Energy Balances and Constraints

Or $dU(S,V,n_i) = TdS - pdV + \sum_i \mu_i dN_i$

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Agenda for Intensive

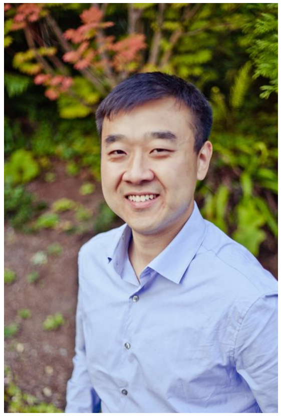
AM

- Introductions
- Energy Balance
- Niagara Falls Case Study

PM

- The Utility Business Model
- Team Formation and Term Project
- General Q&A

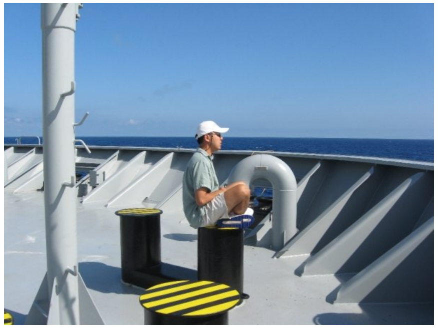
Hi! - Jimmy



- CEO, Distributed Energy Management
- Chair, MIT Enterprise Forum of the Northwest

- Territory Manager, Olympus
- Associate Engineer, Panasonic

- BS, MS, MIT Material Science
- MBA, Oxford University



- Energy pervades everything we do.
- How should we interact with it?

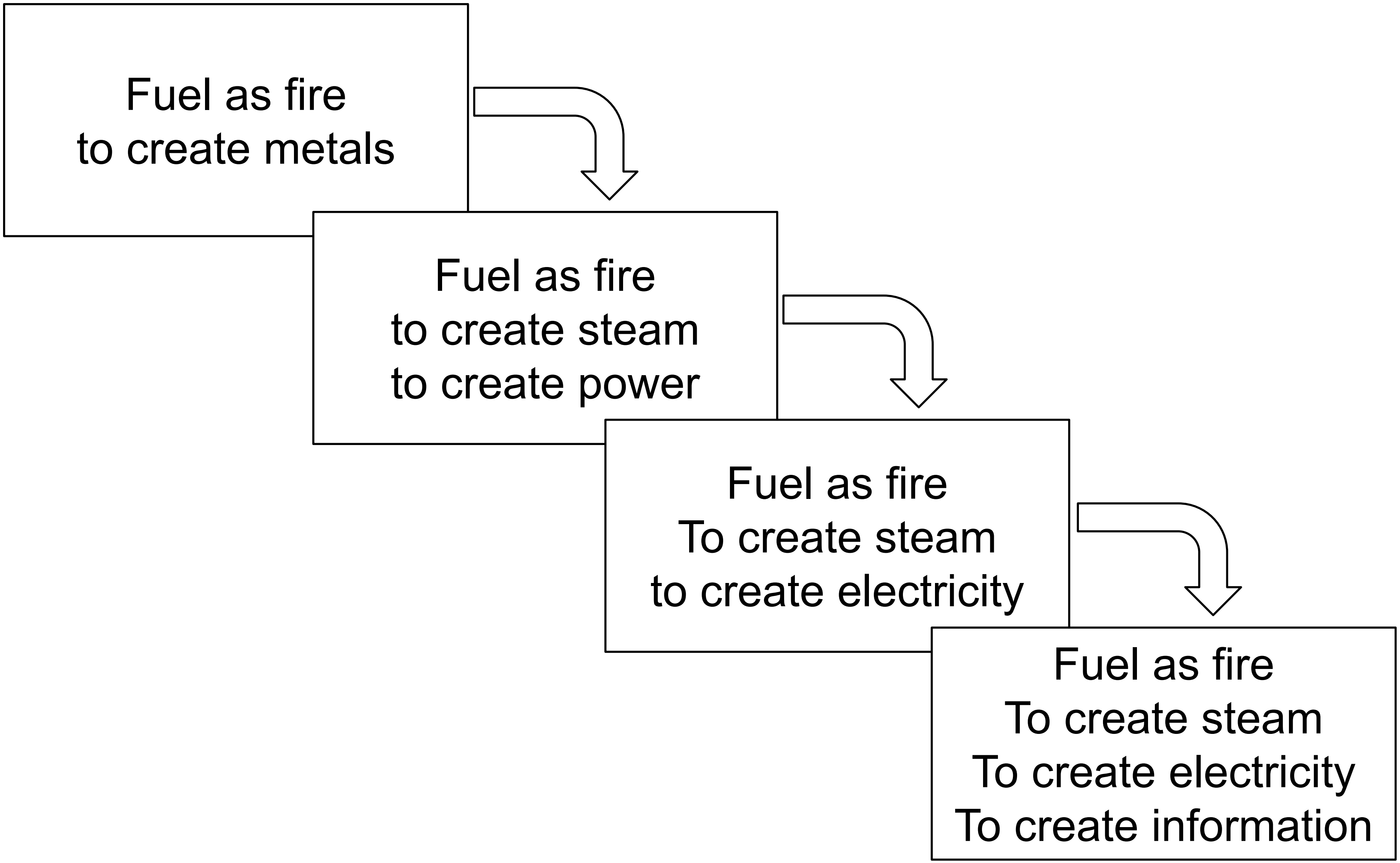
Introductions

- What do you do?
- A quandary or a question that the world faces
- How energy may/may not impact that issue
- How you wish to contribute to that answer

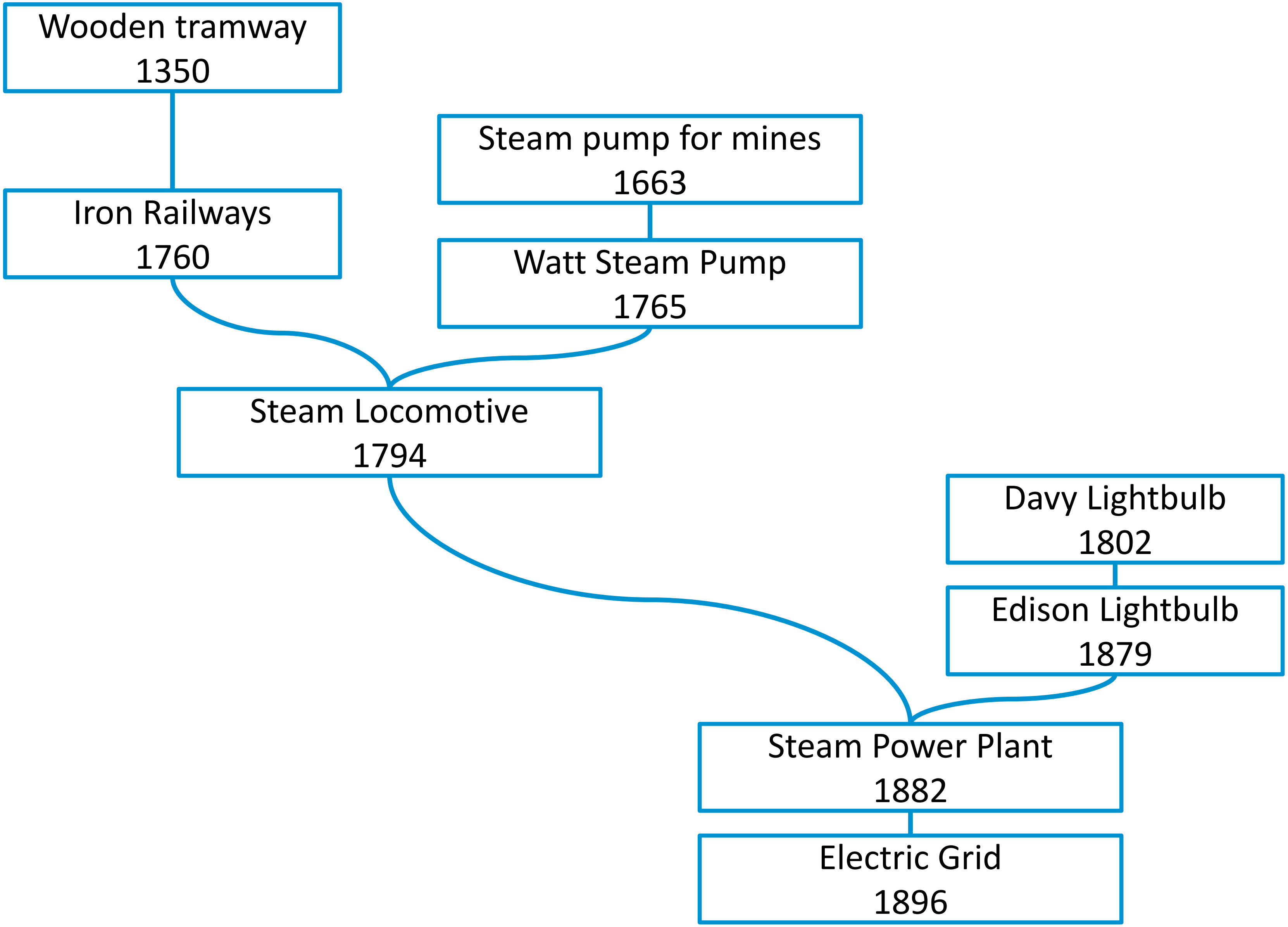
Historical timeline – the need for high temperatures

Ages of Man	Metallurgical	Fuel	Technology
Stone Age 1.5M BCE – 2400 BCE	N/A	Hunter-Gather	Human
		Agriculture	Animals
		300 ^{o}C Wood	350 ^{o}C Campfire
			800 ^{o}C Pit Kiln
Bronze Age 3000 BCE – 1500 BCE	850 ^{o}C Bronze	2000 ^{o}C Oil	1000 ^{o}C Bloomery
Iron Age 1300 BCE – 500 AD	1538 ^{o}C Iron	2000 ^{o}C Coal	2000 ^{o}C Blast Furnace

