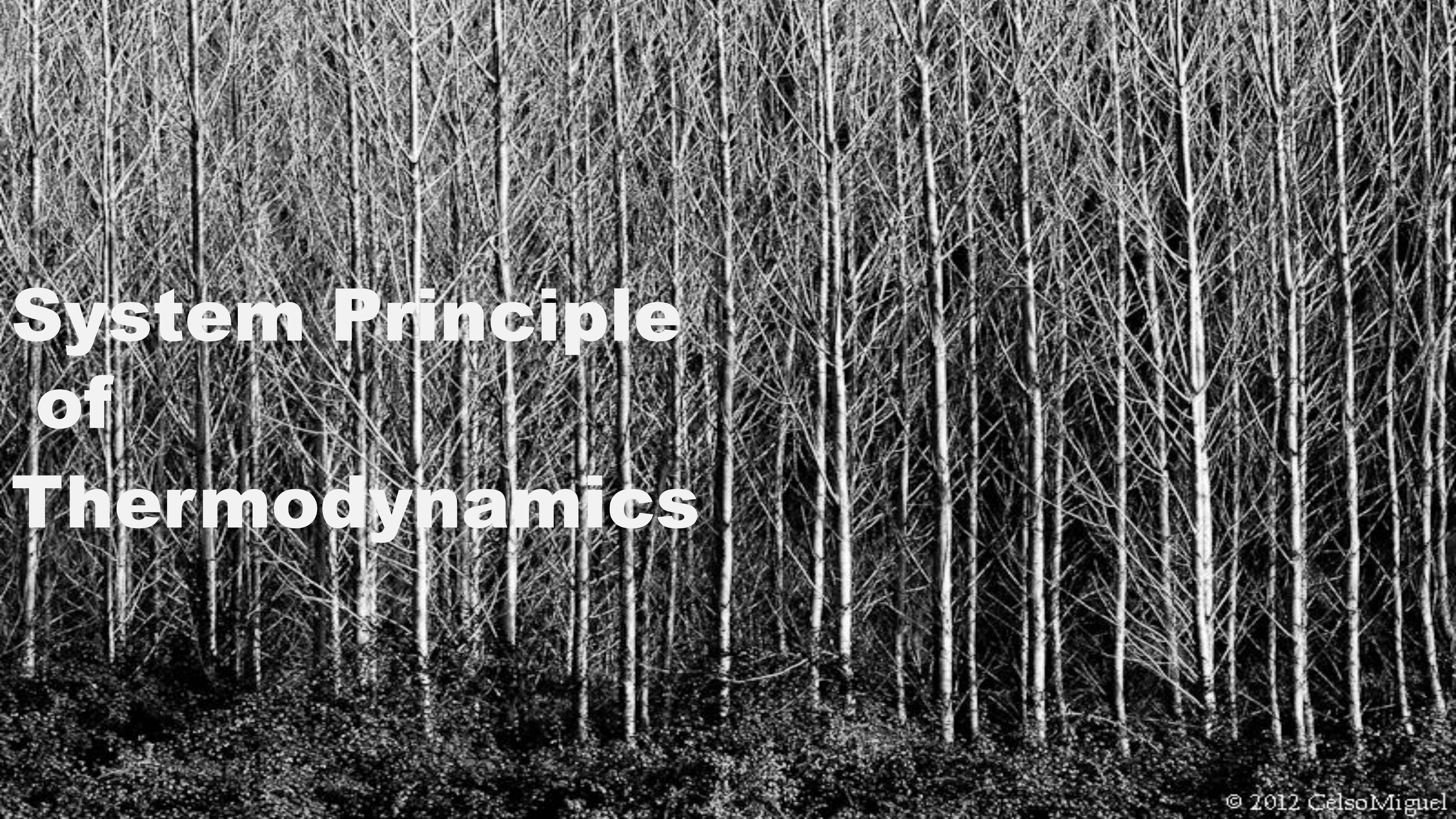
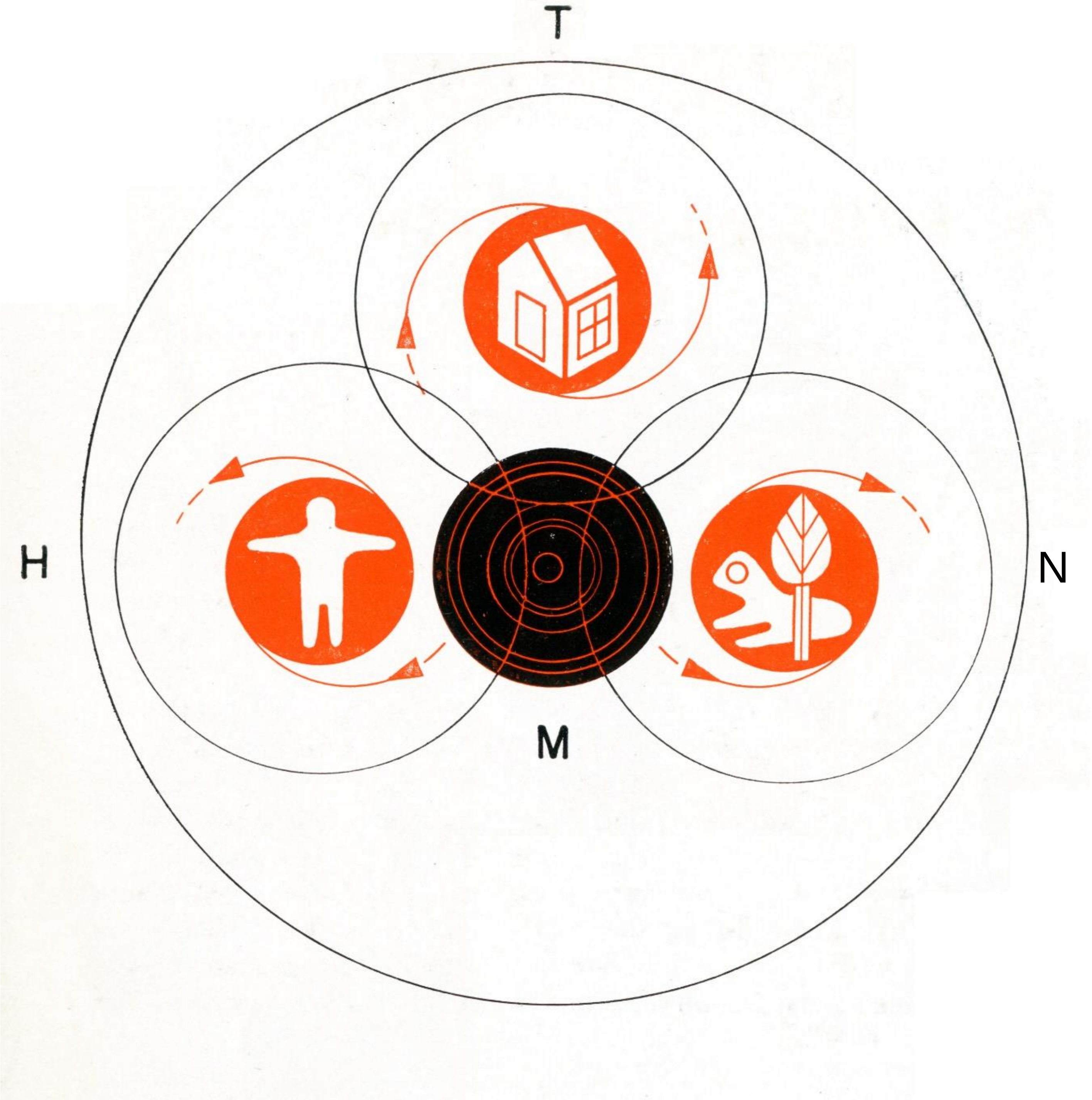
System Principle of Thermodynamics



Correalism

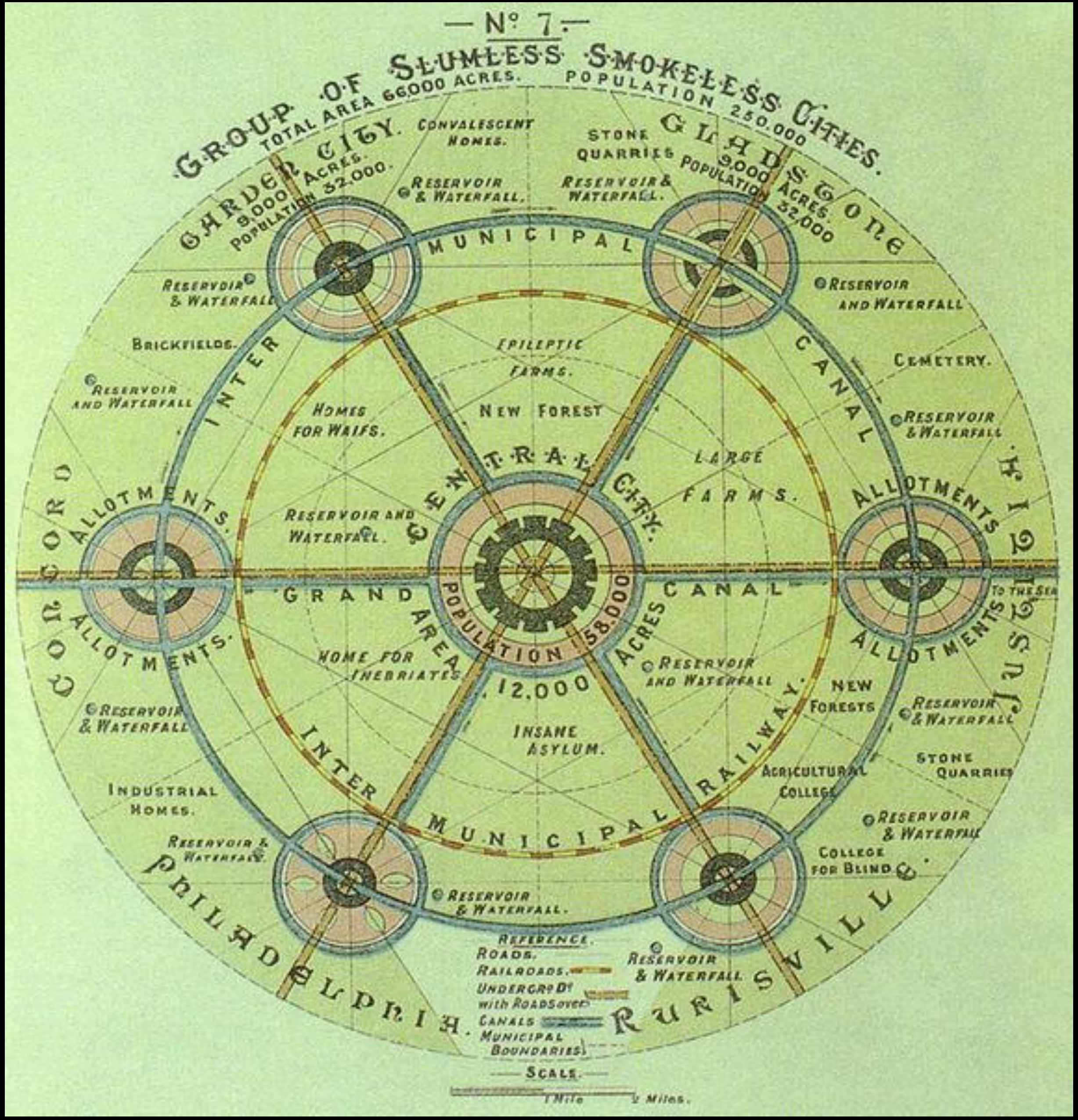


Human (H)
Technological (T)
Natural (N)
environments

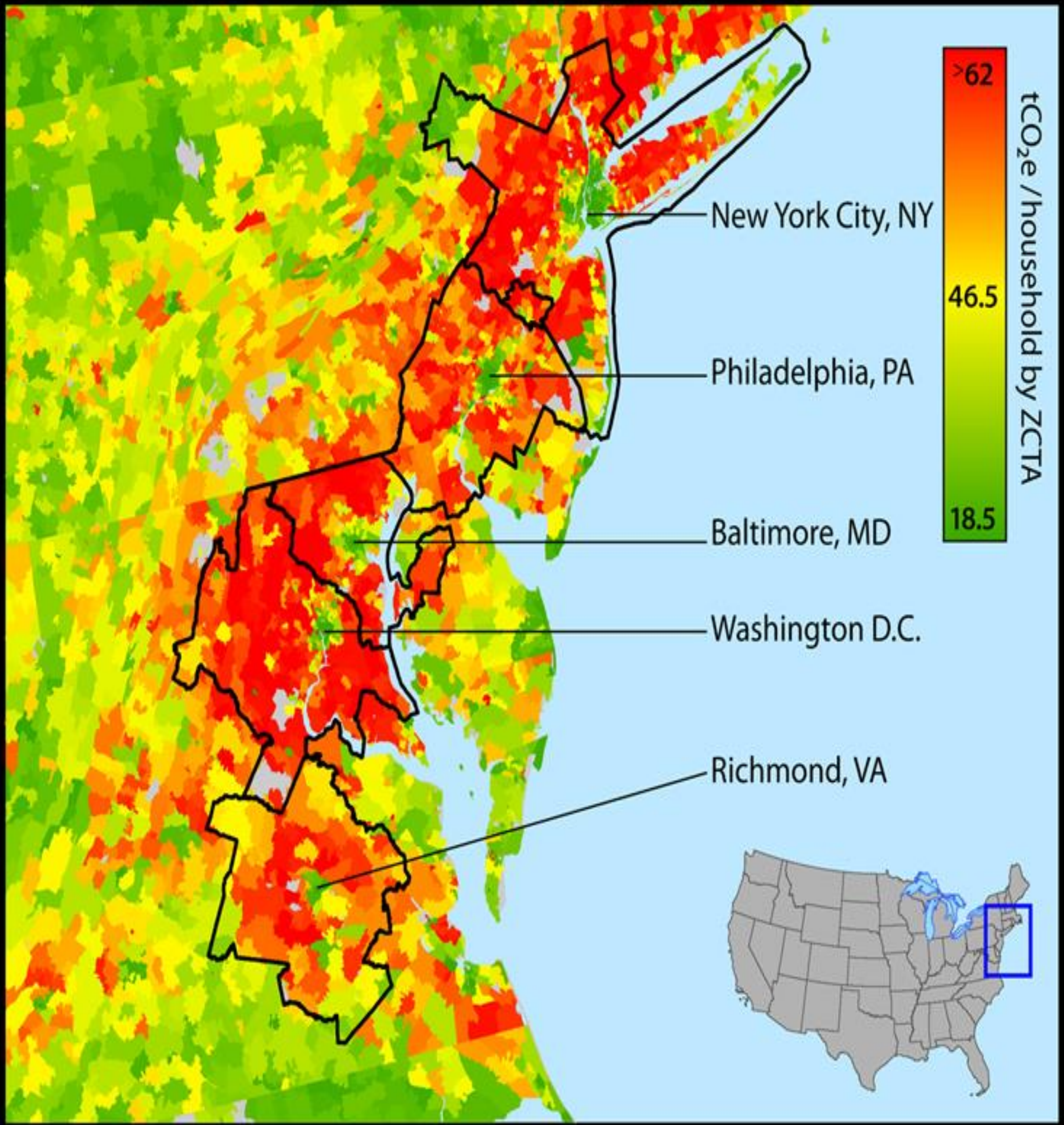
Frederick Kiesler,
Architectural Record, 1939

