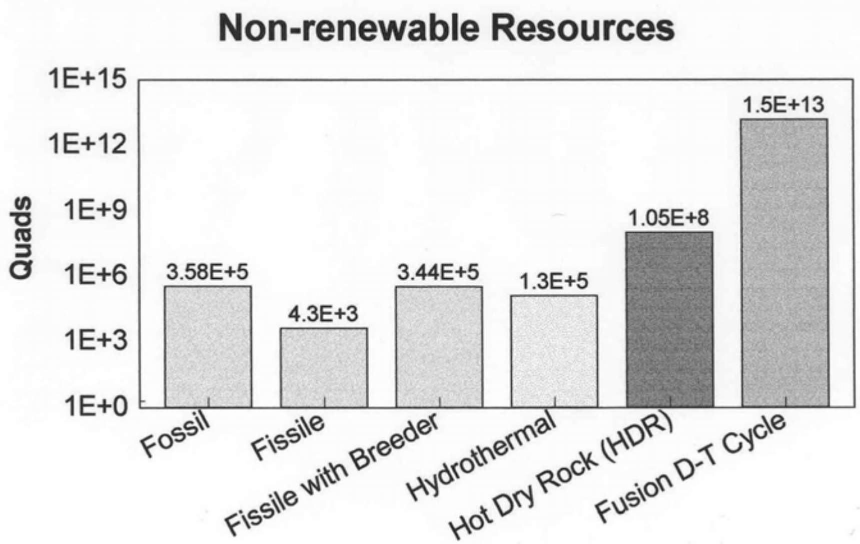
McKelvey diagram

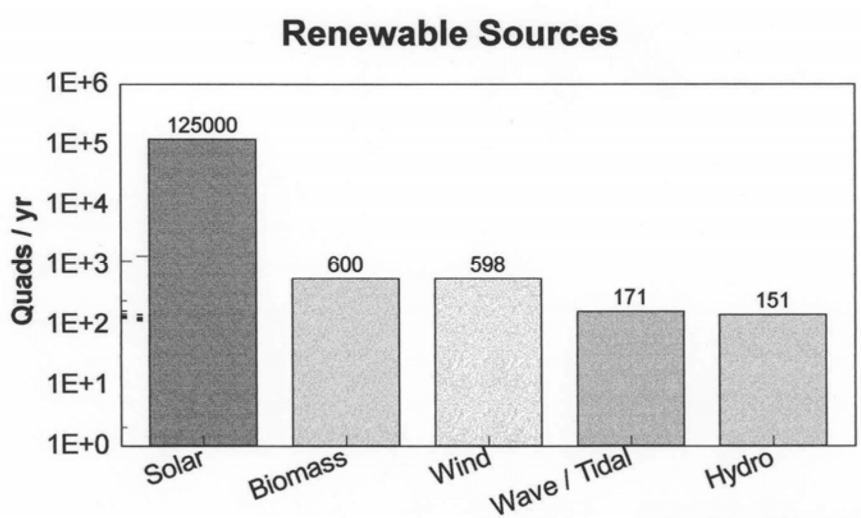


Resource base – total energy technically accessible

Reserve – economically recoverable portion

Global Resource Bases





MIT Energy Lab, 1996

Estimating resource bases is highly uncertain –

(i) for mineral- based resources like oil, gas, and coal – dependence on technology and has limited data.