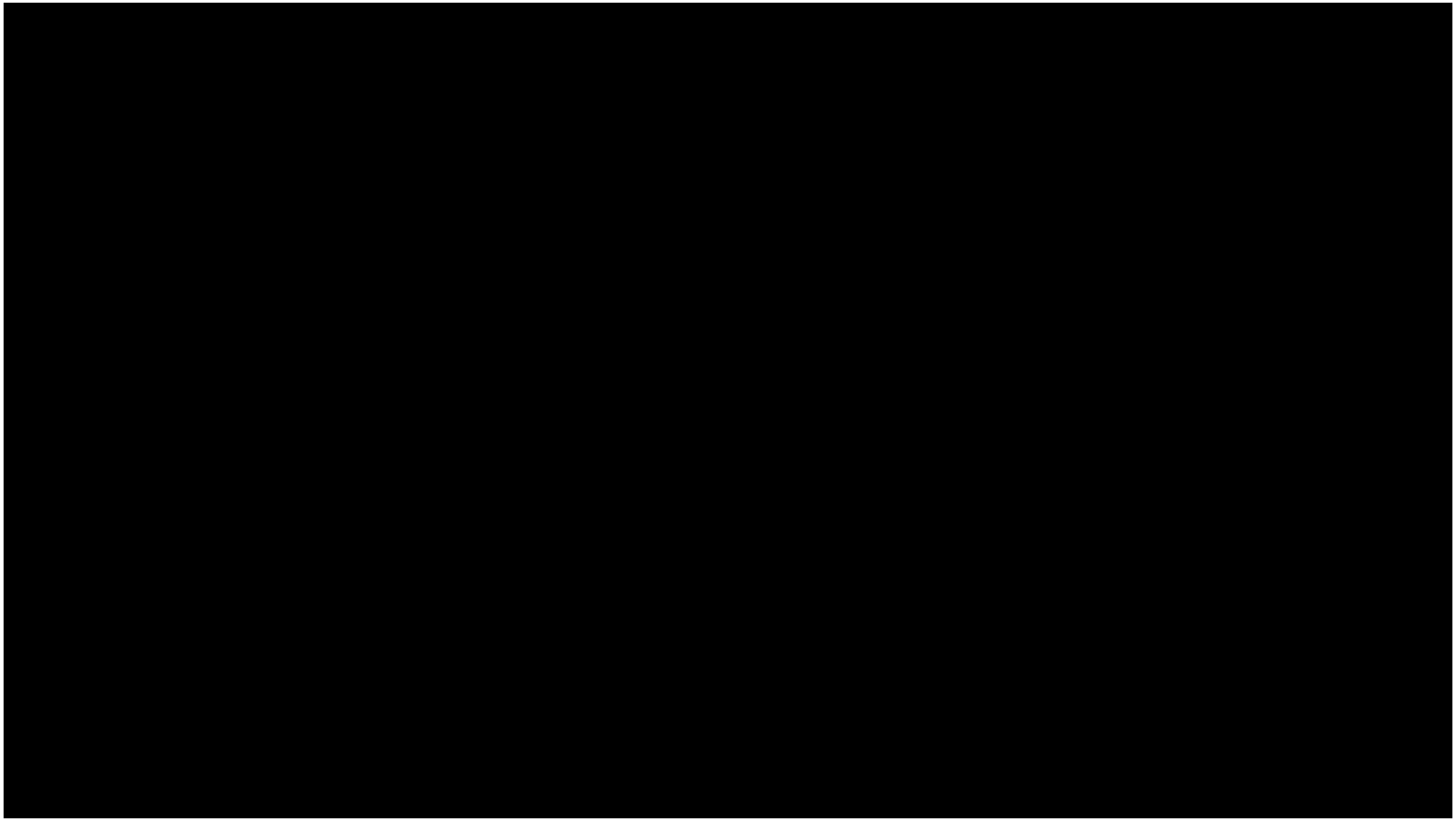
Evolution of energy consumption in society



Need → manual → automation



Is this how we relate to energy?



http://www.youtube.com/watch?v=BVxOb8-d7Ic

What the Greeks thought

- Energy (Ancient Greek: ἐνέργεια *energeia* "*activity*, operation")

- an indirectly observed quantity that is often understood as the ability to *do* Work.

- Work is the ability of one physical object to *move* a second physical object.

<u>Energy is never stationary</u>

Forms of Energy

Light

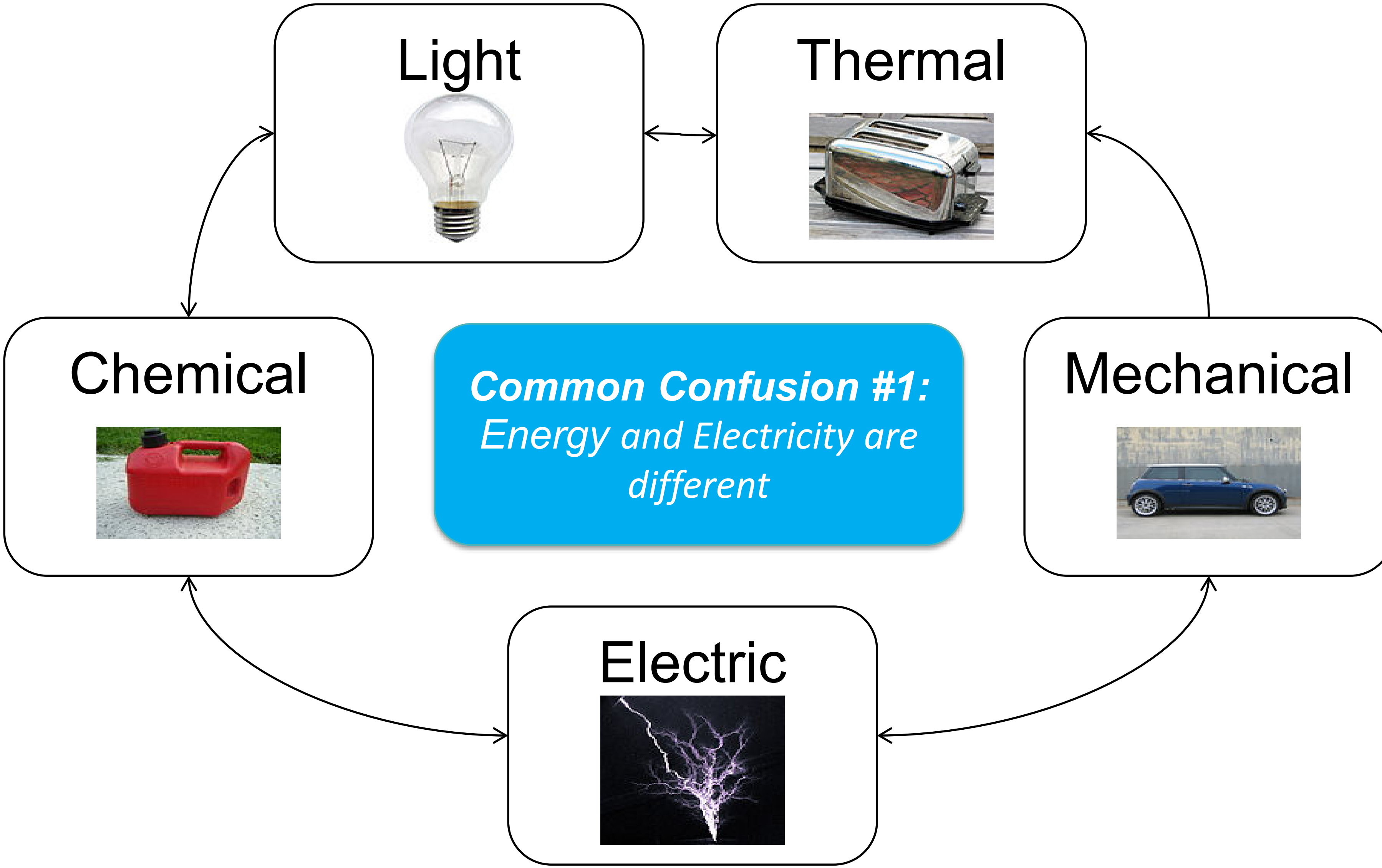
Thermal

Chemical

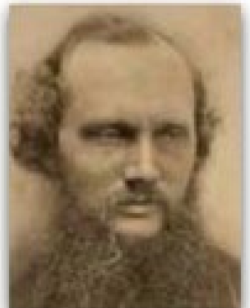
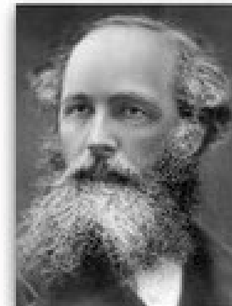
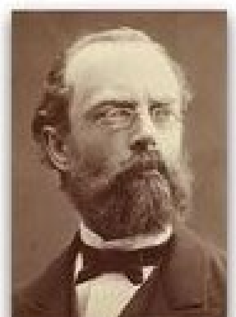
Mechanical

Electric

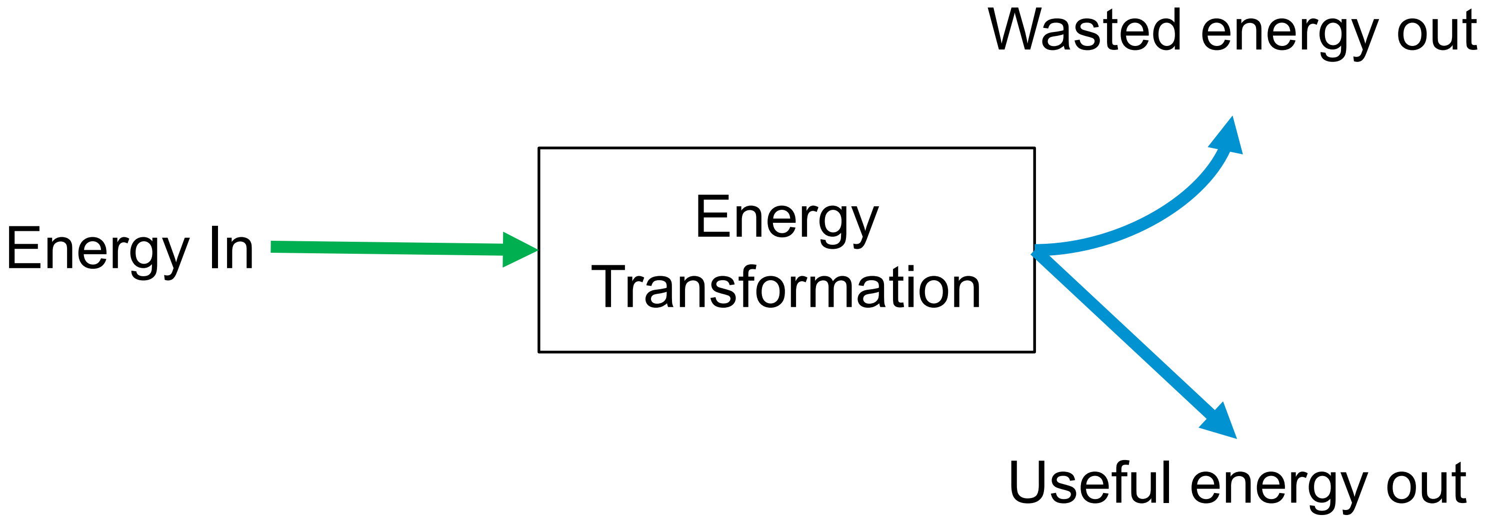
Forms of Energy



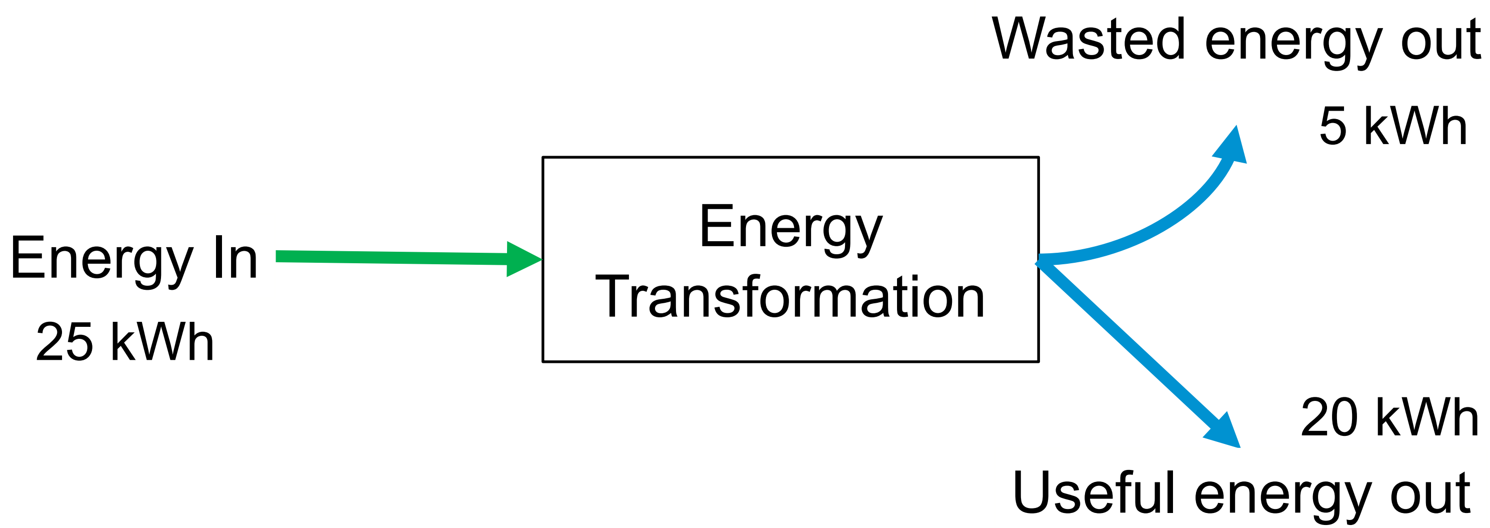
Three laws of thermodynamics

École Polytechnique	Glasgow school	Berlin school	Edinburgh school
 Sadi Carnot (1796-1832)	 William Thomson (1824-1907)	 Rudolf Clausius (1822-1888)	 James Maxwell (1831-1879)
Vienna school	Gibbsian school	Dresden school	Dutch school
 Ludwig Boltzmann (1844-1906)	 Willard Gibbs (1839-1903)	 Gustav Zeuner (1828-1907)	 Johannes der Waals (1837-1923)