Pittsburgh, PA

Beijing, China



Garden City, Ebenezer Howard, 1902



eCO2, East Coast Megalopolis

Biotic Community:
Primary Succession

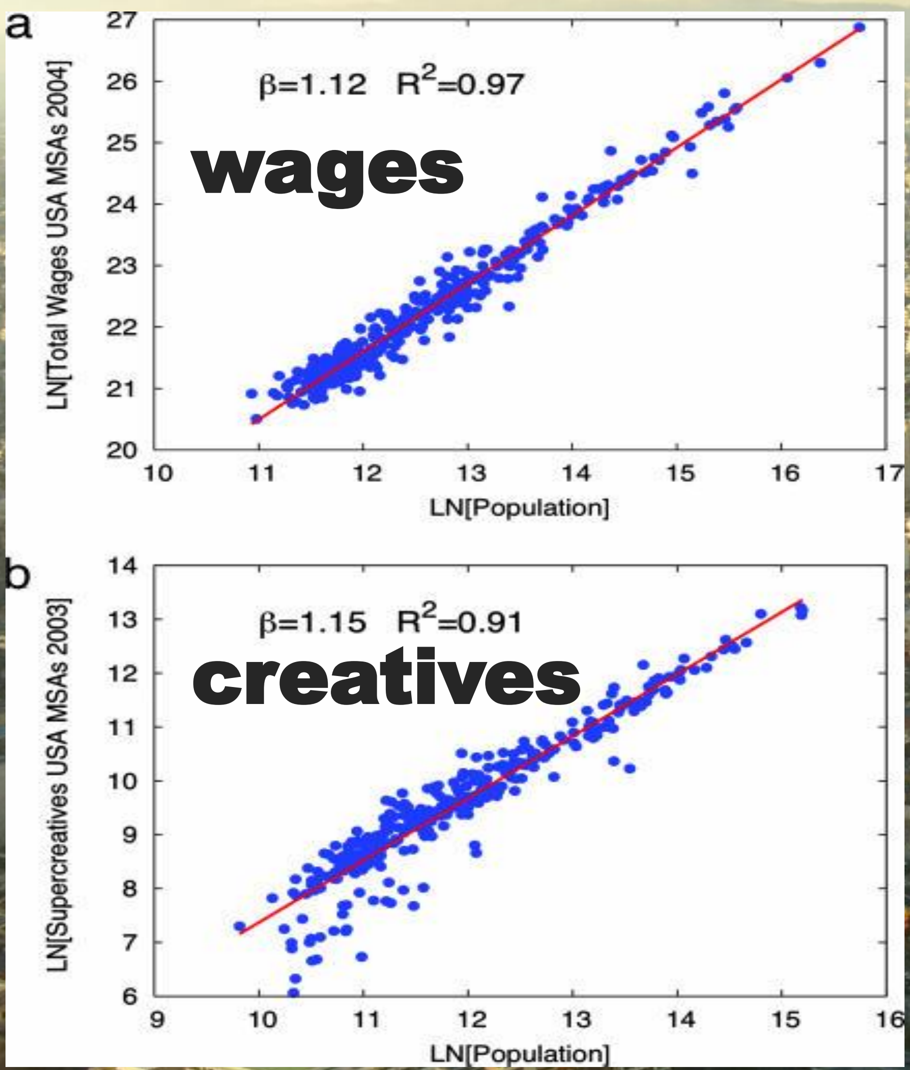
The processes involved in changing an area from one lacking any community to one consisting of individuals, populations, communities, and ecosystems.

succession


In this eco-system
your lawn wants to be...


a temperate forest

Cities: Kleiber's law



Growth, innovation, scaling, and the pace of life in cities.

Luís M. A. Bettencourt,[*†] José Lobo,[‡] Dirk Helbing,[§] Christian Kühnert,[§] and Geoffrey B. West[*¶]

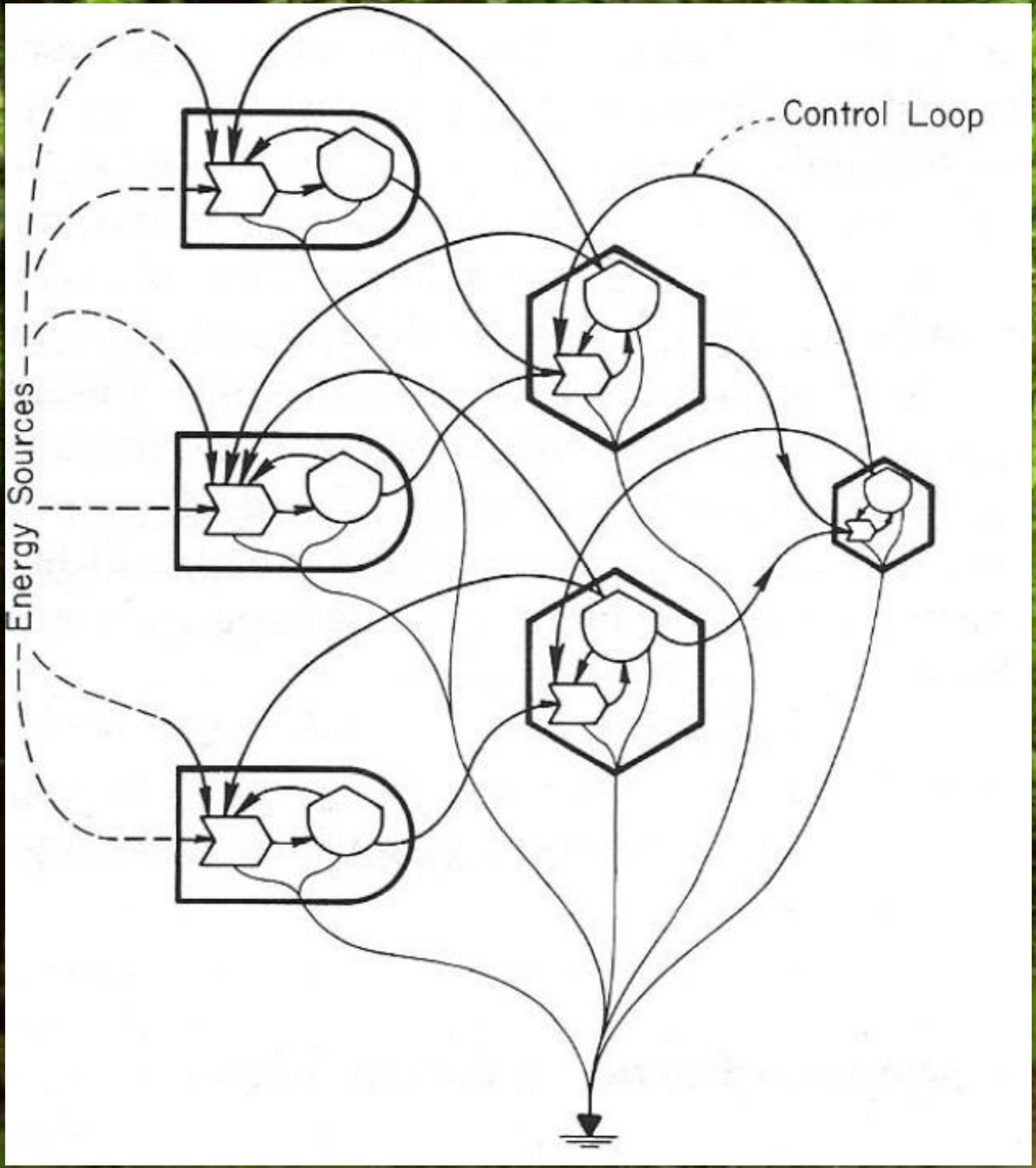
Table 1. Scaling exponents for urban indicators vs. city size

Y	*β*	95% CI	Adj-R^2	Observations	Country–year
New patents	1.27	[1.25,1.29]	0.72	331	U.S. 2001
Inventors	1.25	[1.22,1.27]	0.76	331	U.S. 2001
Private R&D employment	1.34	[1.29,1.39]	0.92	266	U.S. 2002
"Supercreative" employment	1.15	[1.11,1.18]	0.89	287	U.S. 2003
R&D establishments	1.19	[1.14,1.22]	0.77	287	U.S. 1997
R&D employment	1.26	[1.18,1.43]	0.93	295	China 2002
Total wages	1.12	[1.09,1.13]	0.96	361	U.S. 2002
Total bank deposits	1.08	[1.03,1.11]	0.91	267	U.S. 1996
GDP	1.15	[1.06,1.23]	0.96	295	China 2002
GDP	1.26	[1.09,1.46]	0.64	196	EU 1999–2003
GDP	1.13	[1.03,1.23]	0.94	37	Germany 2003
Total electrical consumption	1.07	[1.03,1.11]	0.88	392	Germany 2002
New AIDS cases	1.23	[1.18,1.29]	0.76	93	U.S. 2002–2003
Serious crimes	1.16	[1.11, 1.18]	0.89	287	U.S. 2003
Total housing	1.00	[0.99,1.01]	0.99	316	U.S. 1990
Total employment	1.01	[0.99,1.02]	0.98	331	U.S. 2001
Household electrical consumption	1.00	[0.94,1.06]	0.88	377	Germany 2002
Household electrical consumption	1.05	[0.89,1.22]	0.91	295	China 2002
Household water consumption	1.01	[0.89,1.11]	0.96	295	China 2002
Gasoline stations	0.77	[0.74,0.81]	0.93	318	U.S. 2001
Gasoline sales	0.79	[0.73,0.80]	0.94	318	U.S. 2001
Length of electrical cables	0.87	[0.82,0.92]	0.75	380	Germany 2002
Road surface	0.83	[0.74,0.92]	0.87	29	Germany 2002

Data sources are shown in *SI Text*. CI, confidence interval; Adj-R^2, adjusted R^2; GDP, gross domestic product.

"Which, then, of these two dynamics, **efficiency or wealth creation,** is the primary determinant of urbanization, and how does each impact urban growth?"

Bettencourt et al



H.T. Odum

Two key principles:

Systems self-organize to maximize their power

Systems self-organize into hierarchies of energy exchange and feedback (to maximize power)

*CONTRIBUTION TO THE ENERGETICS OF EVOLUTION**

BY ALFRED J. LOTKA

SCHOOL OF HYGIENE AND PUBLIC HEALTH, JOHNS HOPKINS UNIVERSITY

Communicated, May 6, 1922

It has been pointed out by Boltzmann[1] that the fundamental object of contention in the life-struggle, in the evolution of the organic world, is available energy.[2] In accord with this observation is the principle[3] that, in the struggle for existence, the advantage must go to those organisms whose energy-capturing devices are most efficient[4] in directing available energy into channels favorable to the preservation of the species.

The first effect of natural selection thus operating upon competing species will be to give relative preponderance (in number or mass) to those most efficient in guiding available energy in the manner indicated. Primarily the *path* of the energy flux through the system will be affected.

But the species possessing superior energy-capturing and directing devices may accomplish something more than merely to divert to its own advantage energy for which others are competing with it. If sources are presented, capable of supplying available energy in excess of that actually being tapped by the entire system of living organisms, then an opportunity is furnished for suitably constituted organisms to enlarge the total energy flux[5] through the system. Whenever such organisms arise, natural selection will operate to preserve and increase them. The result, in this case, is not a mere diversion of the energy flux through the system of organic nature along a new path, but an increase of the total flux through that system.

Again, so long as sources exist, capable of supplying matter, of a character suitable for the compositon of living organisms, in excess of that actually embodied in the system of organic nature, so long is opportunity furnished for suitably constituted organisms to enlarge the total mass of the system of organic nature. Whenever such organisms arise, natural selection will operate to preserve and increase them, provided always that there is presented a residue of untapped available energy. The result will be to increase the total mass of the system, and, with this total mass, also the total energy flux through the system, since, other things equal, this energy flux is proportional to the mass of the system.