(ii) for renewables land-use and capture efficiency are critical

Quantifying depletion – the Hubbert curve

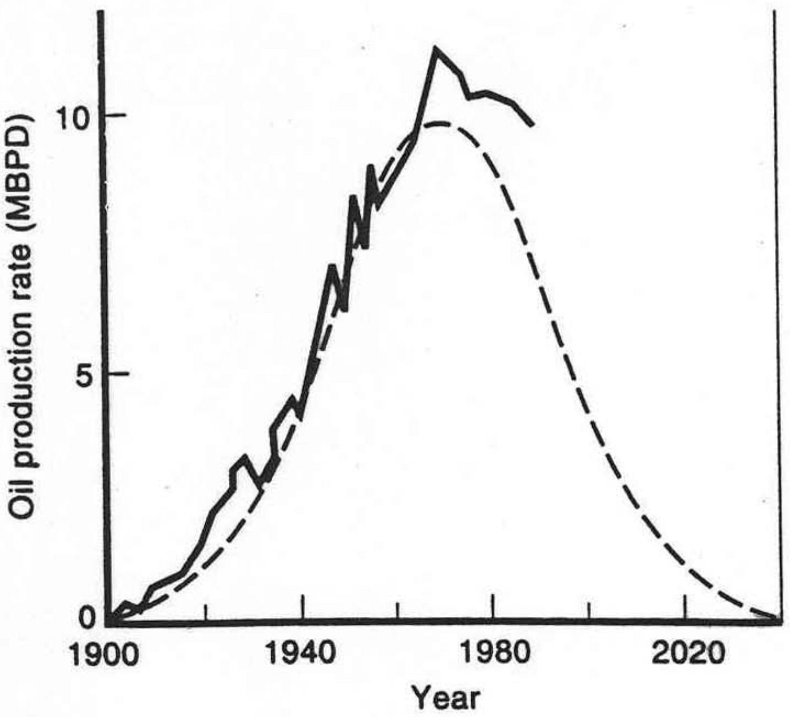
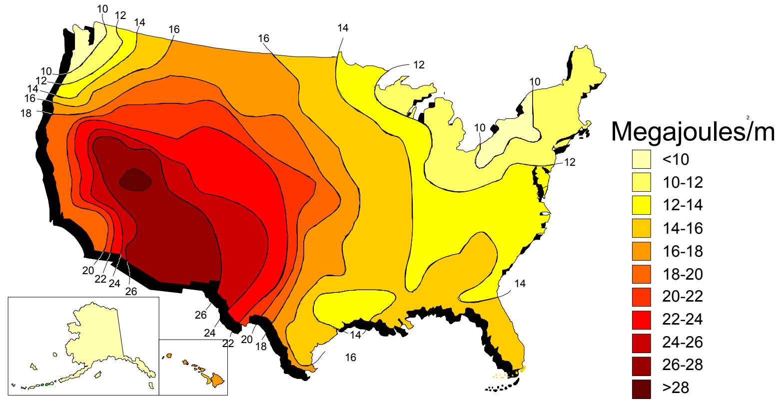


FIGURE 1–12

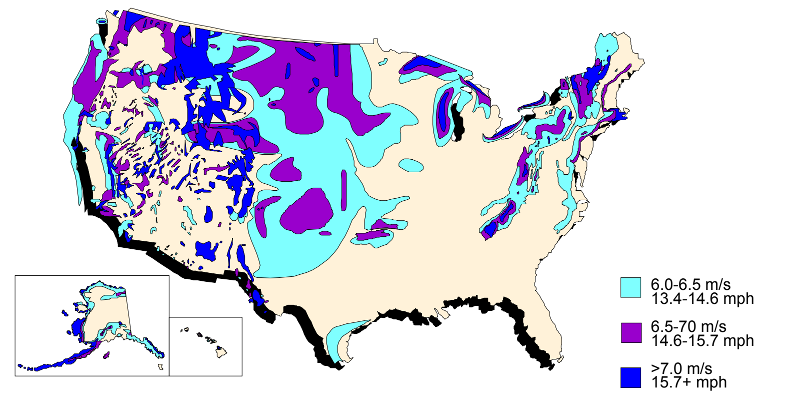
United States crude oil production. Comparison of estimated (Hubbert) production curve and actual production (solid line).