The three laws of thermodynamics

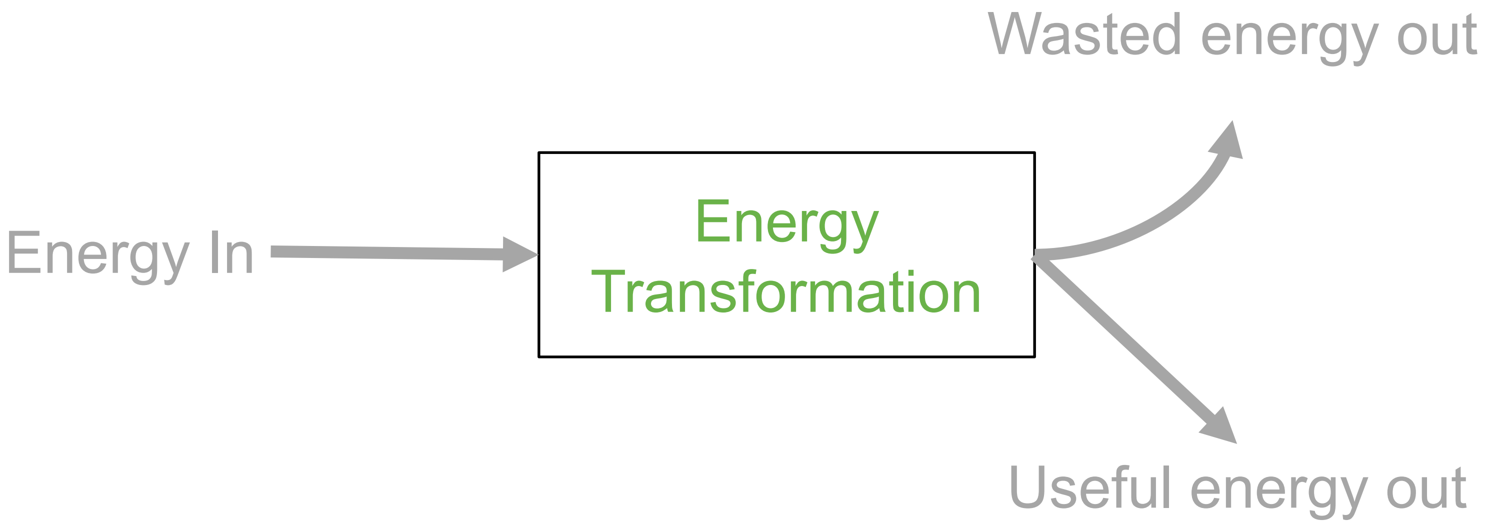


First Law: Energy must always be in balance



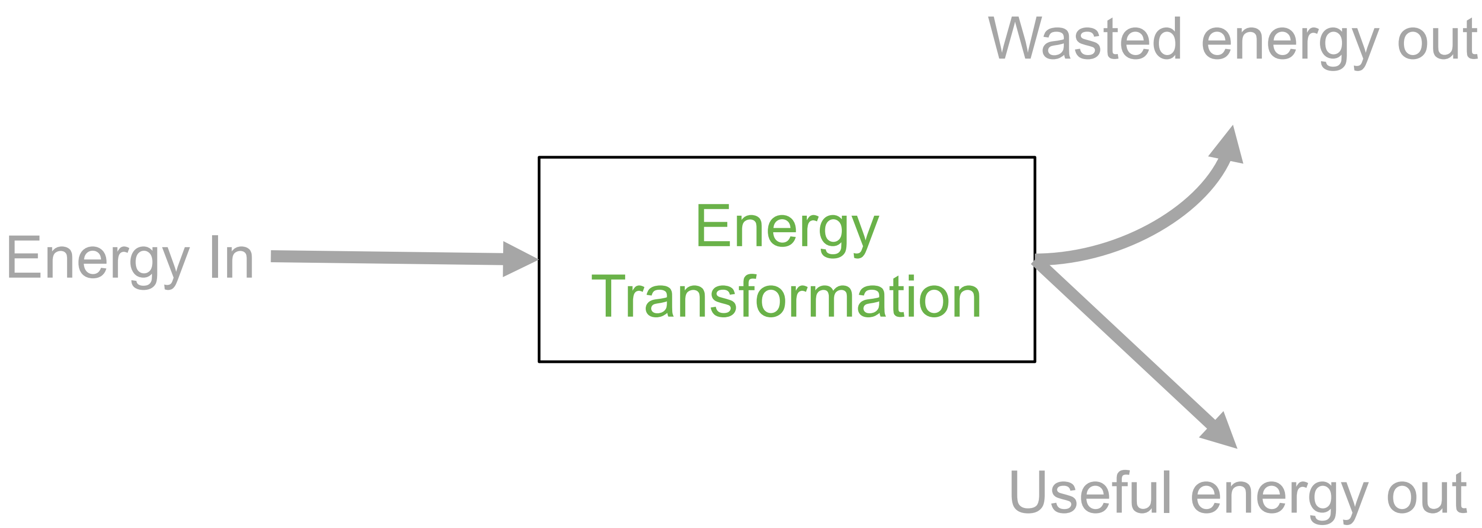
(Energy in) == (Useful energy out) + (Wasted energy out)

Second Law: We transform energy between forms

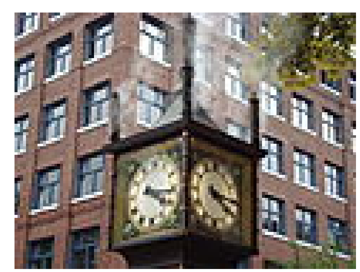


From	With	To
Light	Solar Cell	Electricity
Electricity	Stove	Heat
Petroleum	Engine	Motion

Transformations need dedicated machinery

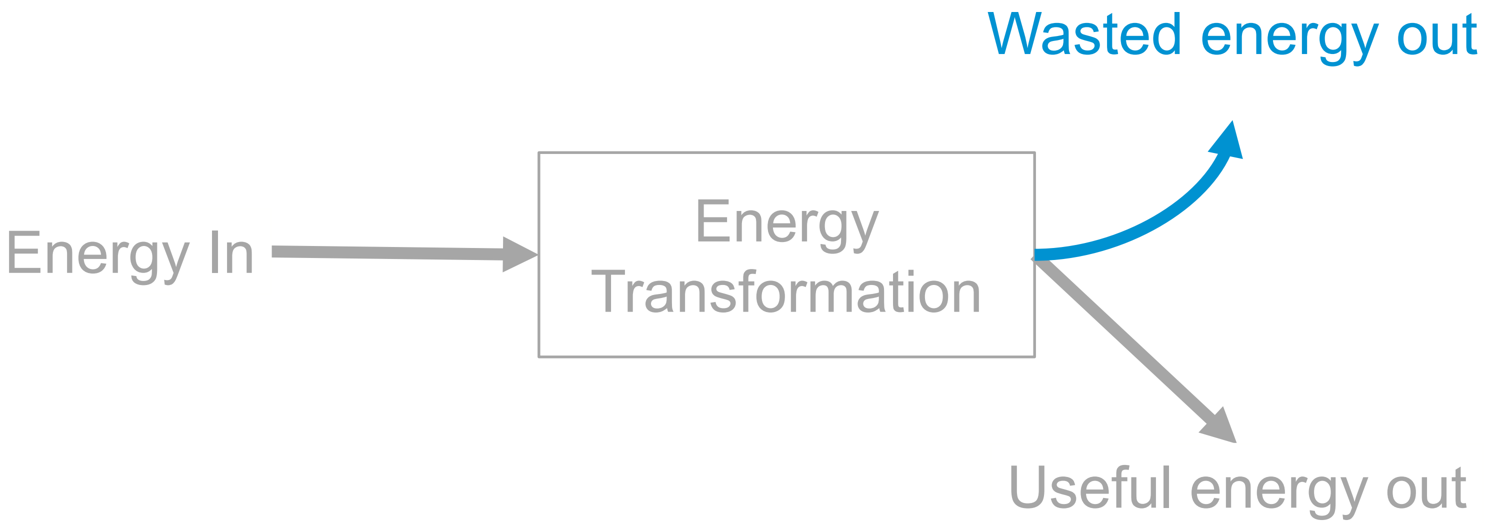


Steam Engine



Steam Clock

Third Law: There will always be loss



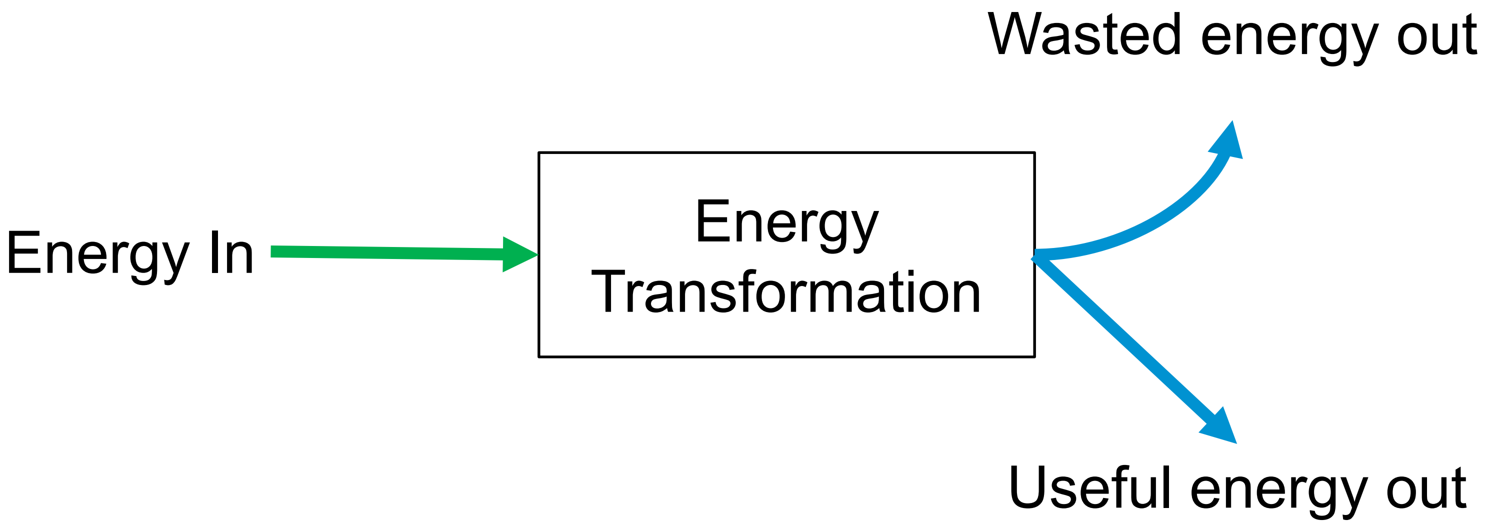
$$\frac{\textbf{Useful Energy Out}}{\textbf{Energy In}} = \textbf{Efficiency}$$