Where a limit, either constant or slowly changing,[6] is imposed upon the total mass available for the operation of life processes, the available energy per unit of time (available power) placed at the disposal of the organisms, for application to their life tasks and contests, may be capable of increase by increasing the rate of turnover of the organic matter through the life cycle. So, for example, under present conditions,[7] the United States produce annually a crop of primary and secondary food amounting to

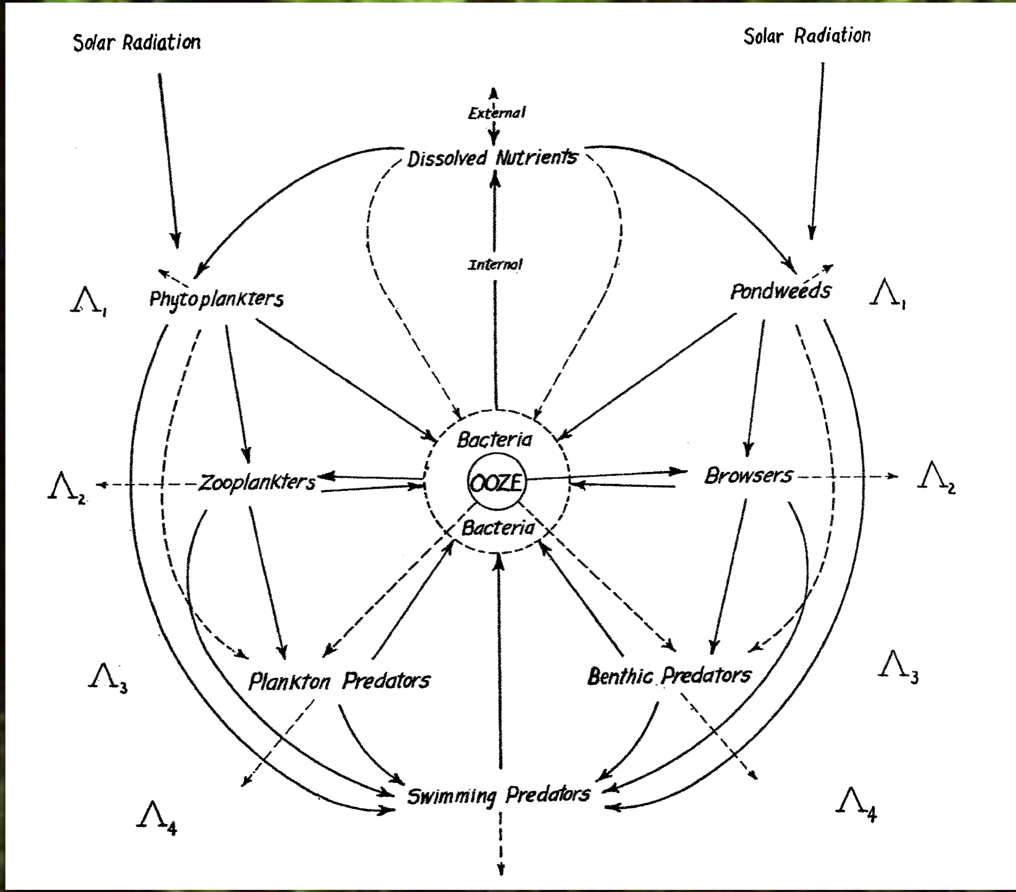
It has been pointed out by Boltzmann' that the fundamental object of contention in the life-struggle, in the evolution of the organic world, is available energy. In accord with this observation is the principle that, in the struggle for existence, the advantage must go to those organisms whose energy-capturing devices are most efficient in directing available energy into channels favorable to the preservation of the species.

…

The influence of man, as the most successful species in the competitive struggle, seems to have been to accelerate the circulation of matter through the life cycle, both by ‘enlarging the wheel,’ and by causing it to ‘spin faster.’ The question was raised whether, in this, man has been unconsciously fulfilling a law of nature, according to which some physical quantity in the system tends toward a maximum. This is now made to appear probable; and it is found that the **physical quantity in question is of the dimensions of power**, or energy per unit time

A. Lotka, 1922

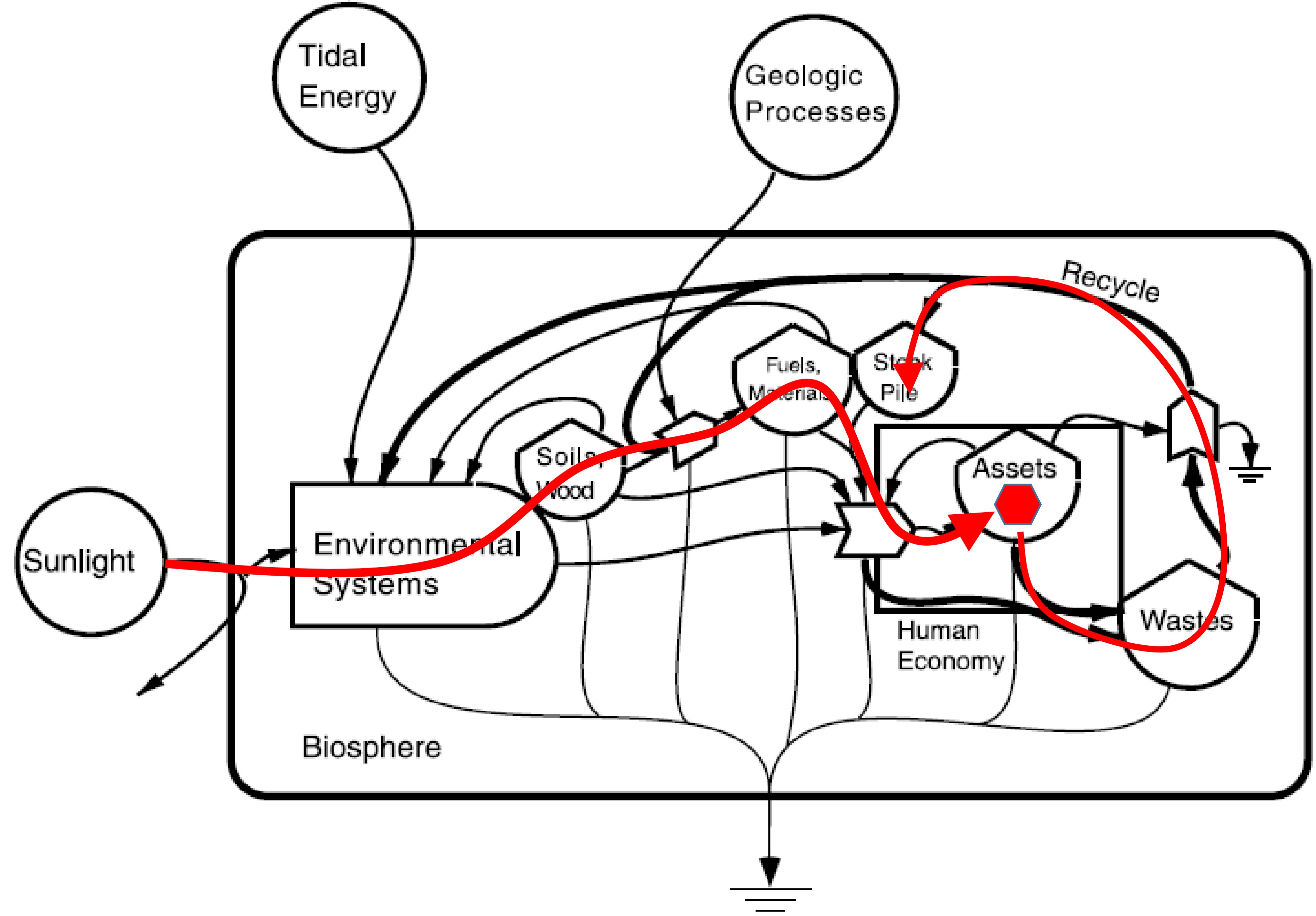
Trophic web or food-chain



R. Lindeman, “Dynamic-Tropic Aspect of Ecology,” 1942

H.T. Odum:

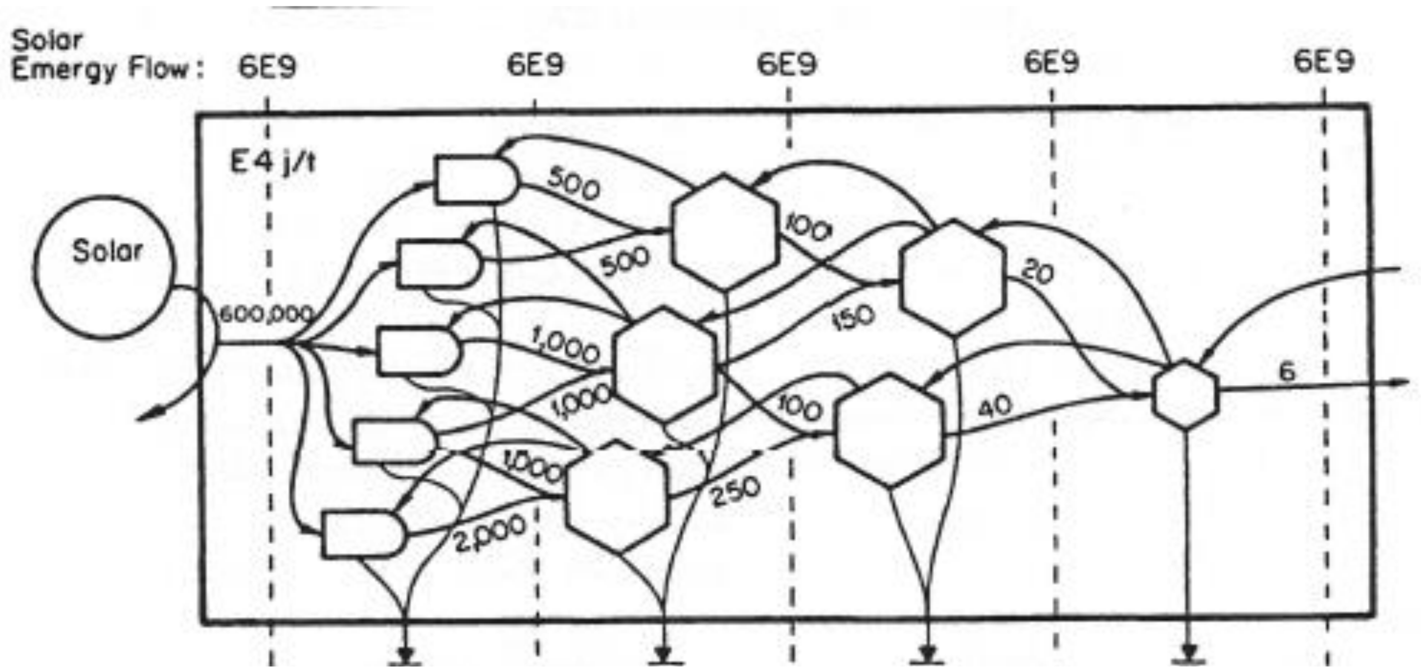
E[m]ergy synthesis



E[m]ergy:

“Em”bodied energy
or cumulative, dissipated exergy
Solar em-Joules, sej

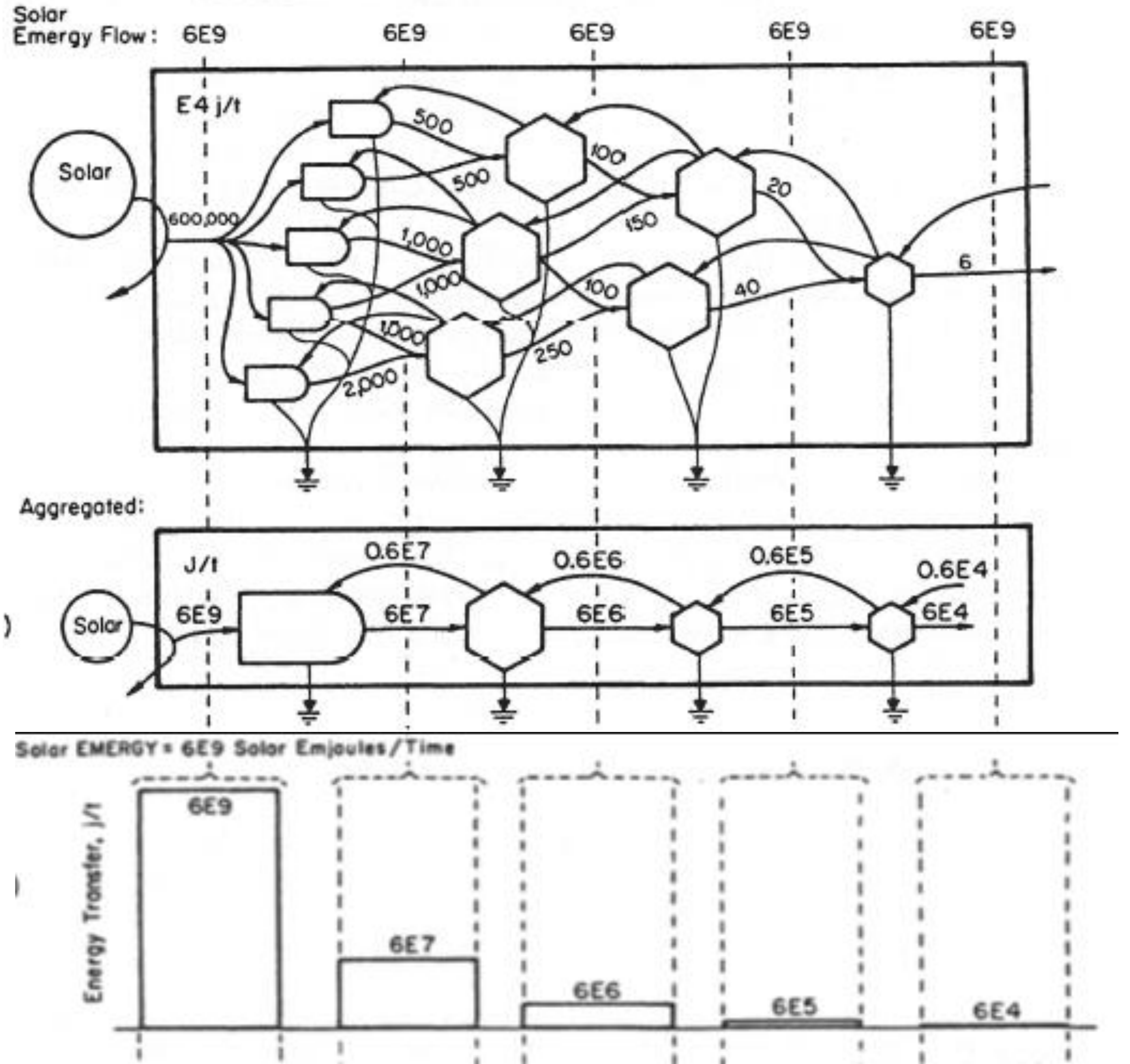
E[m]ergy, sej



E[m]ergy:

“Em”bodied energy
or cumulative, dissipated exergy
Solar em-Joules, sej

Energy, J



E[m]ergy:

"Em"bodied energy
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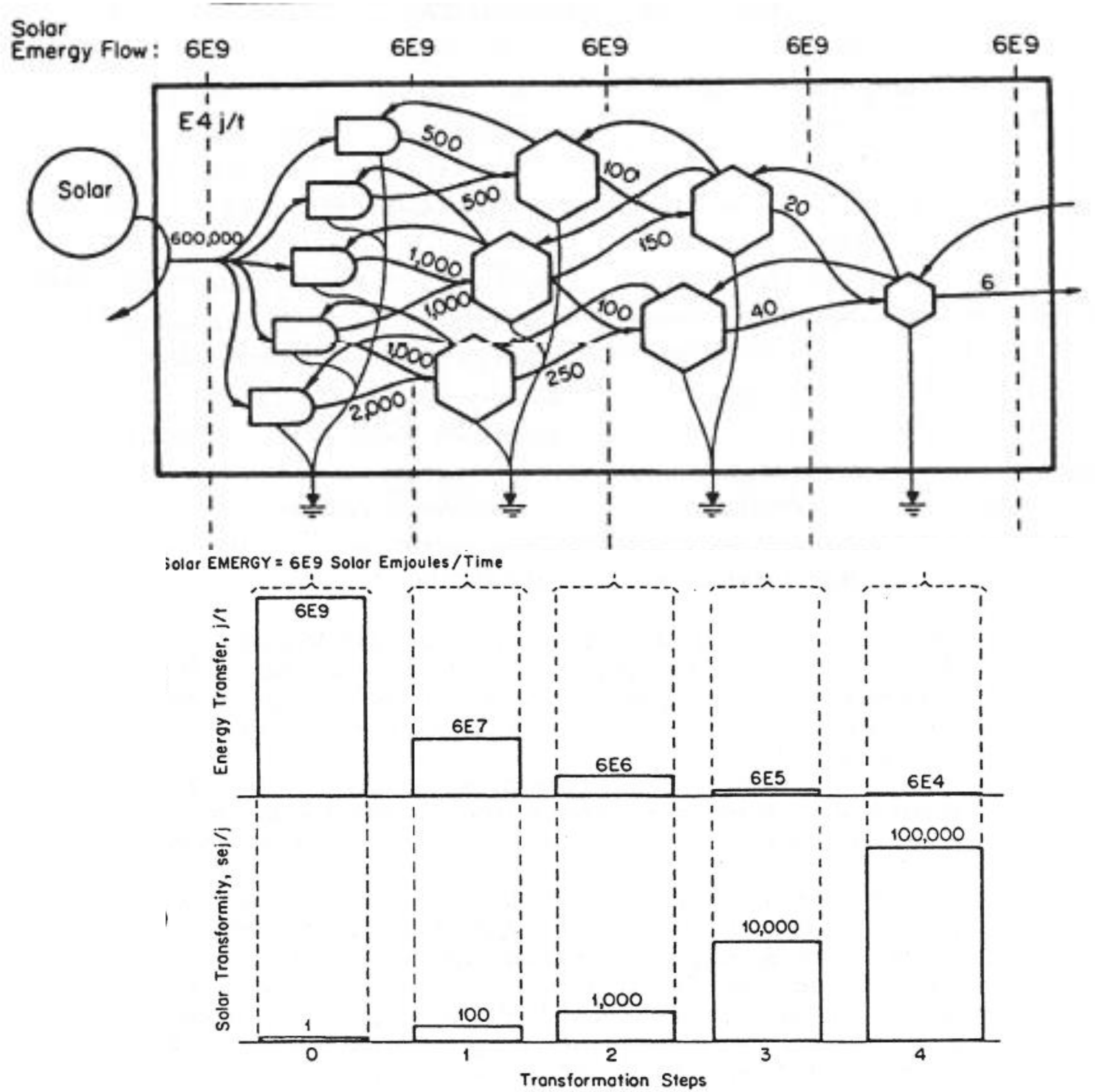
Solar em-Joules, sej



Intensity or Transformity

E[m]ergy/Energy, sej/J

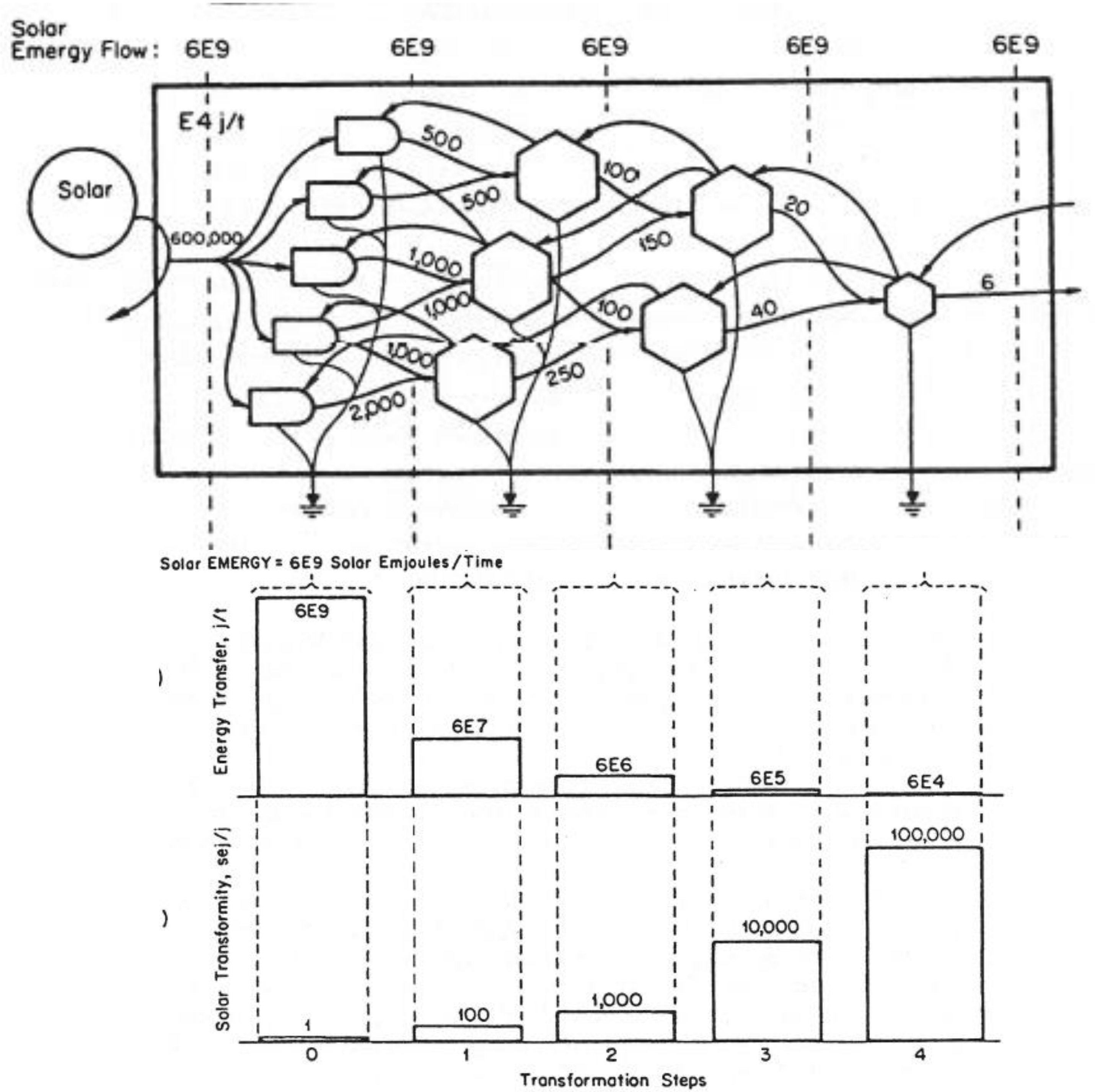
E[m]ergy:

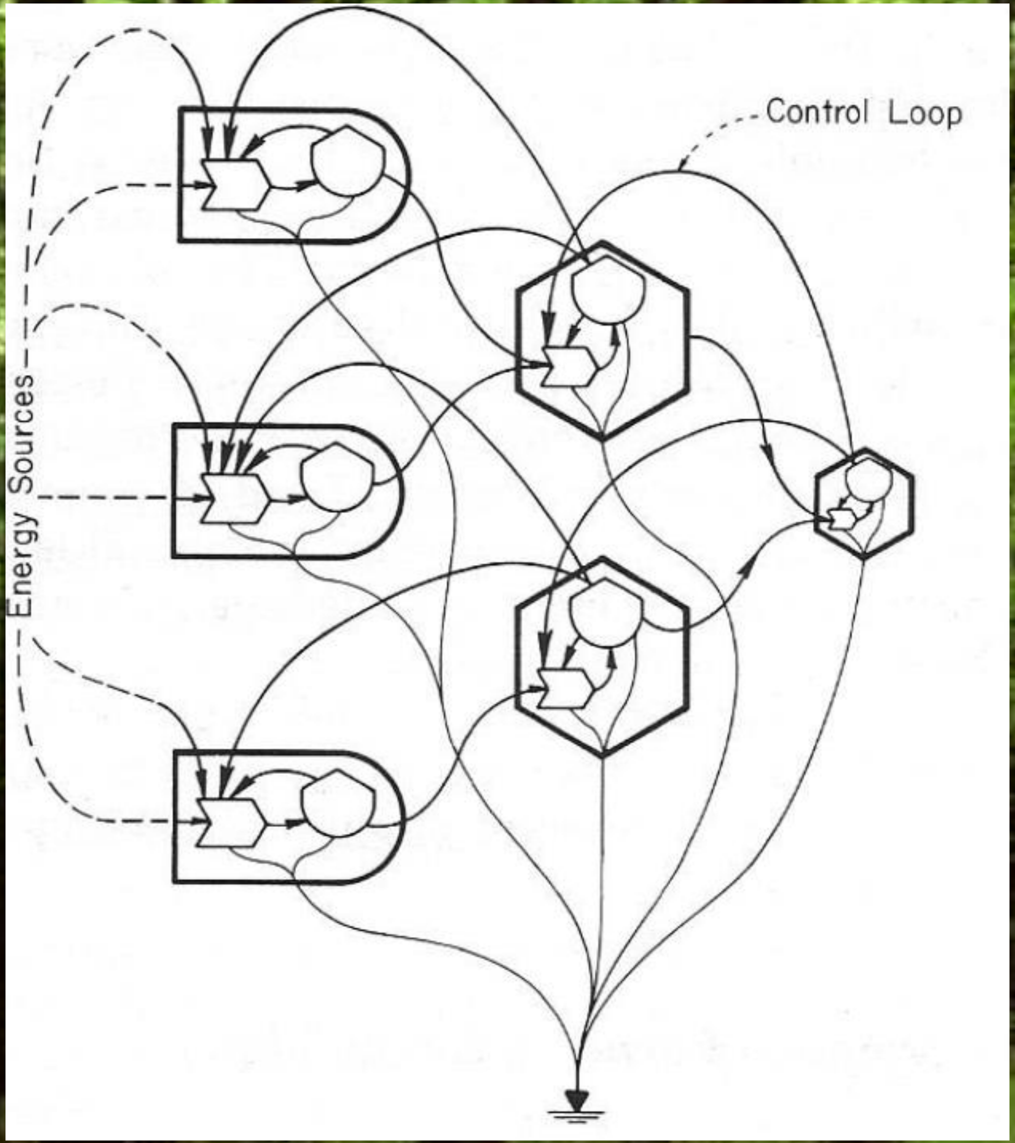
"Em"bodied energy
or cumulative, dissipated exergy
Solar em-Joules, sej

E[m]ergy, sej

Energy, J

E[m]ergy/Energy, sej/J





Three system principles:

4 The Lotka–Odum principle of **maximum e[m]power** as the selection goal toward which self-organizing systems evolve over time.

5 The Lindeman–Odum principle of **energy transformation hierarchies**, which emerge over time to achieve maximum e[m]power.

6 The Odum-Holling principle of **material concentration hierarchies**, closely coupled to energy transformation hierarchies, which **cycle or pulse** at different spatial and temporal scales to achieve maximum e[m]power.

Odum, Systems Ecology, 1983

Carnot

Darwin

Laws

1 The Mayer–Joule principle of the conservation of energy measured as heat equivalents.

2 The Carnot–Clausius principle of the increase of entropy, or loss of available energy, in any energy conversion or work process.