U.S. Renewable Energy Resource Assessment

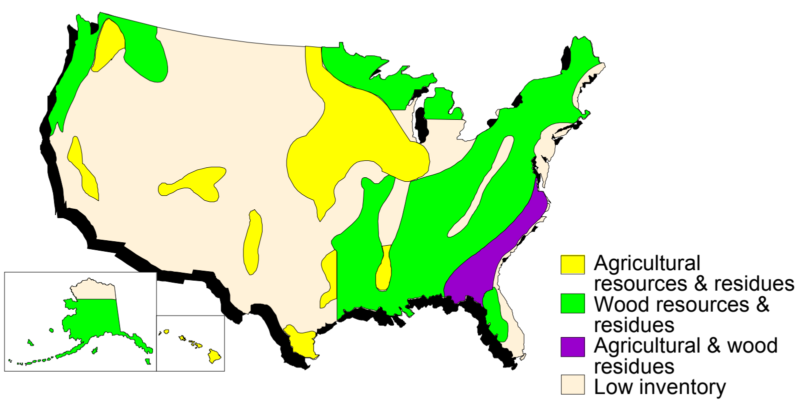
Solar



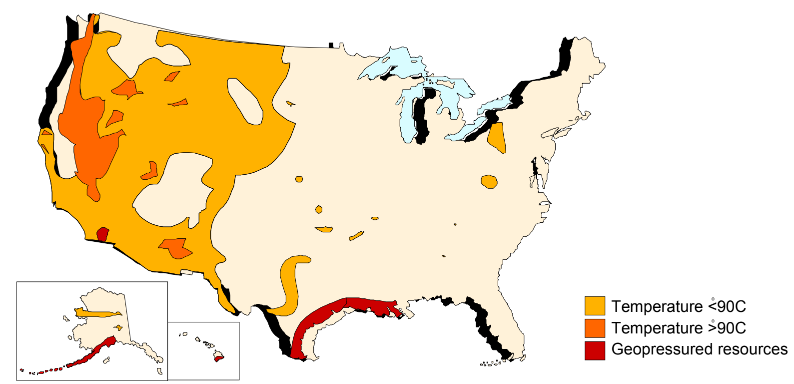
Wind



Biomass



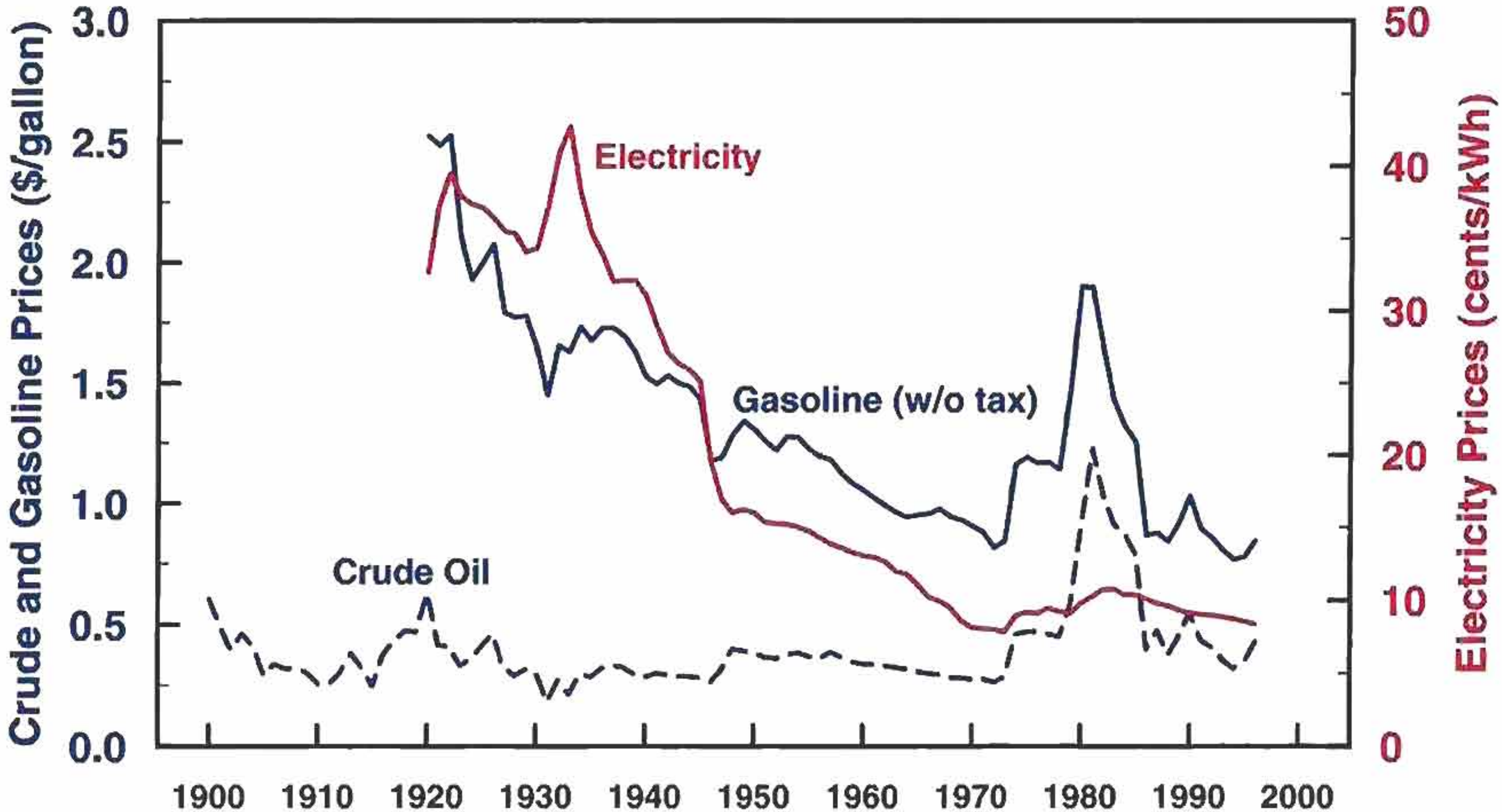
Geothermal



Courtesy of NREL.

Do you understand the difference between price and cost ??

Historical Energy Prices (1900 - 1996)
(1996 Dollars)



Data courtesy of M. Lynch, 1997

Price versus cost versus value

- 1 liter of gasoline = $ 0.50
- 1 liter of gasoline without tax = $0.35
- 1 liter of liquid hydrogen = $0.85
- 1 liter of bottled water = $1.00
- 1 liter of milk = $1.50
- 1 liter of orange juice = $ 3.00
- 1 liter of Dom Perignon 1995 = $150.00
- 1 liter Ralph Lauren aftershave = $ 450.00
- 1 liter of Chanel #5 perfume = 12,000.00

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Also be aware of hidden costs
including those for environmental damages