Common Devices that Convert

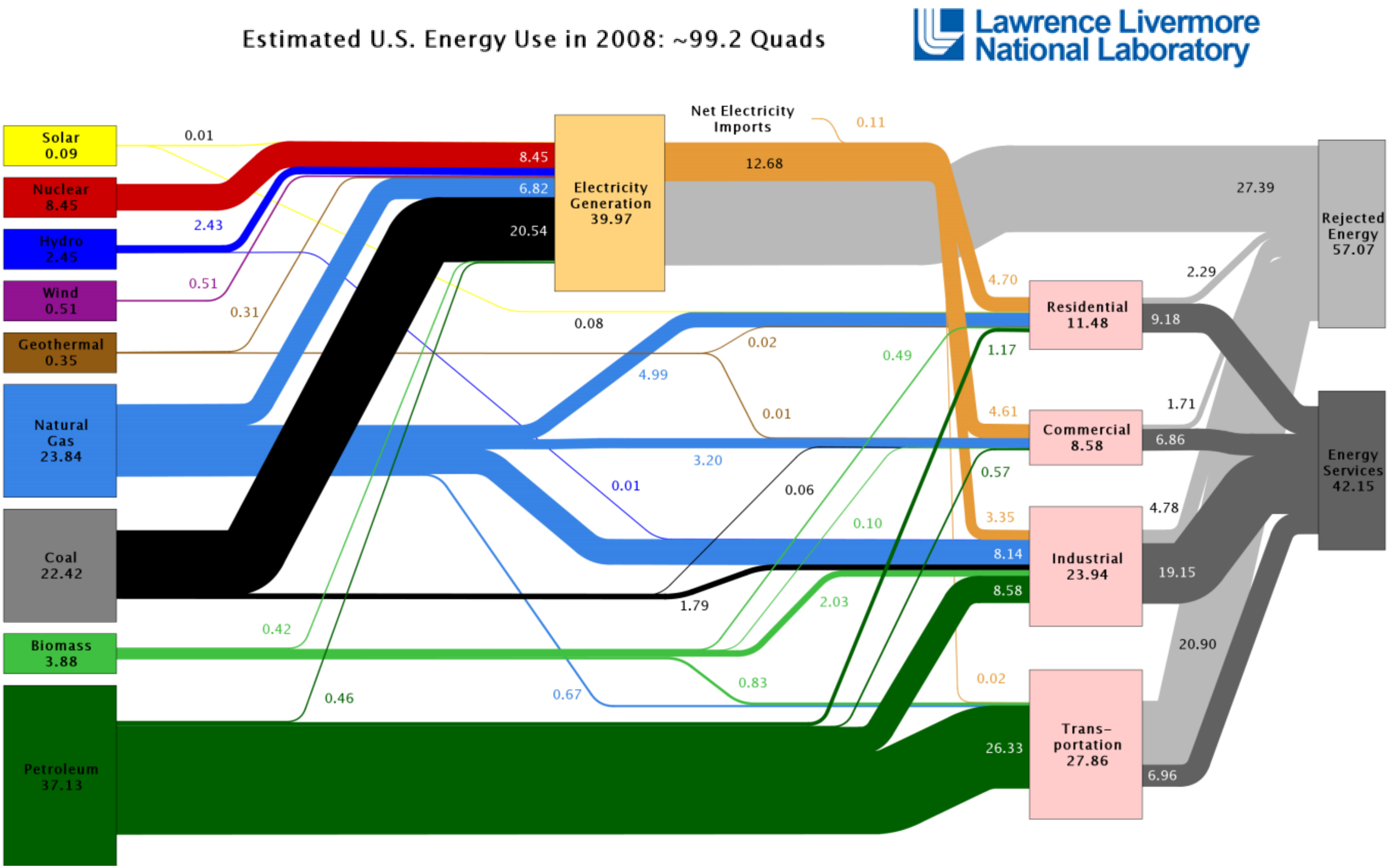
Efficiencies of common energy conversion devices

Energy Conversion Device	Energy Conversion	Typical Efficiency, %
Electric heater	Electricity/Thermal	100
Hair drier	Electricity/Thermal	100
Electric generator	Mechanical/Electricity	95
Electric motor (large)	Electricity/Mechanical	90
Battery	Chemical/Electricity	90
Steam boiler (power plant)	Chemical/Thermal	85
Home gas furnace	Chemical/Thermal	85
Home oil furnace	Chemical/Thermal	65
Electric motor (small)	Electricity/Mechanical	65
Home coal furnace	Chemical/Thermal	55
Steam turbine	Thermal/Mechanical	45
Gas turbine (aircraft)	Chemical/Mechanical	35
Gas turbine (industrial)	Chemical/Mechanical	30
Automobile engine	Chemical/Mechanical	25
Fluorescent lamp	Electricity/Light	20
Silicon solar cell	Solar/Electricity	15
Steam locomotive	Chemical/Mechanical	10
Incandescent lamp	Electricity/Light	5

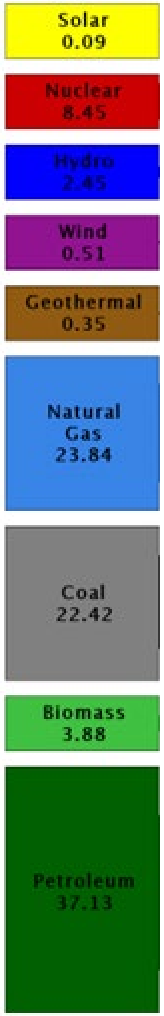
The three laws of thermodynamics



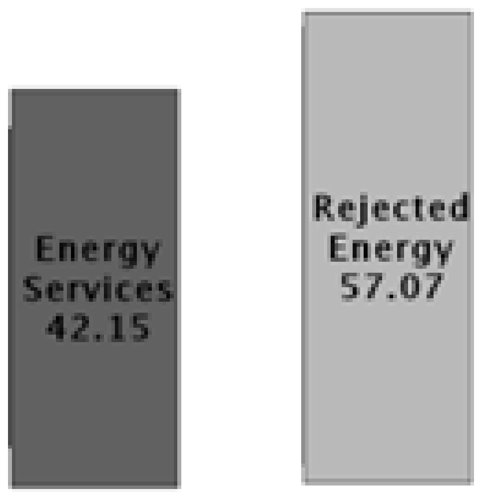
Energy Balance of the USA



Supply (or Energy In)