3 The principle of an absolute zero temperature at which the entropy of a perfect crystal is zero.

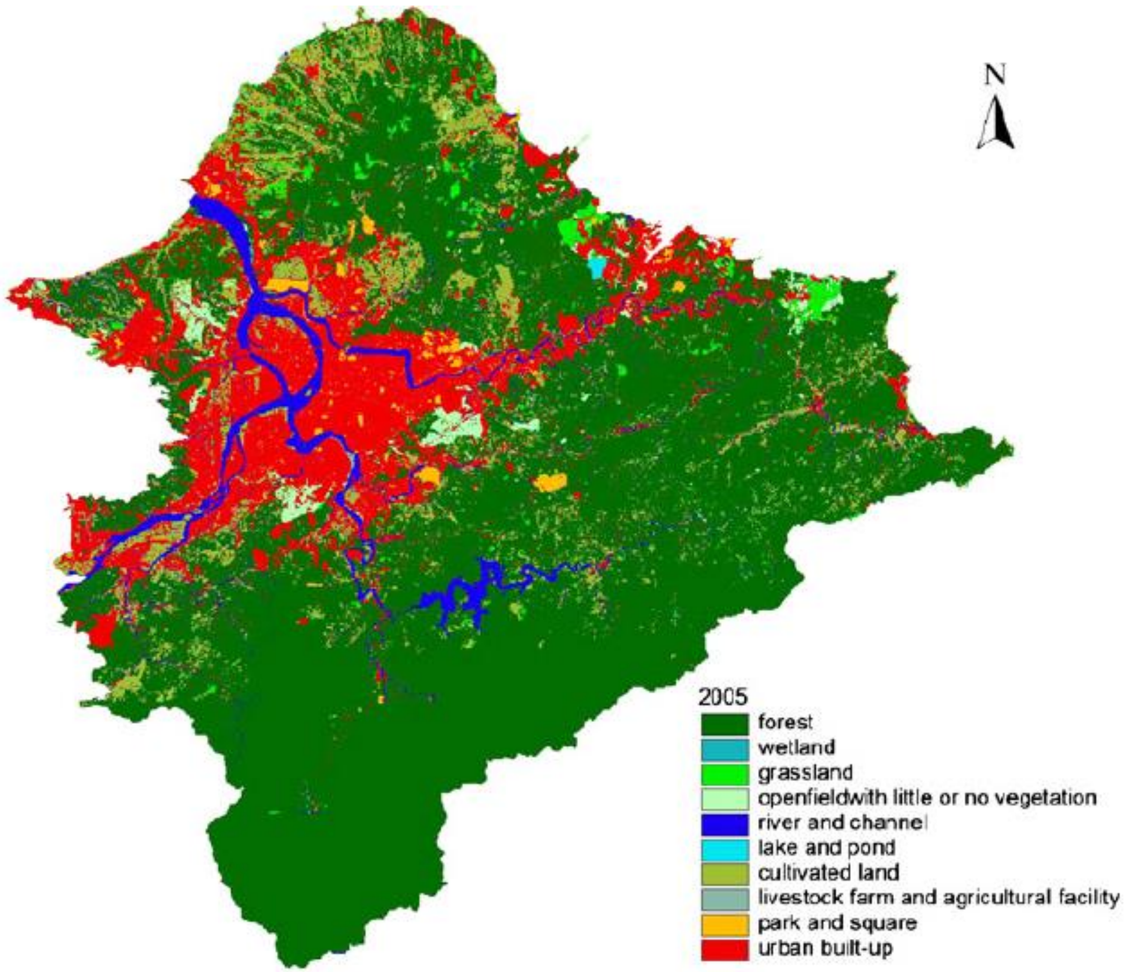
System Principles

4 The Lotka–Odum principle of maximum empower as the final or selection goal toward which self-organizing systems evolve over time.

5 The Lindeman–Odum principle of energy transformation hierarchies, which emerge over time to achieve maximum power.

6 The principle of material concentration hierarchies, closely coupled to energy transformation hierarchies, which cycle or pulse at different spatial and temporal scales to achieve maximum power.

Location (site) **within urban land-use hierarchies**



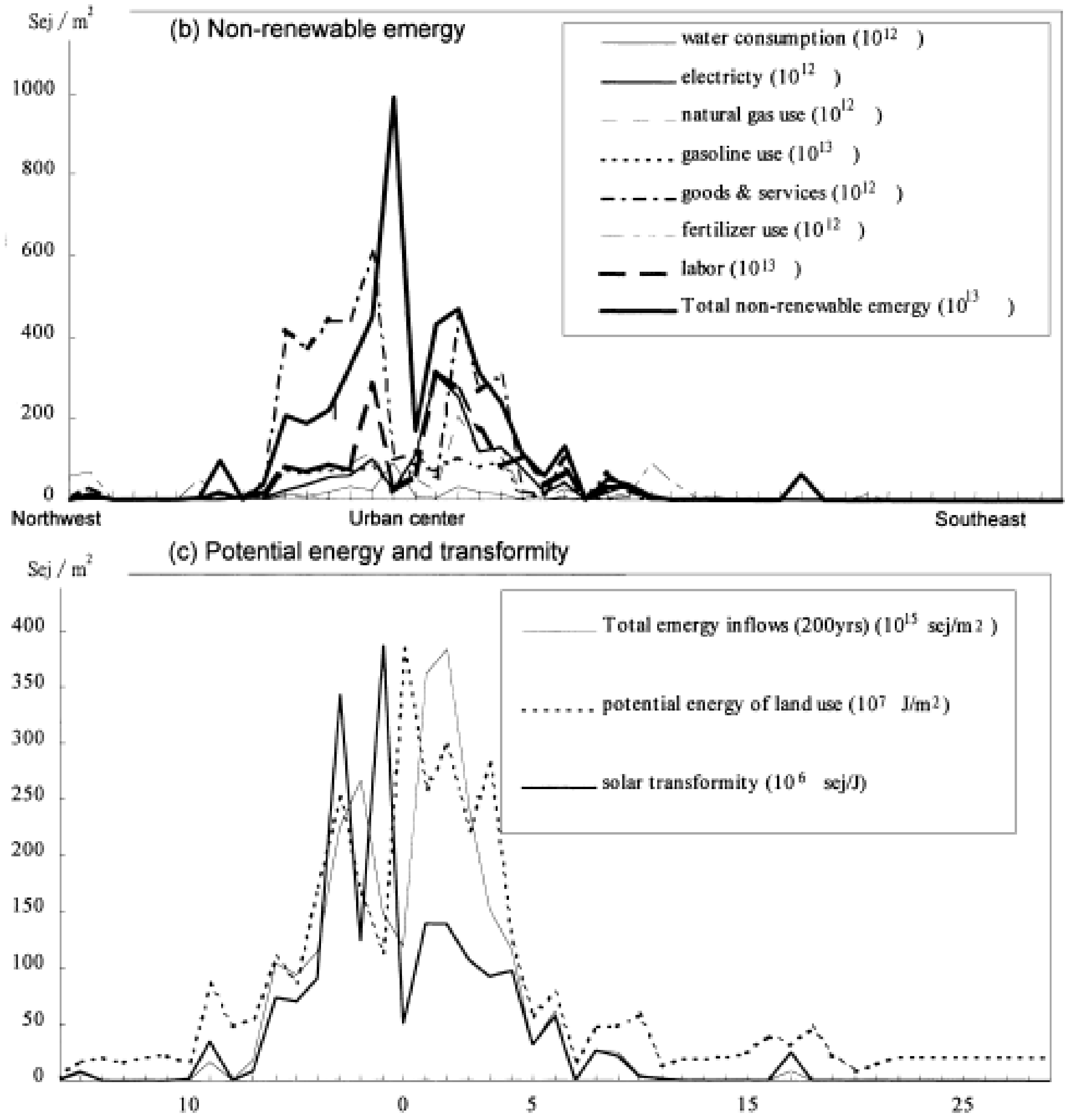


Fig. 4. Northwest–southeast transact of emergy flows and transformity of Taipei metropolitan region.

Huang, "Urban Hierarchy," 2001

Cities by themselves are not sustainable, they gather & concentrate the resources of their region

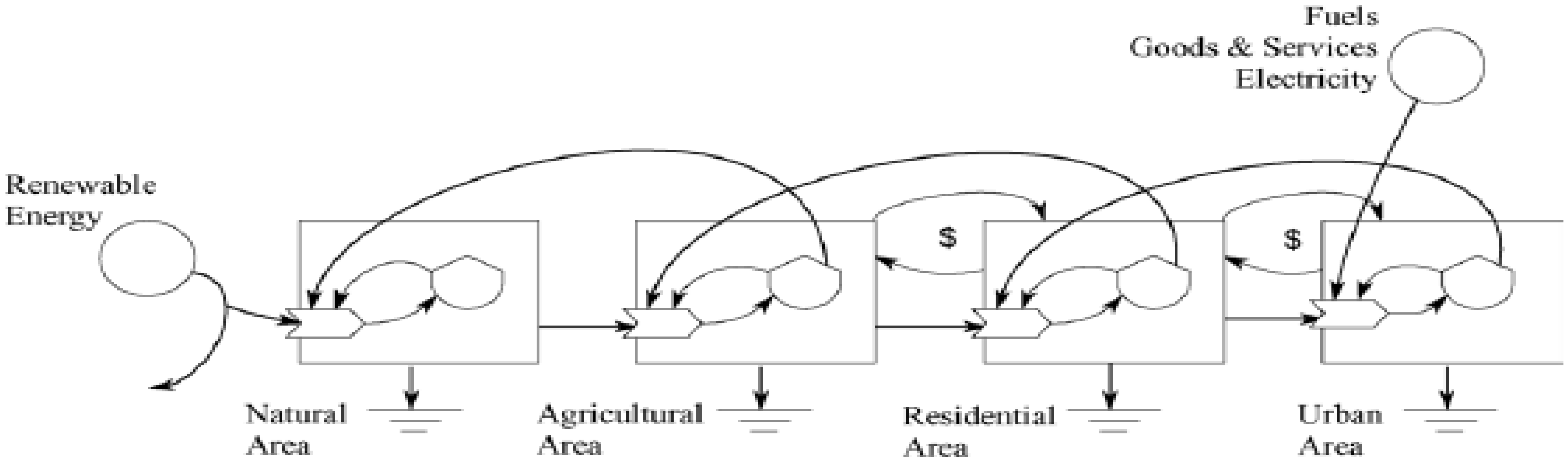
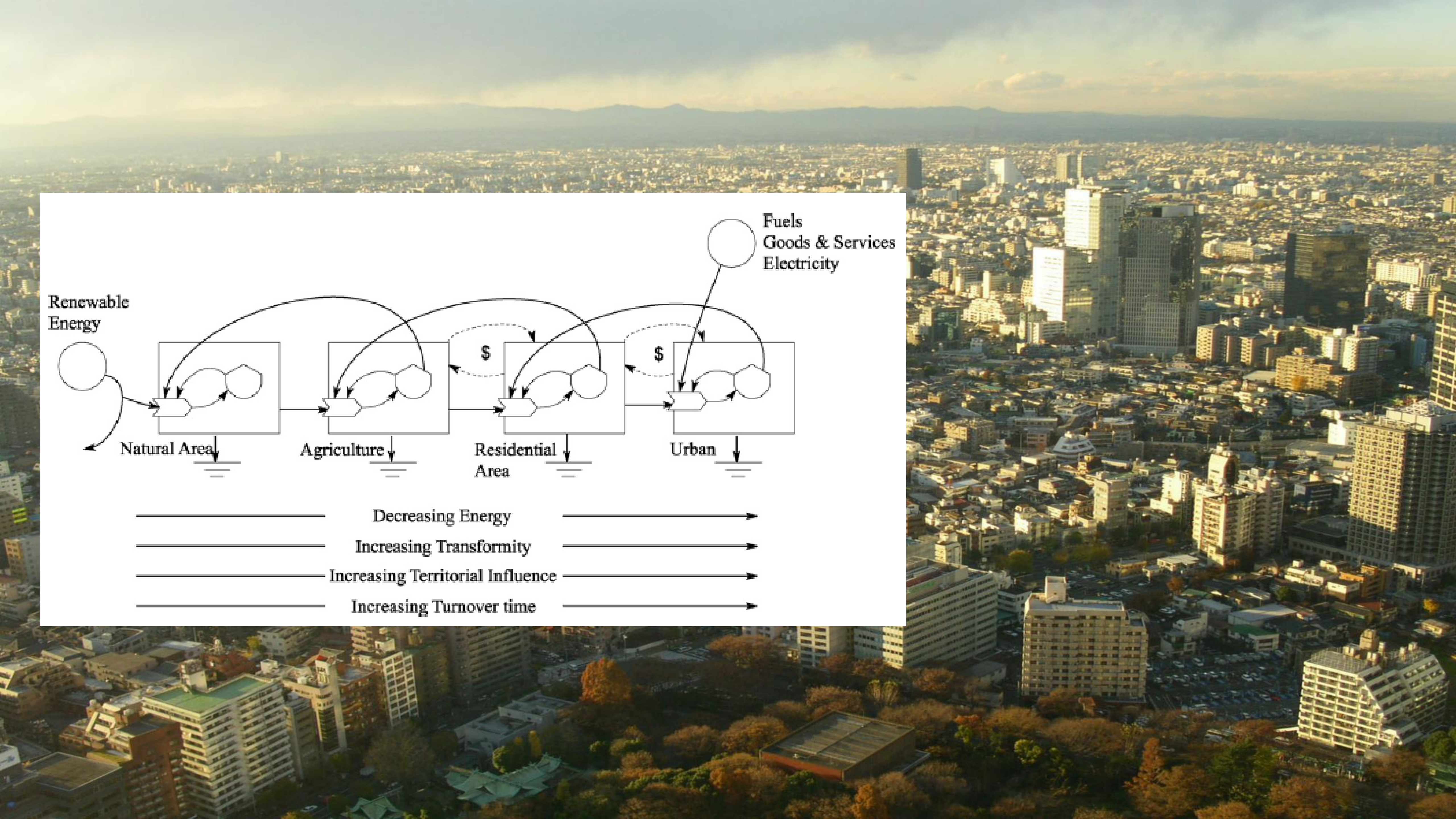


Table 1
Empower densities, turnover time, and transformity of each land use in Taipei metropolitan region

