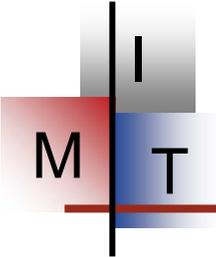
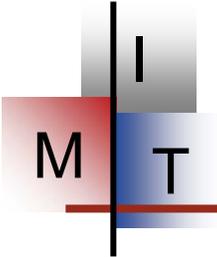


What is Energy ?

- $\frac{1}{2} mv^2$
 - mgh
 - $P_{\text{ext}} \Delta V$
 - $C_v \Delta T$
 - I^2R
 - $h\nu$
 - mc^2
-
- **a 2 trillion dollar per year global industry**



*How much energy do we use
each year?*



How much energy do we use each year?

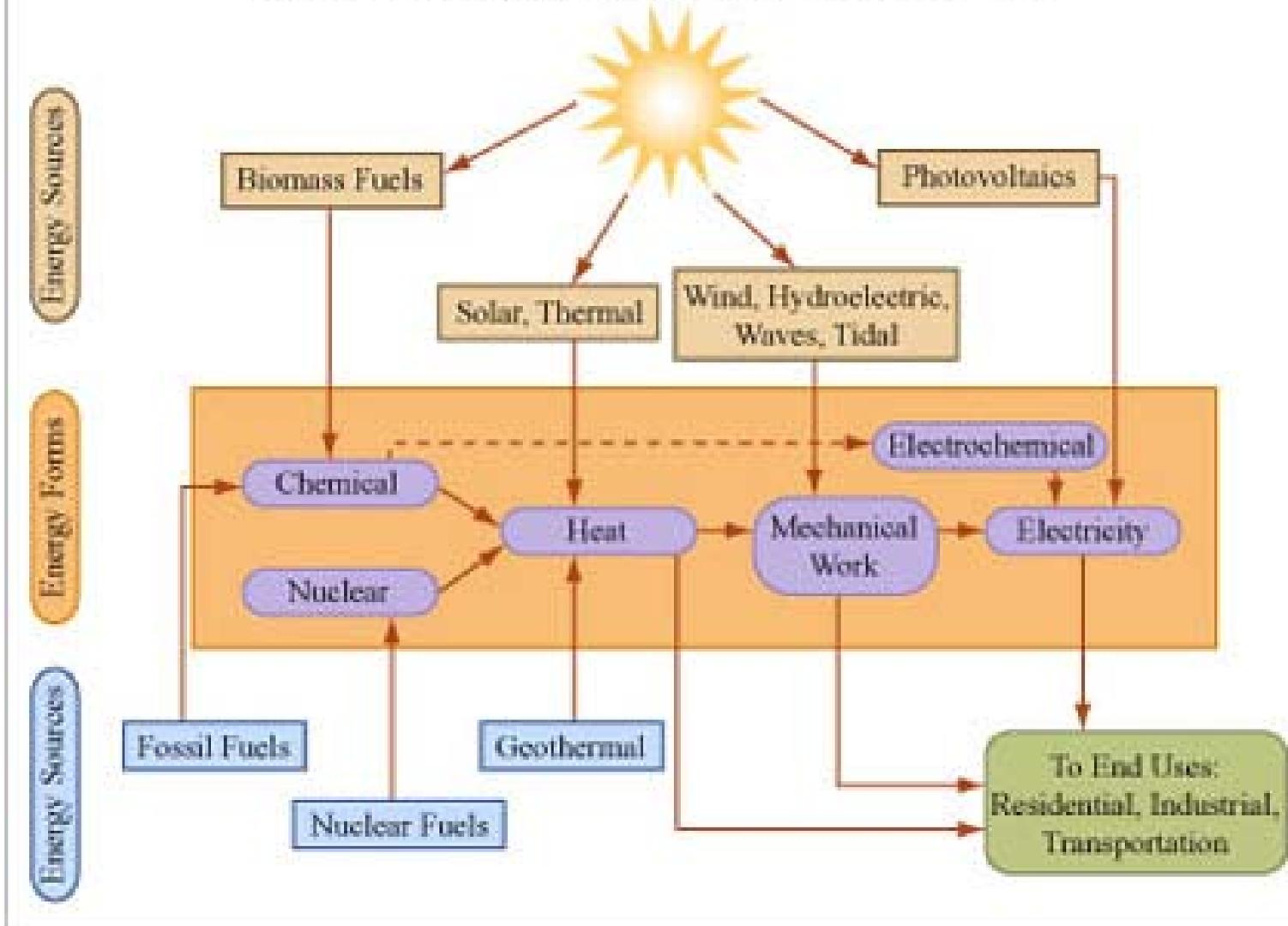
**~ 400,000,000,000,000,000,000 Joules/year
(116,000,000,000,000 Kilowatt-hours / year)**

1 Watt = 1 Joule used per second

12.8 TeraWatts

**Global average = 2000 Watts per person
(24 hrs/day, 365 days/year)**

Energy Sources, Conversions and Use



(Image by MIT OCW)

The issues:

- **Increasing energy demand by increasing population**
- **Associated CO₂ emissions and accumulation**
- **Depletion of petroleum and other resource reserves**
- **1.6 billion people without access to electricity or other forms of “clean” energy**
- **Energy-related security challenges, including**
 - **uneven distribution of resources (the Tenth Commandment does not apply!)**
 - **vulnerability to threats and natural disasters**
 - **geopolitical instability and tensions**
 - **nuclear weapons proliferation**

What are our options for meeting the world's energy needs and reducing GHG emissions?

Hydropower: 0.7 ~ 2.0 TW ... *if we dam all remaining rivers on earth*

Nuclear: ~ 8 TW ... *if we build and commission one new nuclear power plant every two days for the next 45 years*

Wind: 2.1 TW ... *if we place windmills everywhere that the mean wind speed exceeds 5.1 m sec^{-1} at 10 m above the ground*

Biomass: 7 ~ 10 TW ... *if the entire arable land mass is used to grow crops for energy, not for food*

Solar: 120,000 TW of radiant energy is intercepted by the Earth ... *this is 10,000 times the energy we actually use but it is dispersed and intermittent*

-- D. Nocera, *Dædalus*, Fall 2006, p. 112 – 115

Geothermal: 15 million exaJ stored energy in US alone (J. Tester) corresponds to 500,000 Terawatt-years ... *if technologically and economically feasible*

Energy efficiency and conservation are essential — *but improvements in efficiency are usually overwhelmed by increases in consumption (bigger cars, bigger homes, more computers, etc.)*

Fusion? Solar collectors in space? *And what about hydrogen???*

The nature of “the energy problem”

(J.P. Holdren, AAAS Past President; Director, Woods Hole Research Center)

- **Few people, other than energy specialists, are interested in Exajoules, or terawatts, or quads ...**
- **We are interested in *energy services*:**
 - **comfortable rooms, cold beer soda, warm food, convenient transportation, web access 24/7, ...**
- **But all of us are interested in**
 - **the state of the economy *and our piece of it*;**
 - **the state of the environment *and our piece of it*;**
 - **our personal and national security.**

**This translates into concern about energy choices
*if those put any of these values at risk.***