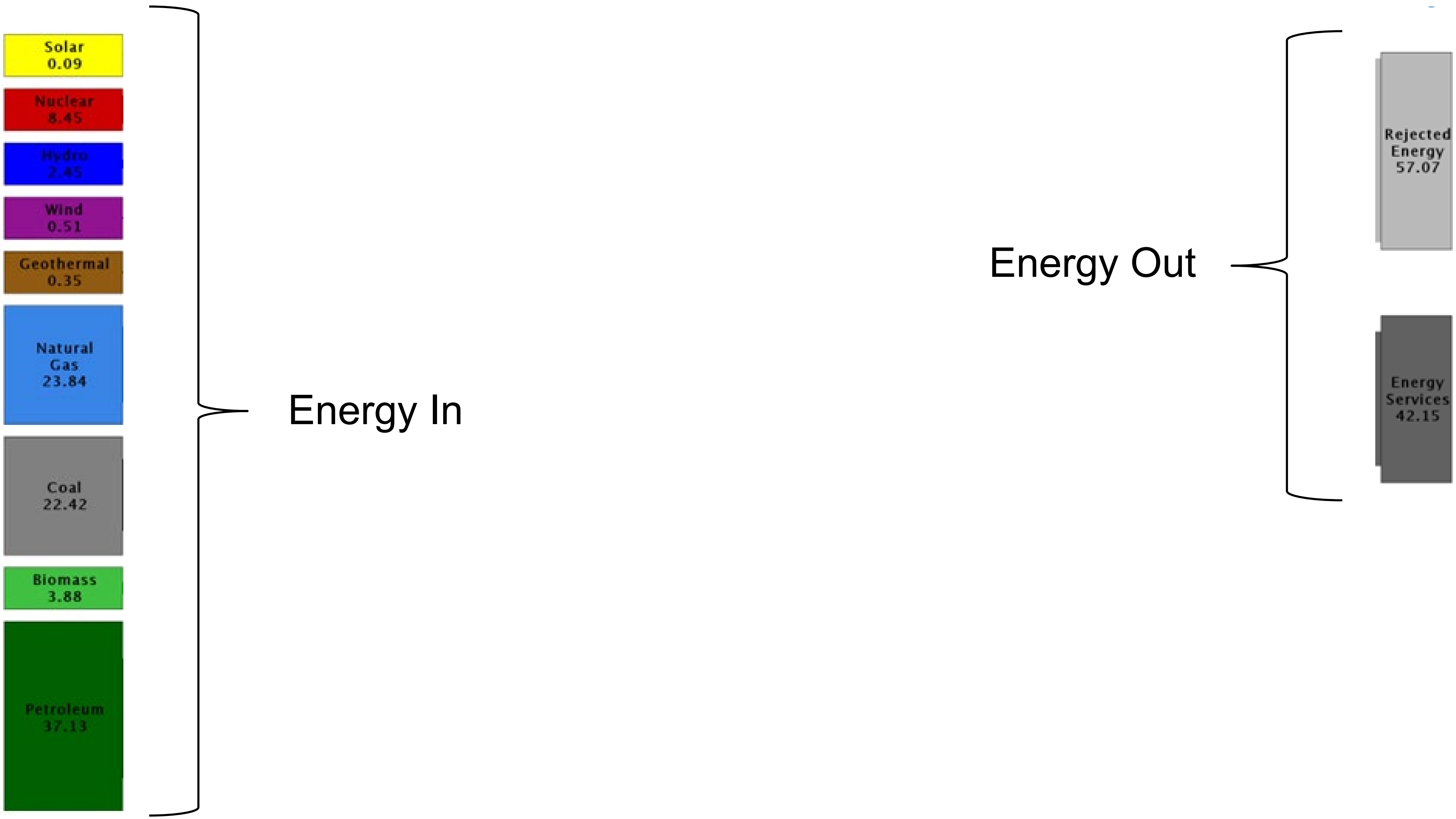


Energy Out

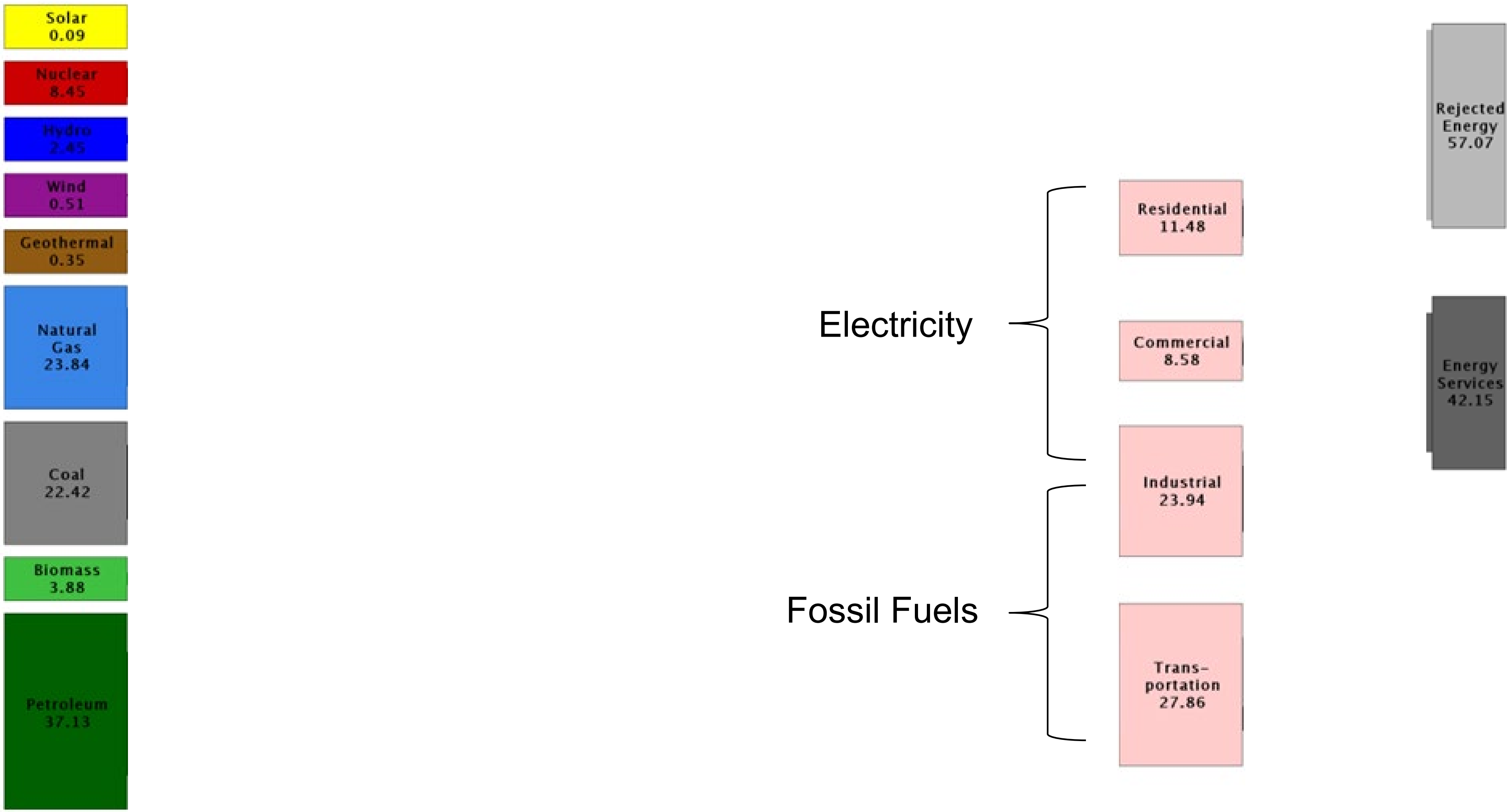


42% of fuel becomes “Energy Services”

Energy Out


Solar 0.09
Nuclear 8.45
Hydro 2.45
Wind 0.51
Geothermal 0.35
Natural Gas 23.84
Coal 22.42
Biomass 3.88
Petroleum 37.13
Energy In
Energy Out
Rejected Energy 57.07
Energy Services 42.15

Demand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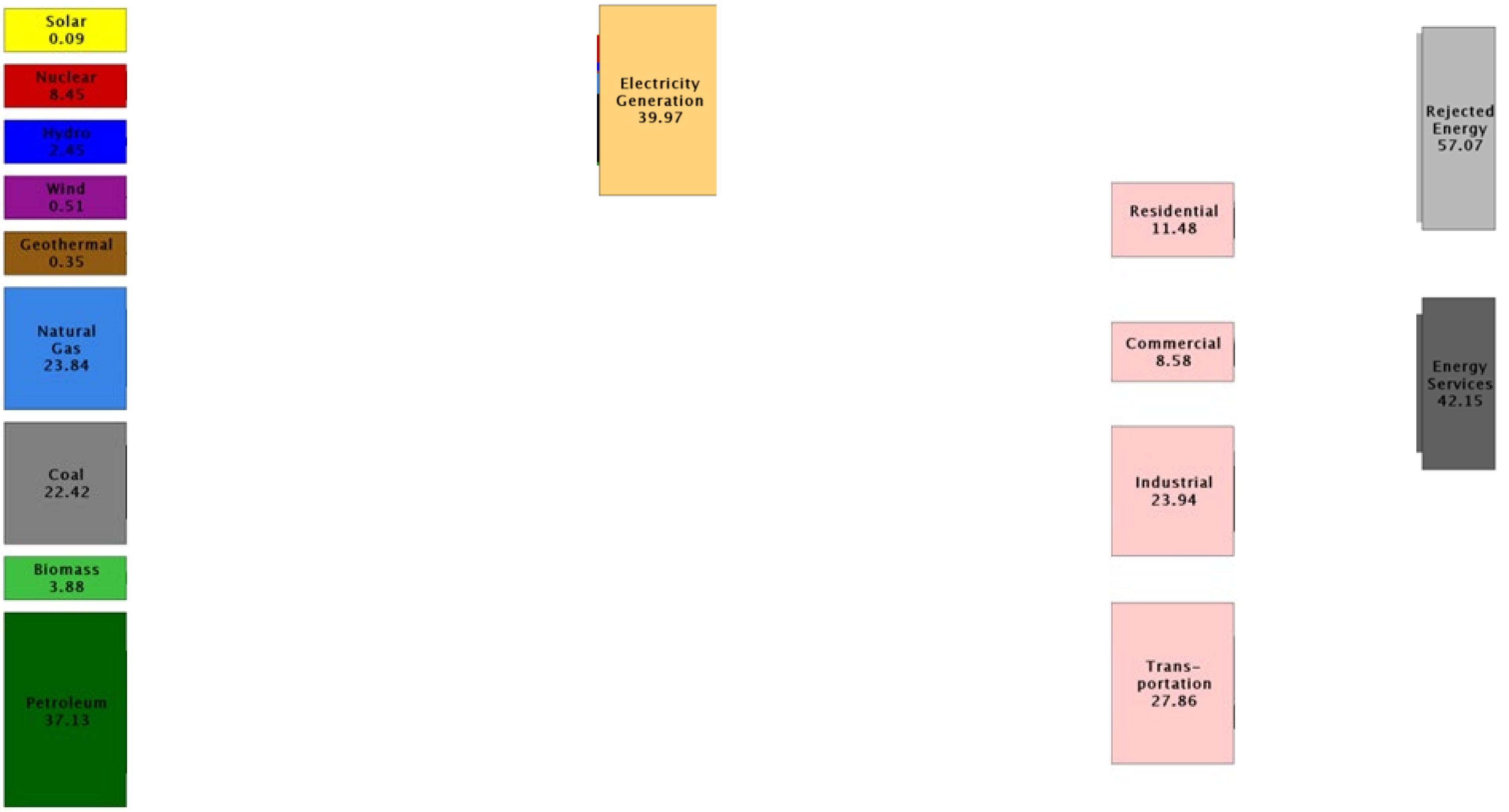
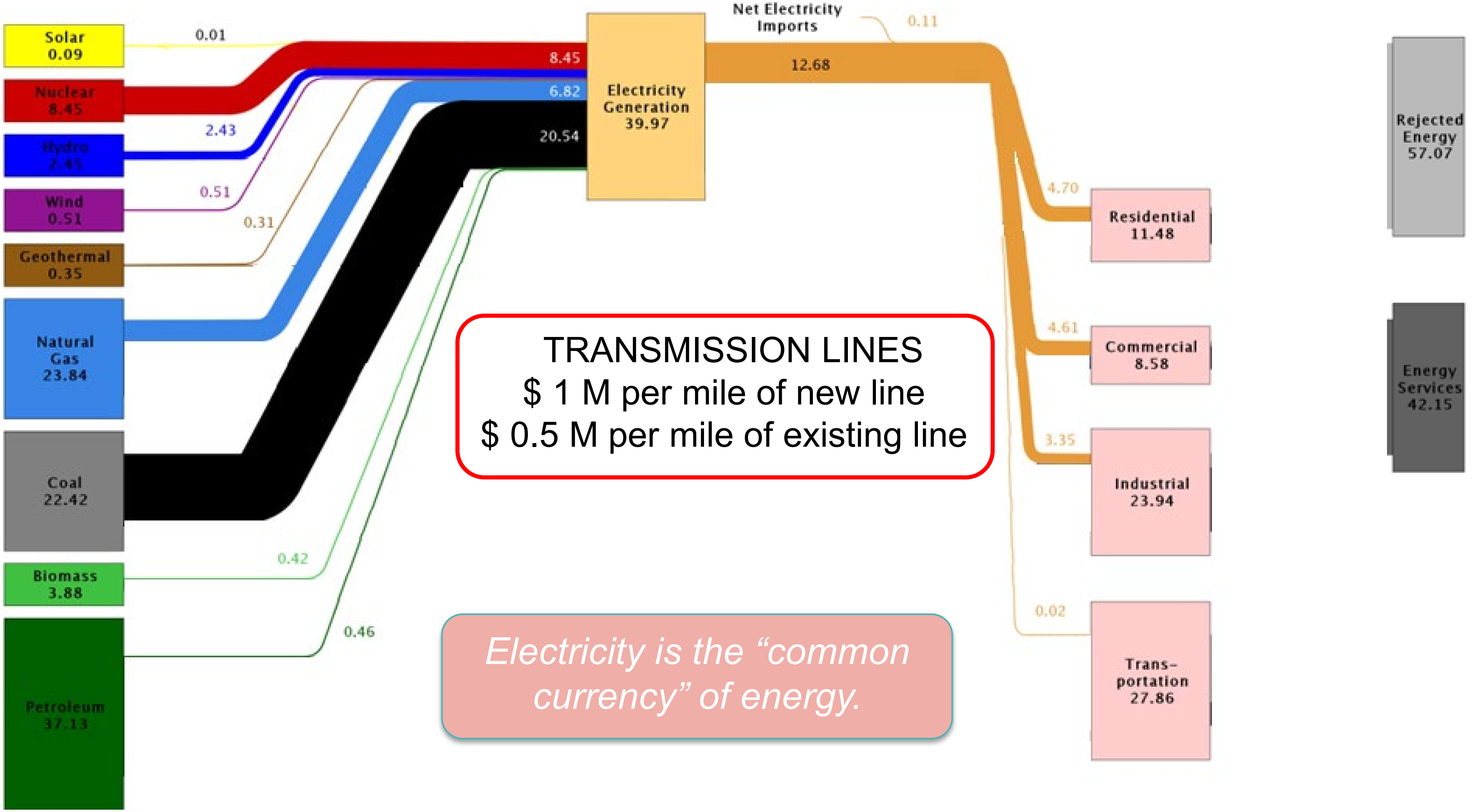
3.88
Petroleum
37.13
Electricity
Fossil Fuels
Residential
11.48
Commercial
8.58
Industrial
23.94
Trans-
portation
27.86
Rejected
Energy
57.07
Energy
Services
42.15