Land use type	Renewable emergy		Non-renewable emergy and economic input		Total empower density (10^{12} sej/m^2)	Potential energy (10^6 J/m^2)	Solar transformity (10^6 sej/J)
	Empower density (10^{12} sej/m^2 per year)	Turnover time (year)	Empower density (10^{10} sej/m^2 per year)	Turnover time (year)			
Forest	60.44	100.00	0.00	0.00	60.44	210.00	0.29
Grassland	36.65	5.00	0.00	0.00	1.83	12.70	0.14
Wetland	33.42	10.00	0.00	0.00	3.34	44.00	0.08
Farm	27.55	20.00	11.75	10.00	123.01	31.90	3.85
River	26.96	1.00	0.00	0.00	0.27	480.00	–[a]
Low density residential	41.30	200.00	1618.68	25.00	78387.10	640.00	122.00
Medium density residential	40.78	200.00	5879.30	50.00	579592.56	1290.00	151.00
High density residential and commercial	42.70	200.00	8158.22	100.00	1129746.40	3020.00	207.00
Industrial	41.99	200.00	1828.91	55.00	181838.08	2250.00	79.80
School	45.81	200.00	1697.60	70.00	166515.22	1200.00	98.00
Institutional	45.32	200.00	1420.79	81.00	232648.12	2250.00	107.00
Utility	45.90	200.00	692.58	65.00	105715.50	1150.00	96.30
Transportation	22.21	200.00	1856.02	70.00	283673.22	8030.00	29.60
Mining	31.43	200.00	49.51	50.00	37087.36	2400.00	15.50
Recreation	42.18	25.00	12.58	12.50	237.80	14.90	10.20
Fallow	22.86	1.00	21.23	0.50	17.97	6.39	2.09
Others	35.20	25.00	565.46	12.50	56403.80	318.00	177.00

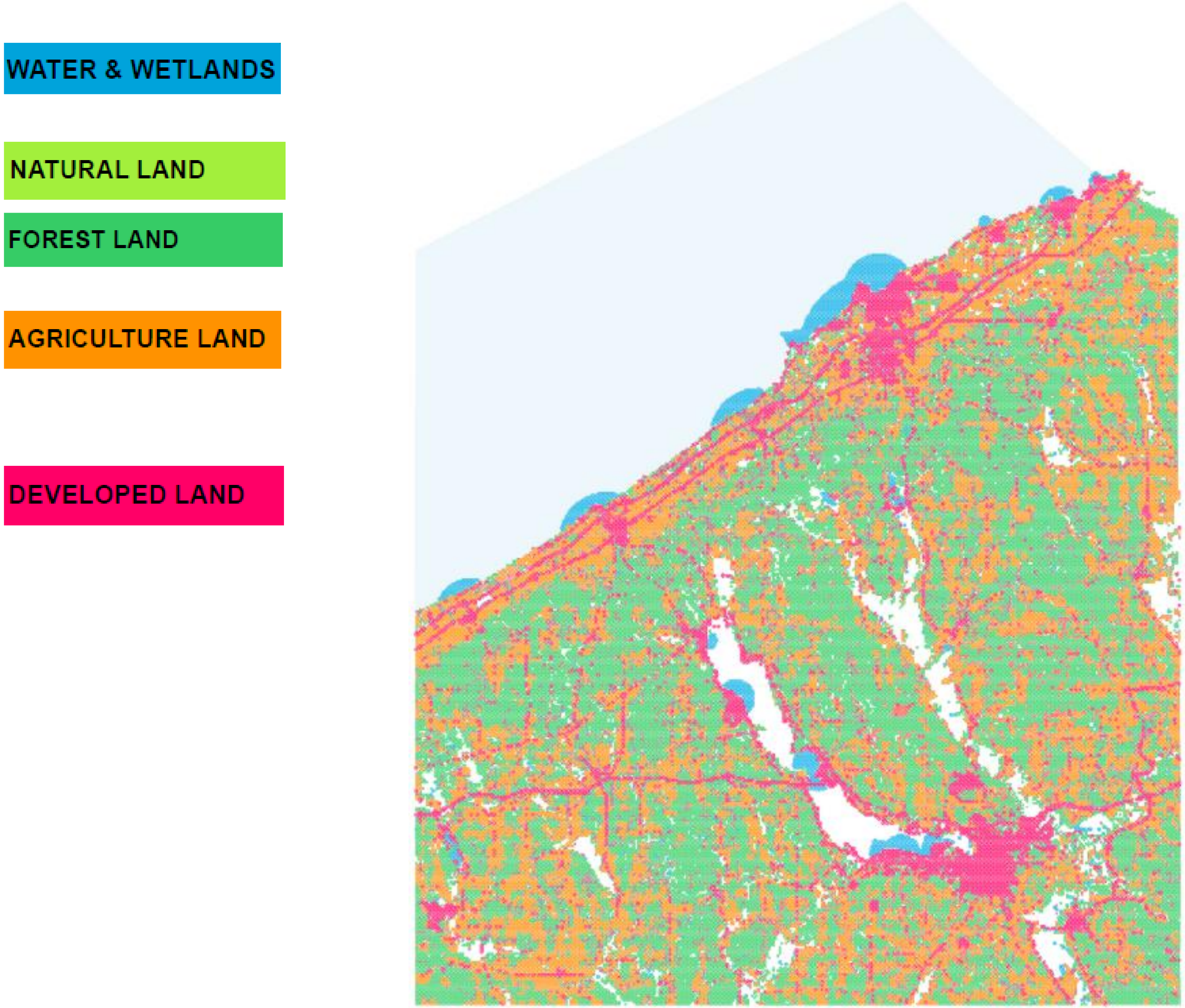
[a] Values less than 0.01.

S.-L. Huang et al. / Landscape and Urban Planning 53 (2001) 145–161


Fuels
Goods & Services
Electricity
Renewable
Energy
$
$
Natural Area
Agriculture
Residential
Area
Urban
Decreasing Energy
Increasing Transformity
Increasing Territorial Influence
Increasing Turnover time

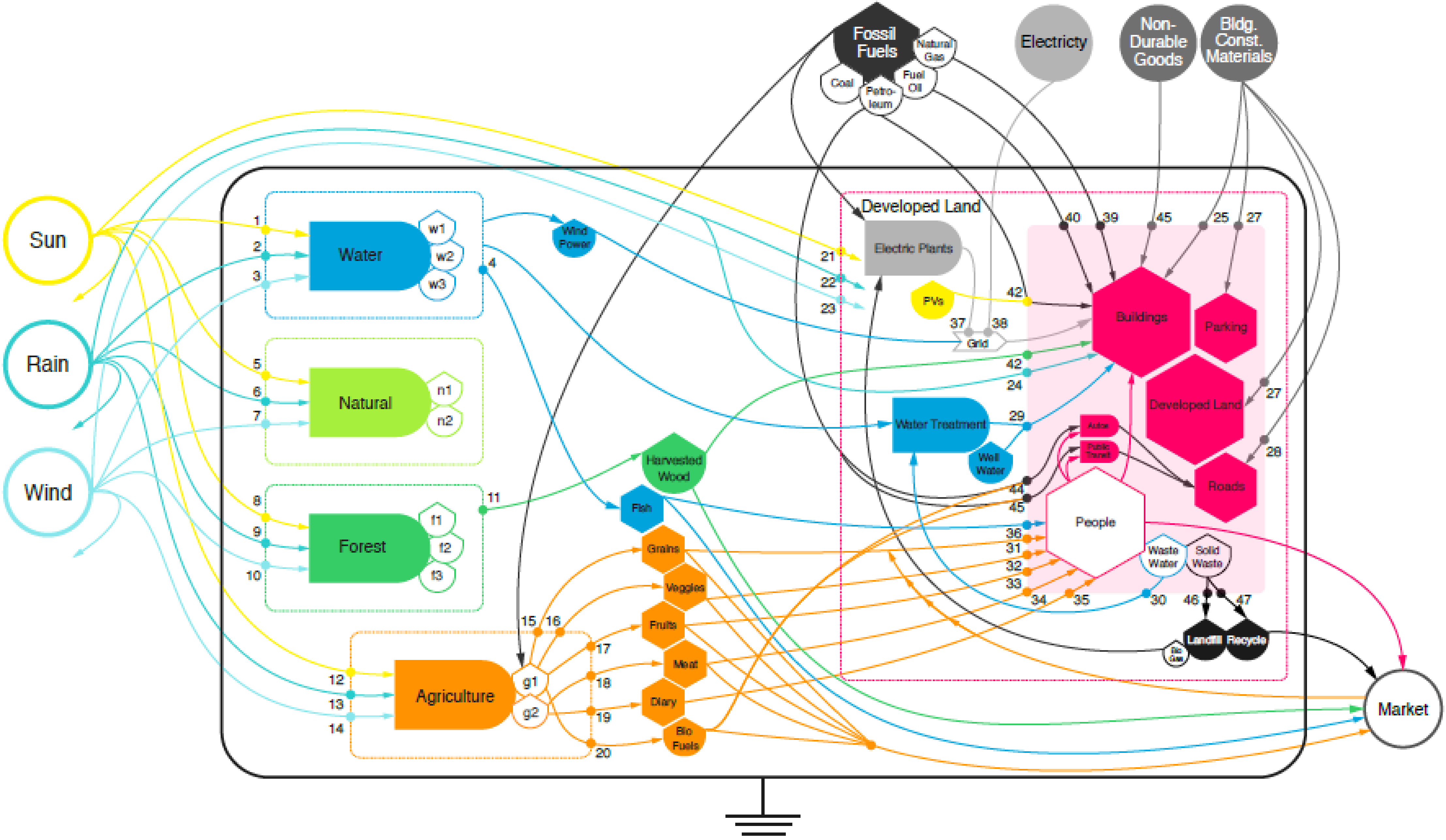
Chautauqua, NY

Existing	Data units/year	Unit Solar Emergy sej/unit	Solar Emergy E14 sej/year	Land Area acres	Normalized Data
WATER & WETLANDS	6.92E+18 J		6,896,803 E14sej	323,981 34%	21.29 E14sej/acre
RENEWABLE INPUTS	6.92E+18 J	1.13E+02	6.67E+06 E14sej	323,981 acres	20.60 E14sej/acre
1 SUNLIGHT	5.84E+18	1.00E+00	58,444 1%	323,981	0.18
2 RAIN - CHEMICAL	1.66E+16	3.02E+04	5,015,289 73%	323,981	15.48
3 WIND KINETIC ENERGY	6.38E+16	2.51E+03	1,600,815 23%	323,981	4.94
PURCHASED INPUTS	8.05E+12 J	2.76E+06	222,255 E14sej	281,178 acres	0.79 E14sej/acre
4 FISH	8.05E+12	2.76E+06	222,255 3%	281,178	0.79
NATURAL LAND	6.78E+17 J		728,582 E14sej	37,062 4%	19.66 E14sej/acre
RENEWABLE INPUTS	6.78E+17 J	1.07E+02	7.29E+05 E14sej	37,062 acres	19.66 E14sej/acre
5 SUNLIGHT	6.69E+17	1.00E+00	6,686 1%	37,062	0.18
6 RAIN - CHEMICAL	1.71E+15	3.02E+04	516,380 71%	37,062	13.93
7 WIND KINETIC ENERGY	8.19E+15	2.51E+03	205,516 28%	37,062	5.55
FOREST LAND	6.20E+18		6,742,142 E14sej	338,758 35%	19.90 E14sej/acre
RENEWABLE INPUTS	6.20E+18 J	1.07E+02	6.66E+06 E14sej	338,758 acres	19.66 E14sej/acre
8 SUNLIGHT	6.11E+18	1.00E+00	61,110 1%	338,758	0.18
9 RAIN - CHEMICAL	1.56E+16	3.02E+04	4,719,644 70%	338,758	13.93
10 WIND KINETIC ENERGY	7.48E+16	2.51E+03	1,878,465 28%	338,758	5.55
PURCHASED INPUTS	1.23E+14 J	6.72E+04	82,923 E14sej	180,558 acres	0.46 E14sej/acre
11 HARVESTED WOOD	1.23E+14	6.72E+04	82,923 1%	180,558	0.46
AGRICULTURE LAND	3.85E+18 J		9,816,620 E14sej	210,464 22%	46.64 E14sej/acre
RENEWABLE INPUTS	3.85E+18 J	1.07E+02	4,137,243.33 E14sej	210,464 acres	19.66 E14sej/acre
12 SUNLIGHT	3.80E+18	1.00E+00	37,966 0%	210,464	0.18
13 RAIN - CHEMICAL	9.70E+15	3.02E+04	2,932,223 30%	210,464	13.93
14 WIND KINETIC ENERGY	4.65E+16	2.51E+03	1,167,054 12%	210,464	5.55
PURCHASED INPUTS	1.29E+15 J	4.42E+05	5,679,377 E14sej	150,567 acres	37.72 E14sej/acre
15 GRAIN CROPS HARVESTED	7.84E+14	5.87E+05	4,604,540 47%	86,066	53.50
16 VEGETABLES HARVESTED	2.30E+11	2.31E+05	530 0%	349	1.52
17 FRUITS HARVESTED	3.55E+14	1.89E+05	670,999 7%	19,440	34.52
18 MEAT PRODUCED	6.44E+12	8.60E+05	55,368 1%	16,375	3.38
19 MILK PRODUCED	2.00E+13	6.00E+05	119,943 1%	23,936	5.01
20 BIOFUELS PRODUCED	1.21E+14	1.89E+05	227,998 2%	4,401	51.81
DEVELOPED LAND			42,361,681 E14sej	49,850 5%	849.78 E14sej/ acre
RENEWABLE INPUTS	9.01E+17	2.90E+01	260,879 E14sej	49,850	5.23 E14sej/acre
21 SUNLIGHT	8.99E+17	1.00E+00	8,993 0%	49,850	0.18
22 RAIN - CHEMICAL	7.88E+14	3.02E+04	238,411 1%	49,850	4.78
23 WIND KINETIC ENERGY	5.20E+14	2.51E+03	13,053 0%	49,850	0.26
24 RAIN - GEOPOTENTIAL	9.00E+11	4.70E+04	423 0%	4,256	0.10
PURCHASED INPUTS			42,100,802 E14sej	49,850	844.55 E14sej/acre
Construction Materials	2.77E+08 m^2	8.32E+11	2,305,101 E14sej	49,850	46.24 E14sej/acre
25 BUILDING CONSTRUCTION	9.26E+07	2.36E+12	43,714 2%	4,256	10.27
27 PARKING CONSTRUCTION	5.08E+06	3.08E+13	1,563,525 68%	1,254	1,246.43
27 DEVELOPED LAND	1.41E+08	7.00E+10	98,355 4%	34,720	2.83
28 ROAD CONSTRUCTION	3.89E+07	3.08E+13	599,507 26%	9,620	62.32
Water	4.86E+10 L	7.25E+08	352,002 E14sej		2.61 E14sej/person
29 POTABLE WATER	2.88E+10	1.22E+09	351,250 100%		2.60
30 WASTE WATER	1.98E+10	3.80E+06	752 0%		0.01
Food	4.00E+14 J	1.18E+06	4,709,023 E14sej		34.91 E14sej/person
31 GRAINS + CEREALS	1.84E+14	6.00E+05	1,105,482 23%		8.19
32 VEGETABLES	4.33E+13	6.00E+05	45,642 1%		0.34
33 FRUITS	3.73E+13	6.00E+05	223,901 5%		1.66
34 MEAT	9.42E+13	3.27E+06	3,080,922 65%		22.84
35 DAIRY	2.00E+13	6.00E+05	119,943 3%		0.89
36 FISH	2.05E+13	6.50E+05	133,134 3%		0.99
Utilities	1.77E+16 J	1.49E+05	26,391,215 E14sej		195.63 E14sej/person
37 ELECTRICTY PRODUCED IN CHAUTAUQUA	2.59E+15	3.42E+05	8,866,976 34%		65.73
38 ELECTRICTY PRODUCED OUTSIDE COUNTY	5.82E+15	2.21E+05	12,875,581 49%		95.44
39 NATURAL GAS	7.70E+15	4.00E+04	3,080,891 12%		22.84
40 FUEL OIL	9.97E+14	5.54E+04	552,592 2%		4.10
41 BIOMASS	1.46E+14	6.72E+04	98,060 0%		0.73
42 OTHER	4.82E+14	1.90E+05	917,116 3%		6.80
Transportation Fuels	1.78E+08 g	1.83E+12	3,262,253 E14sej		24.18 E14sej/person
43 VEHICLE GASOLINE CONSUMPTION	1.78E+08 g	2.97E+11	3,262,172 100%		24.18
44 PUBLIC TRANSIT GASOLINE CONSUMPTION	2.78E+06 g	2.92E+09	81 0%		0.00
Other			5,081,208 E14sej		37.67 E14sej/person
45 NONDURABLE GOODS	1.81E+08 $	2.50E+12	4,527,943 89%		33.56
46 SOLID WASTE GENERATED	1.78E+08 g	2.97E+11	521,593 10%		3.87
47 RECYCLED CONTENT GENERATED	9.24E+07 g	3.43E+10	31,672 1%		0.23
		RENWABLE INPUTS	**18,682,707 e14 sej**	**960,115 acres**	**84.81 e14 sej/acre**
		PURCHASED INPUTS	**48,085,357 e14 sej**		**883.52 e14 sej/acre**