Electricity



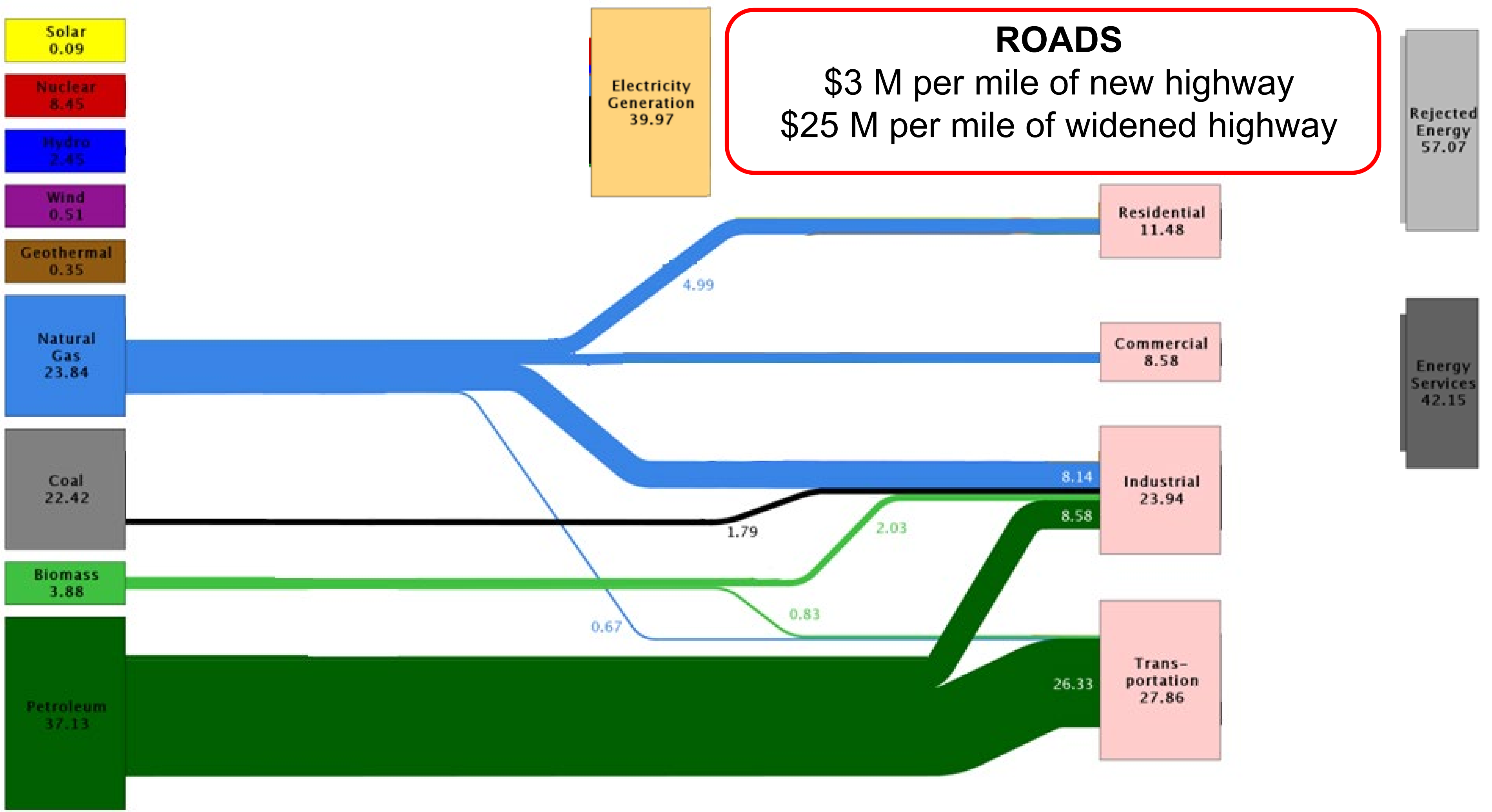
Transport via Transmission Lines



TRANSMISSION LINES
$ 1 M per mile of new line
$ 0.5 M per mile of existing line

Electricity is the "common currency" of energy.

Transport via Roads

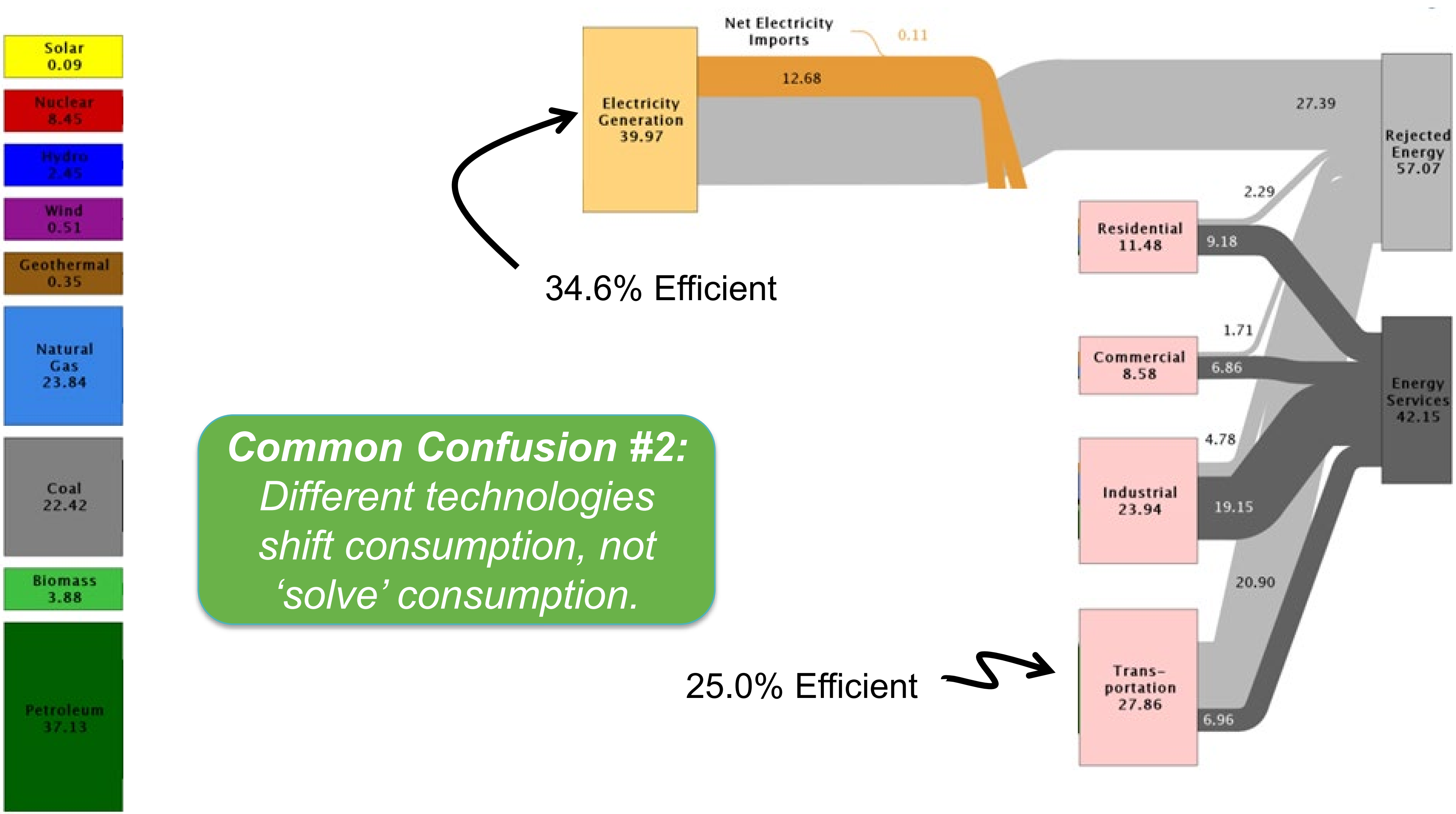


ROADS

$3 M per mile of new highway

$25 M per mile of widened highway

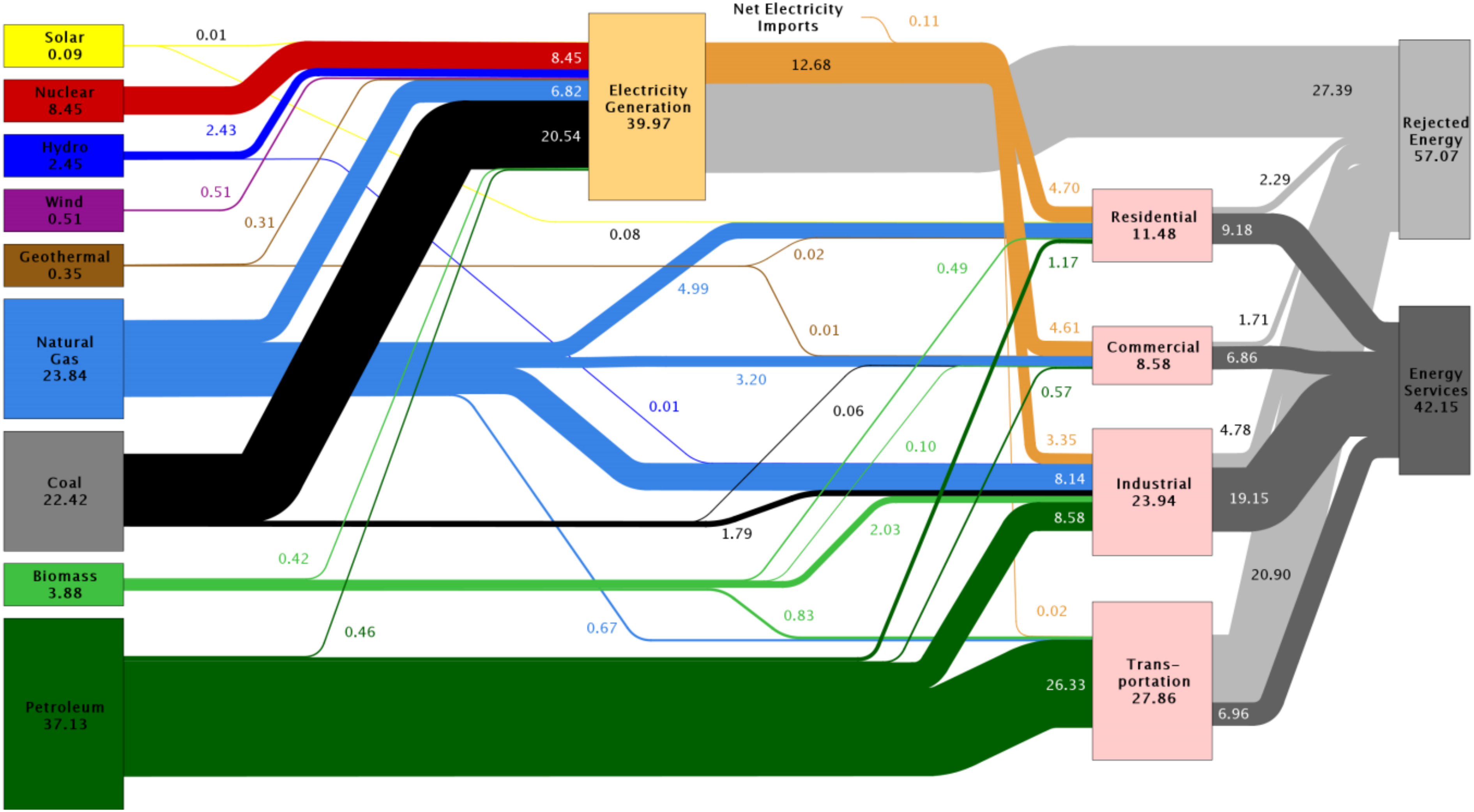
How efficient are we?



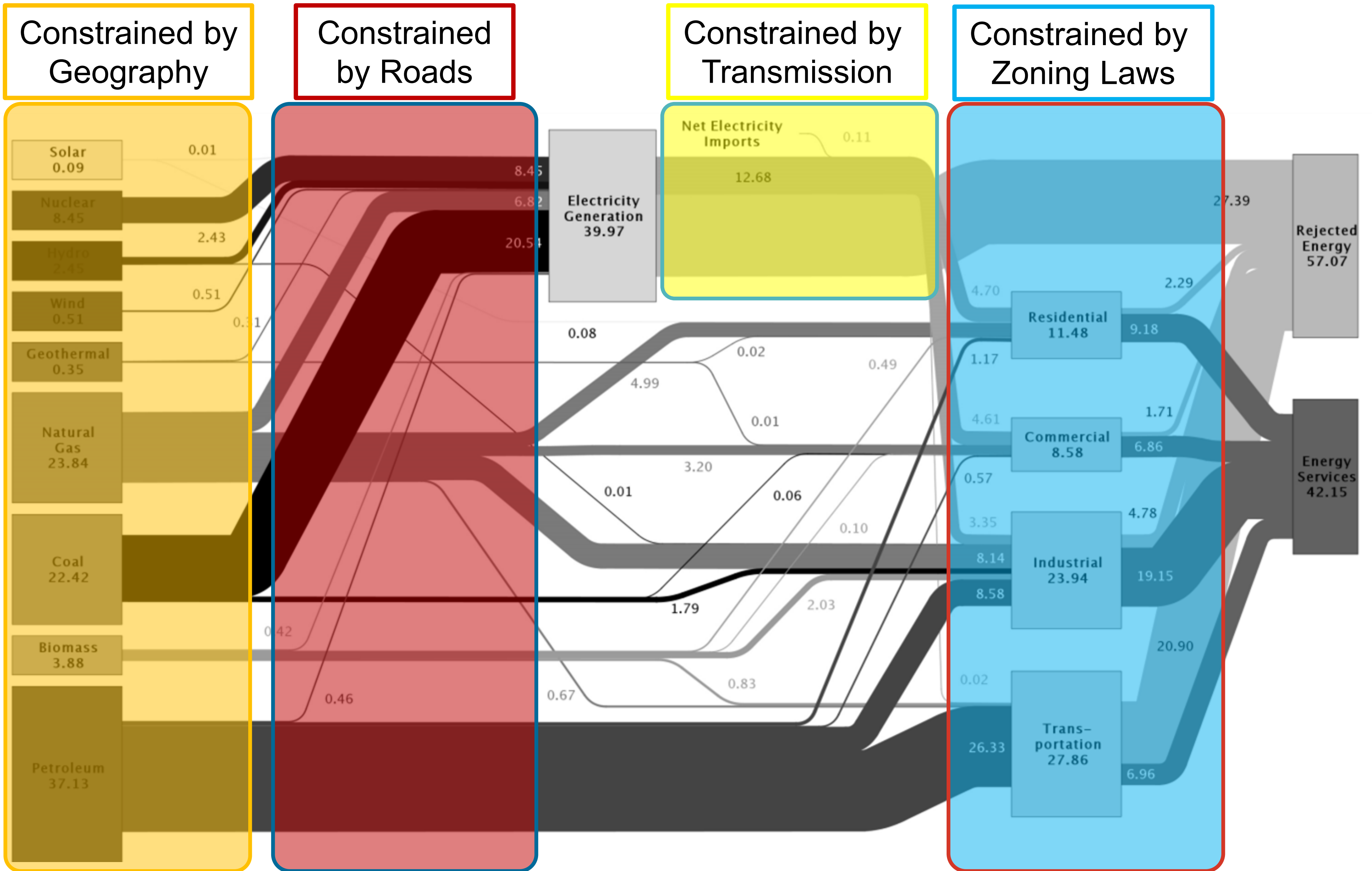
Common Confusion #2:
Different technologies shift consumption, not 'solve' consumption.

Estimated U.S. Energy Use in 2008: ~99.2 Quads

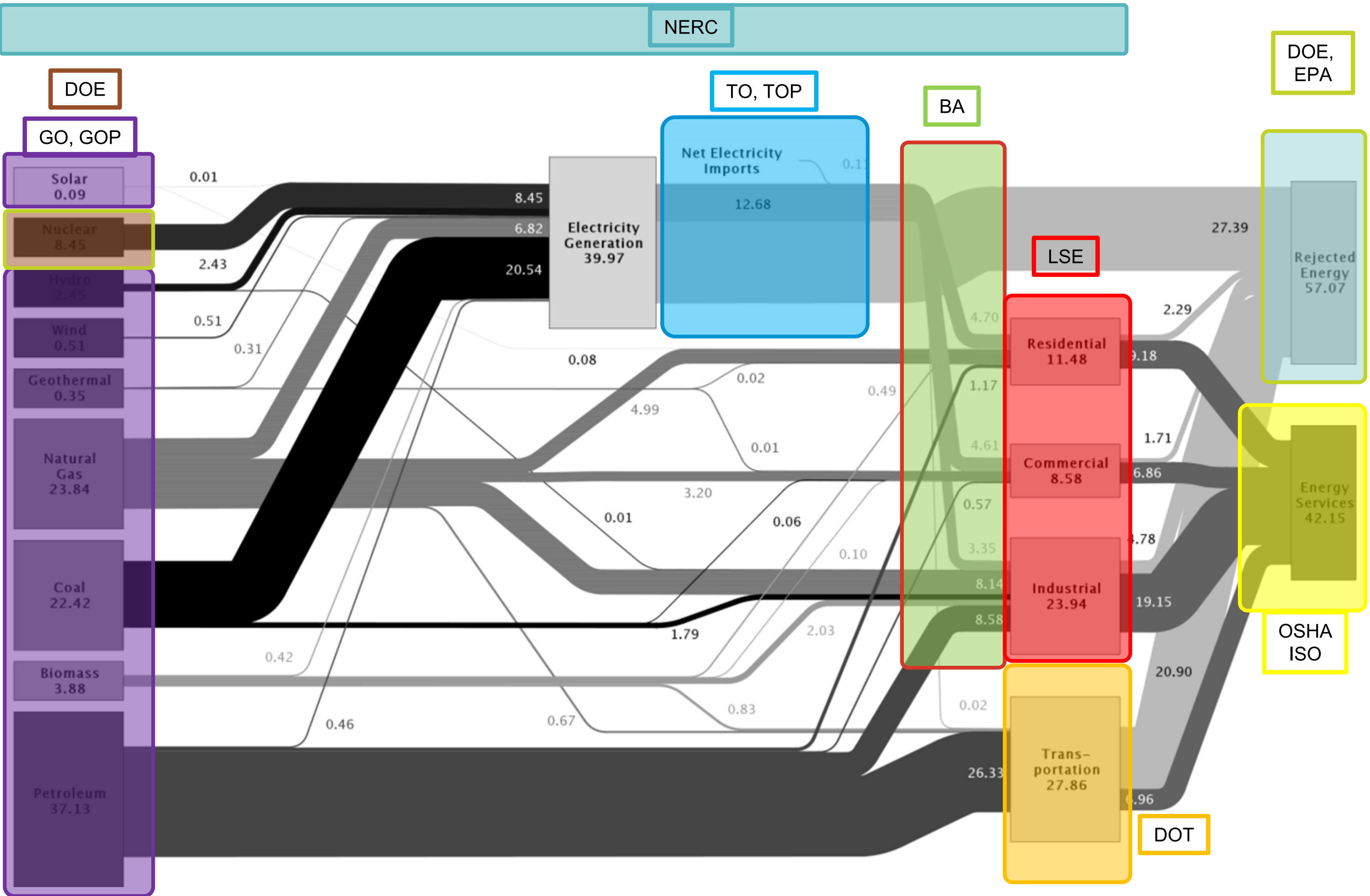
Lawrence Livermore National Laboratory



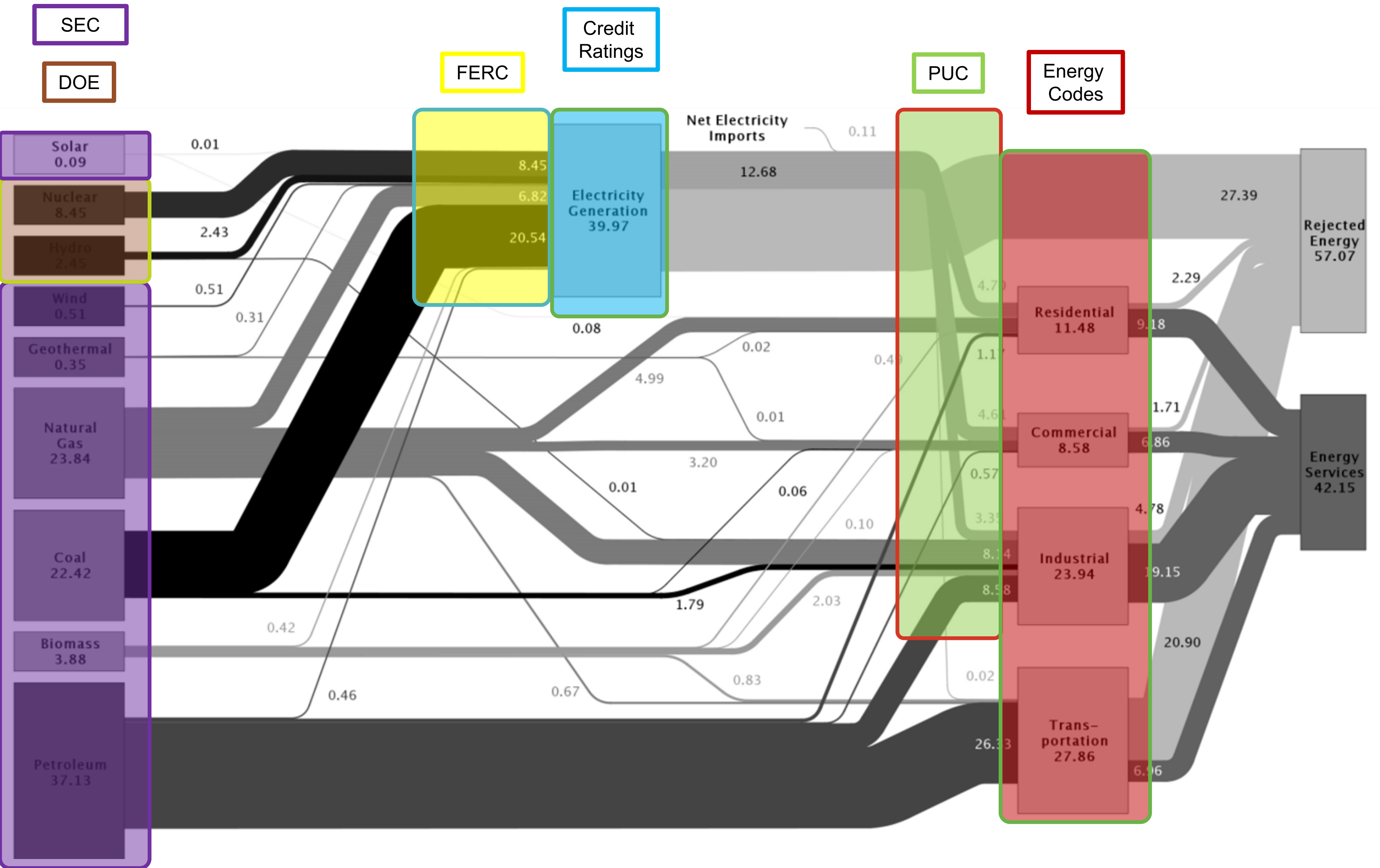
Some Physical Constraints



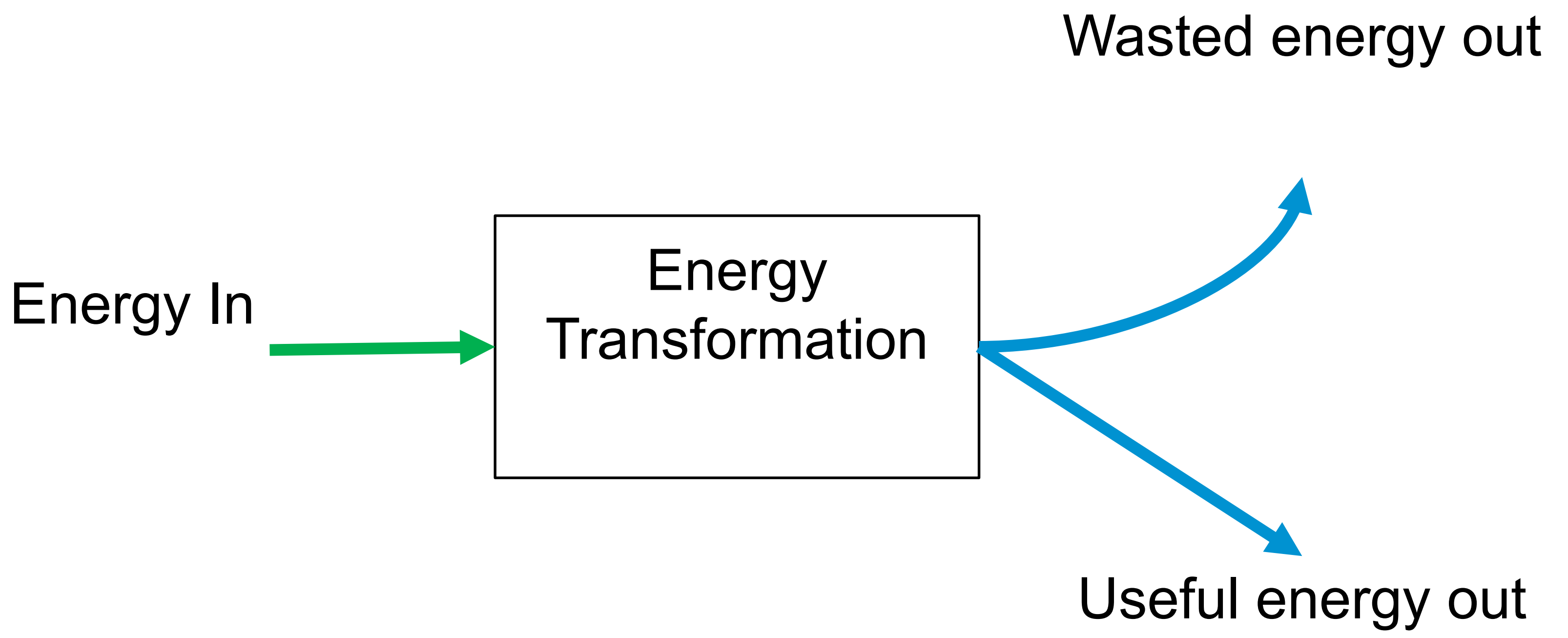
Some Regulatory Constraints



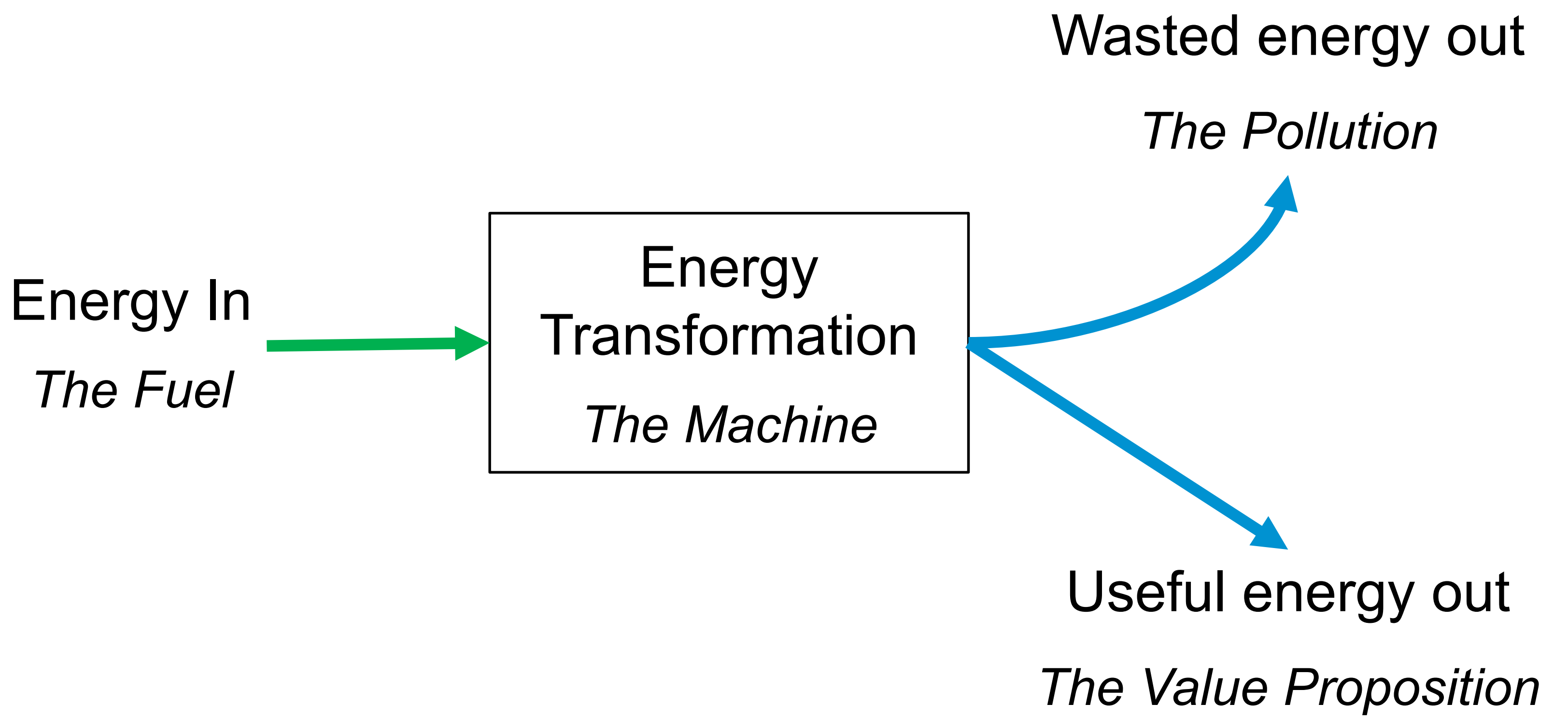
Some Financial Constraints



The Constrained Energy Ecosystem



The Constrained Energy Ecosystem



The People Involved

Rex Tillerson,
CEO ExxonMobil
Gasoline to runs cars

Akio Toyoda
CEO Toyota
Builds cars

Douglas Oberhelman
CEO Caterpillar
Builds paving equipment

Richard Fairbanks
CEO Capital One
Auto loans

Lynn Peterson
WA Sec. of Transportation
Taxes and funds roads

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What this course is about

This is NOT a course about ENERGY

What this course is about

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This IS a course about our societal CONTEXT

and the demands it places on energy

Philosophy of this Term

Energy is what has historically propelled societal accomplishments.

- It is a measure of work and accomplishment.

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- *It is a measure of work and accomplishment.*

Access to energy has traditionally dictated strength of a civilization

- *Energy is merely another resource.*

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- It is a measure of work and accomplishment.

Access to energy has traditionally dictated strength of a civilization

- Energy is merely another resource.

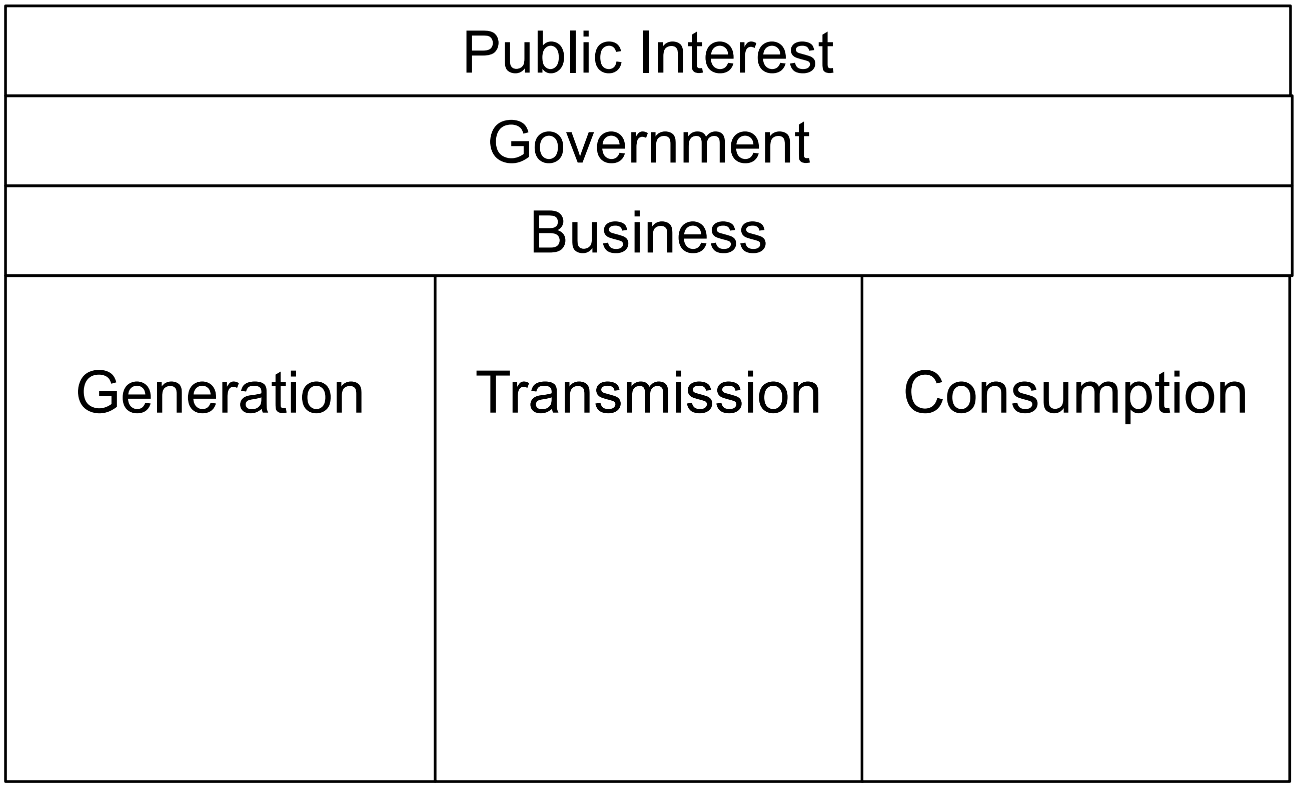
Needs are based on our societal assumptions and expectations.

- Energy is a symptom, not the problem, that society faces.

Framework for the course

Generation	Transmission	Consumption

Framework for the course



Map for the Curriculum

Term 1: *How we got into this mess?*	**Term 2:** *Problem with no solutions*	**Term 3:** *Questions yet to be asked*
• Electric Grid • Transportation • Adv. Manufacturing	• Heat and Steam • The Future Grid • Waste	• Built Environment • Insurance • Marketing
• Generation • Transmission • Regulation • Wholesale Markets • Adv. Manufacturing	• ‘Clean’ Generation • Distributed Generation • Energy Storage • Financial Markets • Law	• National Security • National Treaties • Critical Materials • Developing Countries • Oil Sands

Term 4: Action Learning Practicum

Do something about it!

Expectations

- Prepared for class discussions
- Homework
  - Cite your sources
  - Spell check
  - Well thought out arguments
- Class participation
  - Cold Calls (!)
- Group work

Homework

- Expectation is to turn in on Wednesday before class.
- Discussions on the Forum
- The Course Page is the official guide to homework.
- Each homework is different. Be prepared to think.

Grading

Class Participation	25%
Homework	25%
Team Assignment	25%
Presentation	25%
Total	100%

The Ultimate Rule