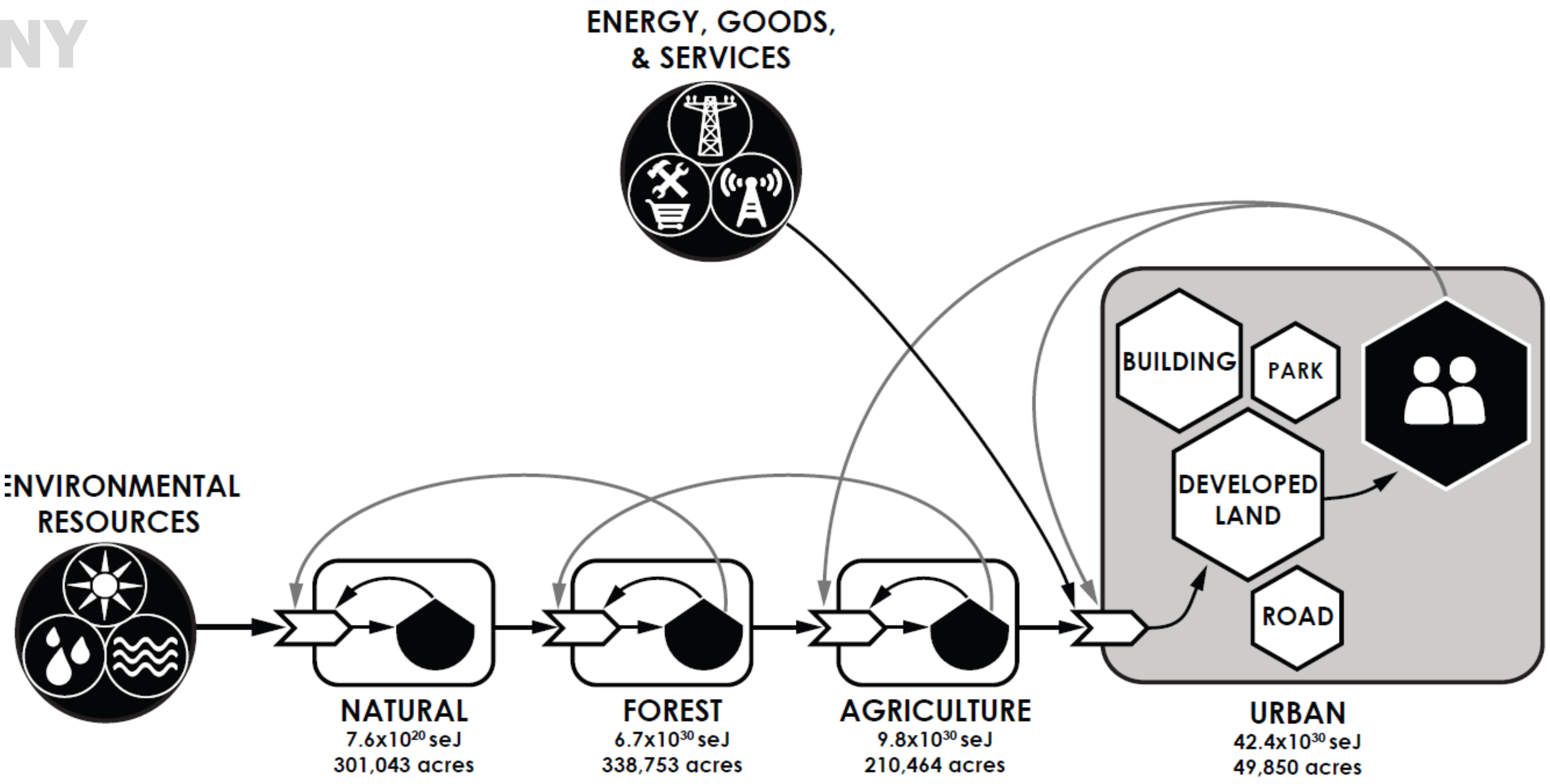


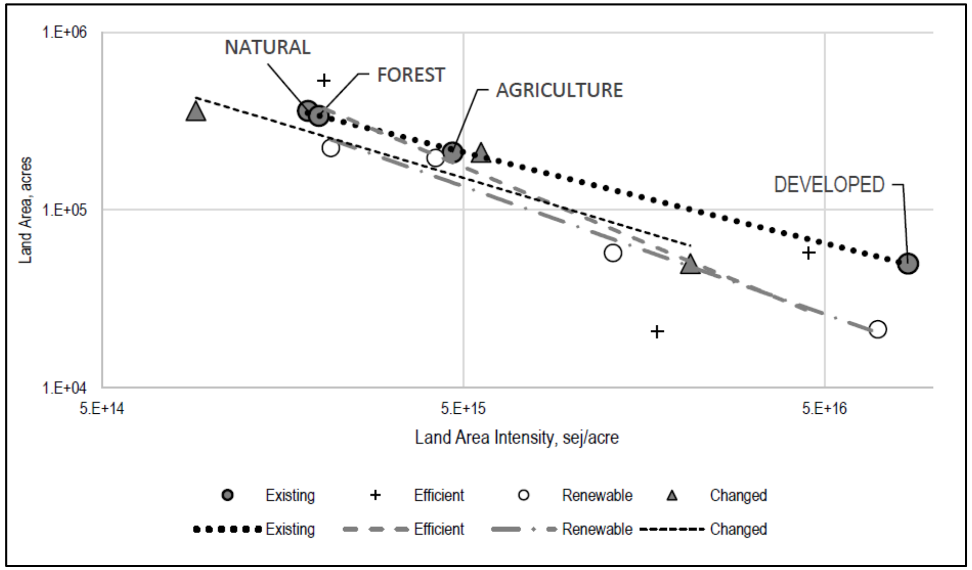
Luke Butcher and Jill Sornson Kurtz

Chautauqua, NY

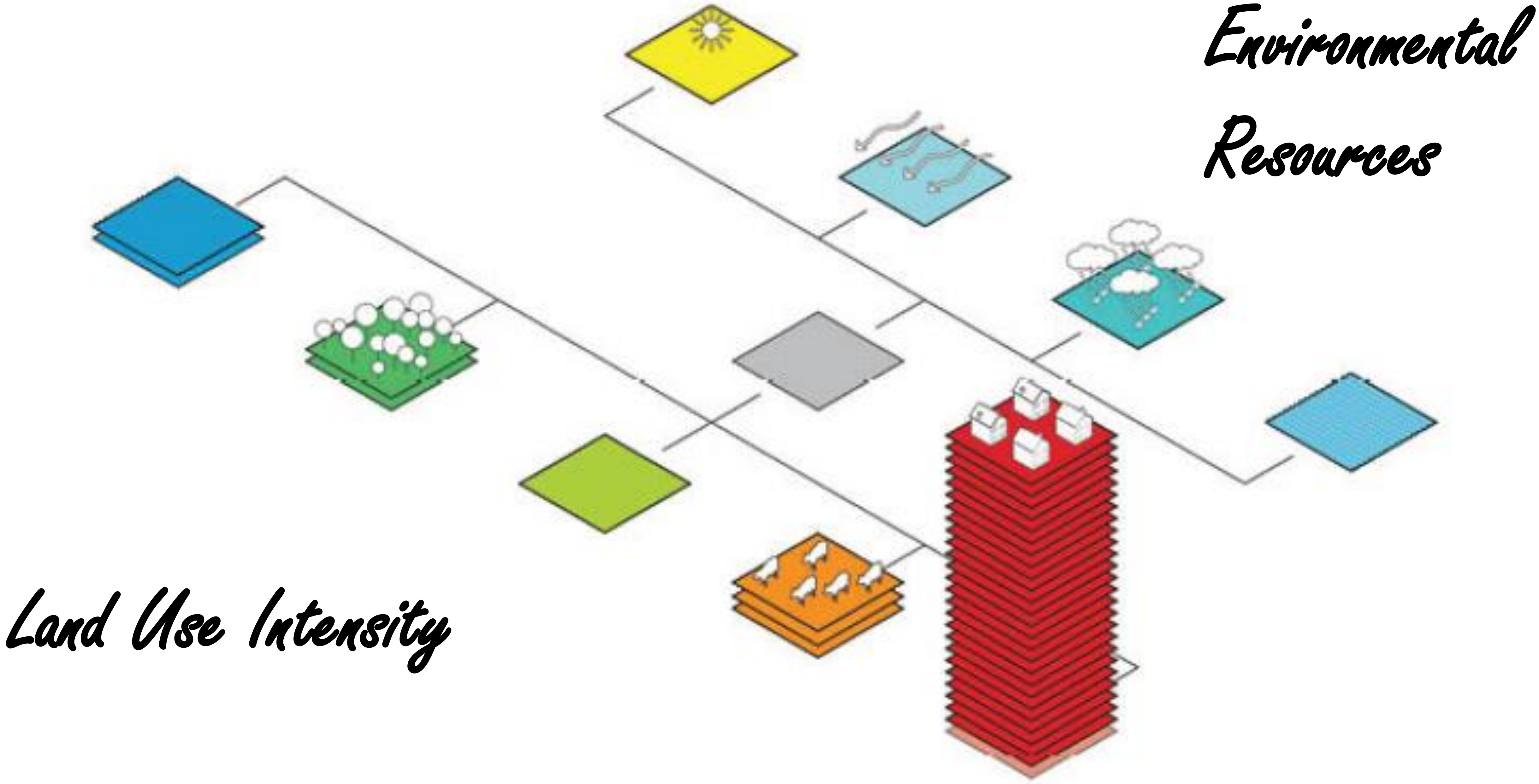


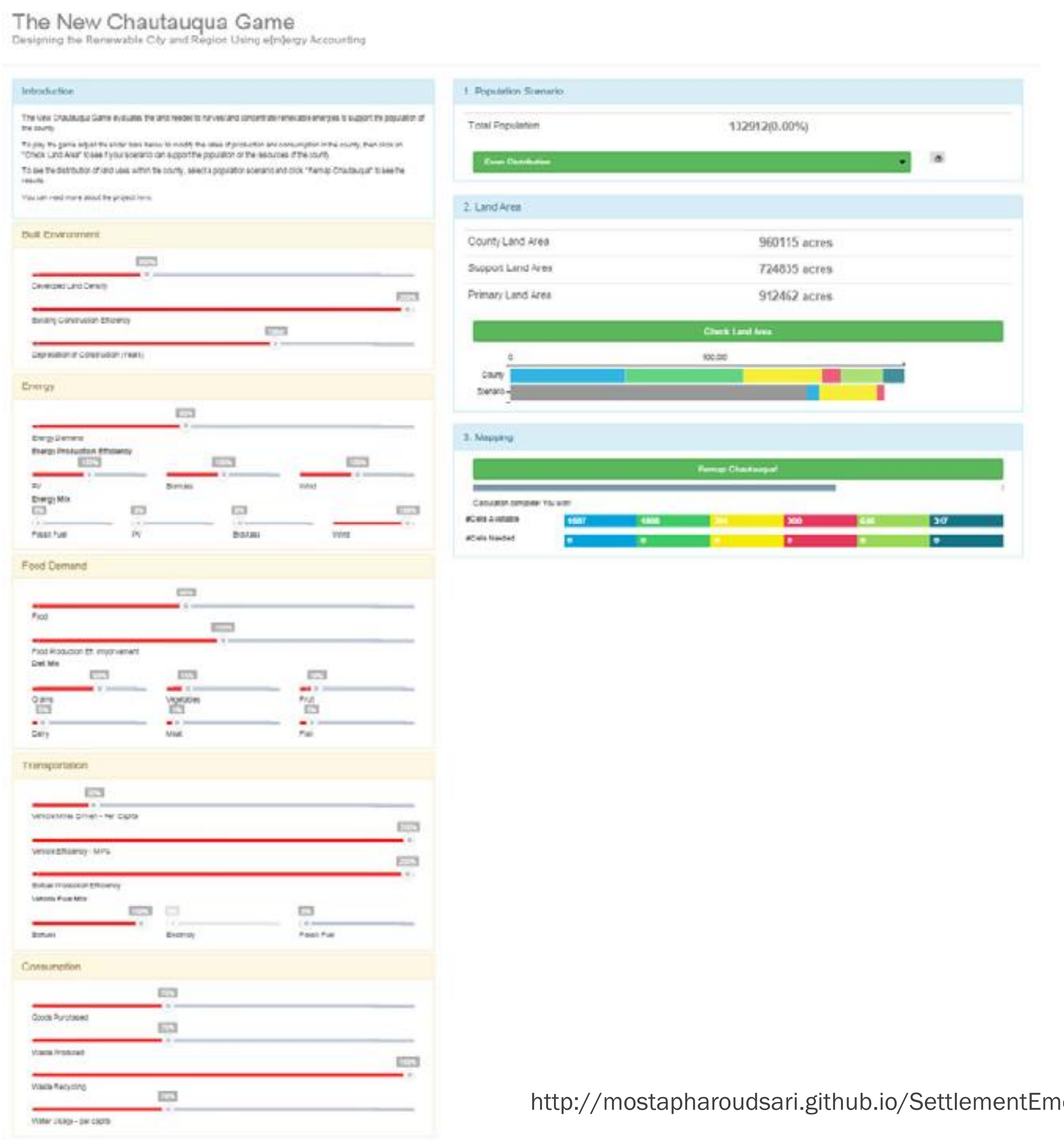
Chautauqua, NY






Land Use

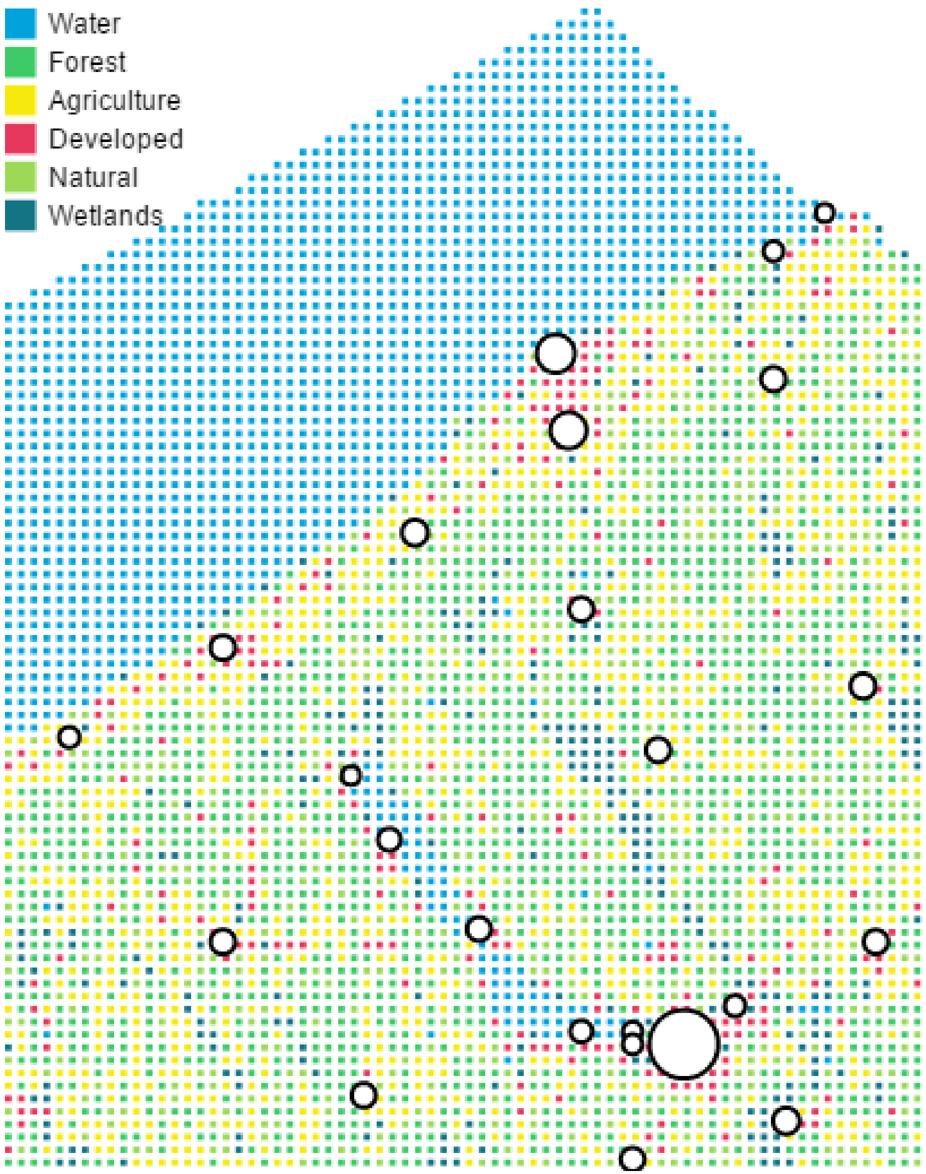

Environmental Resources
Land Use Intensity



http://mostapharoudsari.github.io/SettlementEmerge/

Oops! You need 9.36 Chautauquas to support this lifestyle. Maybe you should try something different?

* Each cell represnts 159.46 acres.



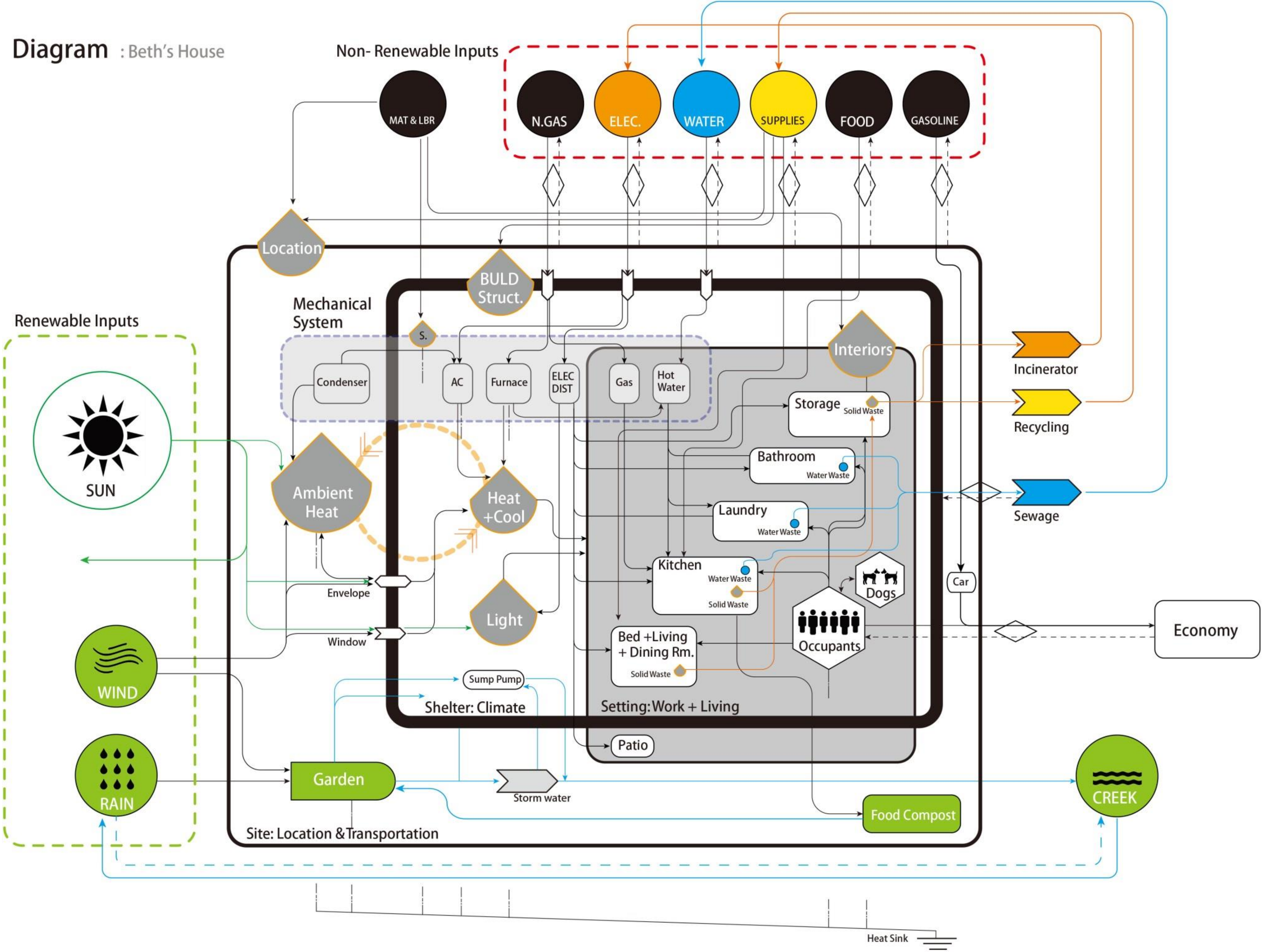
Primary & Support Land

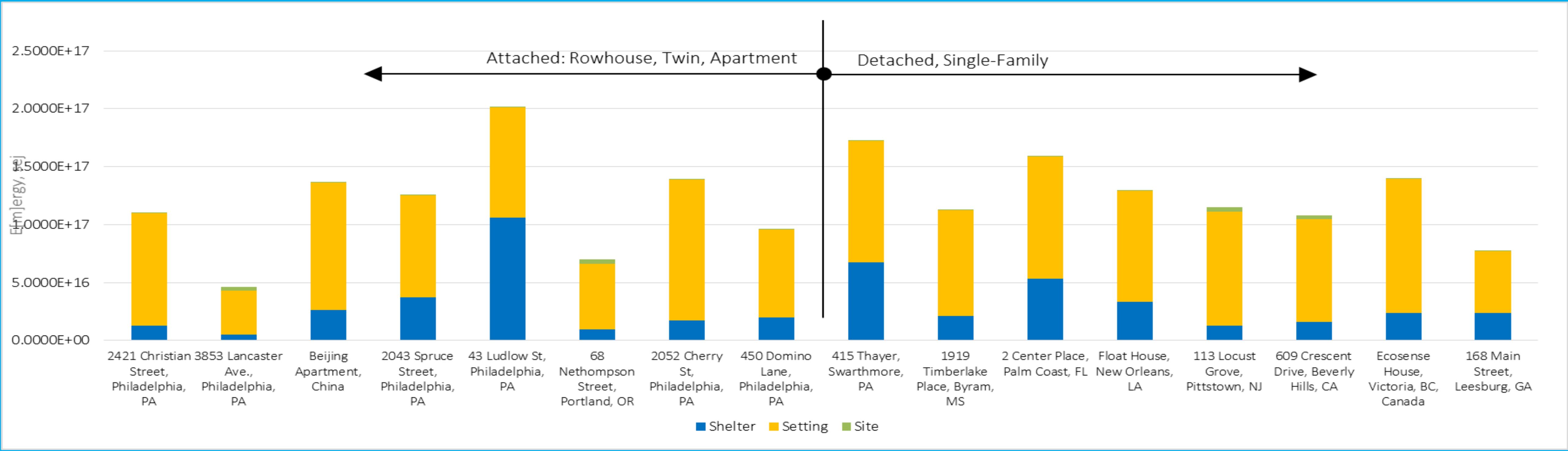
for 1 acre of
bioethanol from corn

[21,300,000 kJ]

	Primary Land	Support Land
Oil Well	1/454 Acre	7 Acres *(in the distant past)*
Corn Field	1 Acre	7 Acres

Diagram : Beth's House





2.5000E+17
2.0000E+17
1.5000E+17
1.0000E+17
5.0000E+16
0.0000E+00
Attached: Rowhouse, Twin, Apartment
Detached, Single-Family
2421 Christian Street, Philadelphia, PA
3853 Lancaster Ave., Philadelphia, PA
Beijing Apartment, China
2043 Spruce Street, Philadelphia, PA
43 Ludlow St, Philadelphia, PA
68 Nethompson Street, Portland, OR
2052 Cherry St, Philadelphia, PA
450 Domino Lane, Philadelphia, PA
415 Thayer, Swarthmore, PA
1919 Timberlake Place, Byram, MS
2 Center Place, Palm Coast, FL
Float House, New Orleans, LA
113 Locust Grove, Pittstown, NJ
609 Crescent Drive, Beverly Hills, CA
Ecosense House, Victoria, BC, Canada
168 Main Street, Leesburg, GA
Shelter
Setting
Site

Material Flows

Water

Wastewater

Food

Supplies

Trash

Labor

Fuels

Electricity

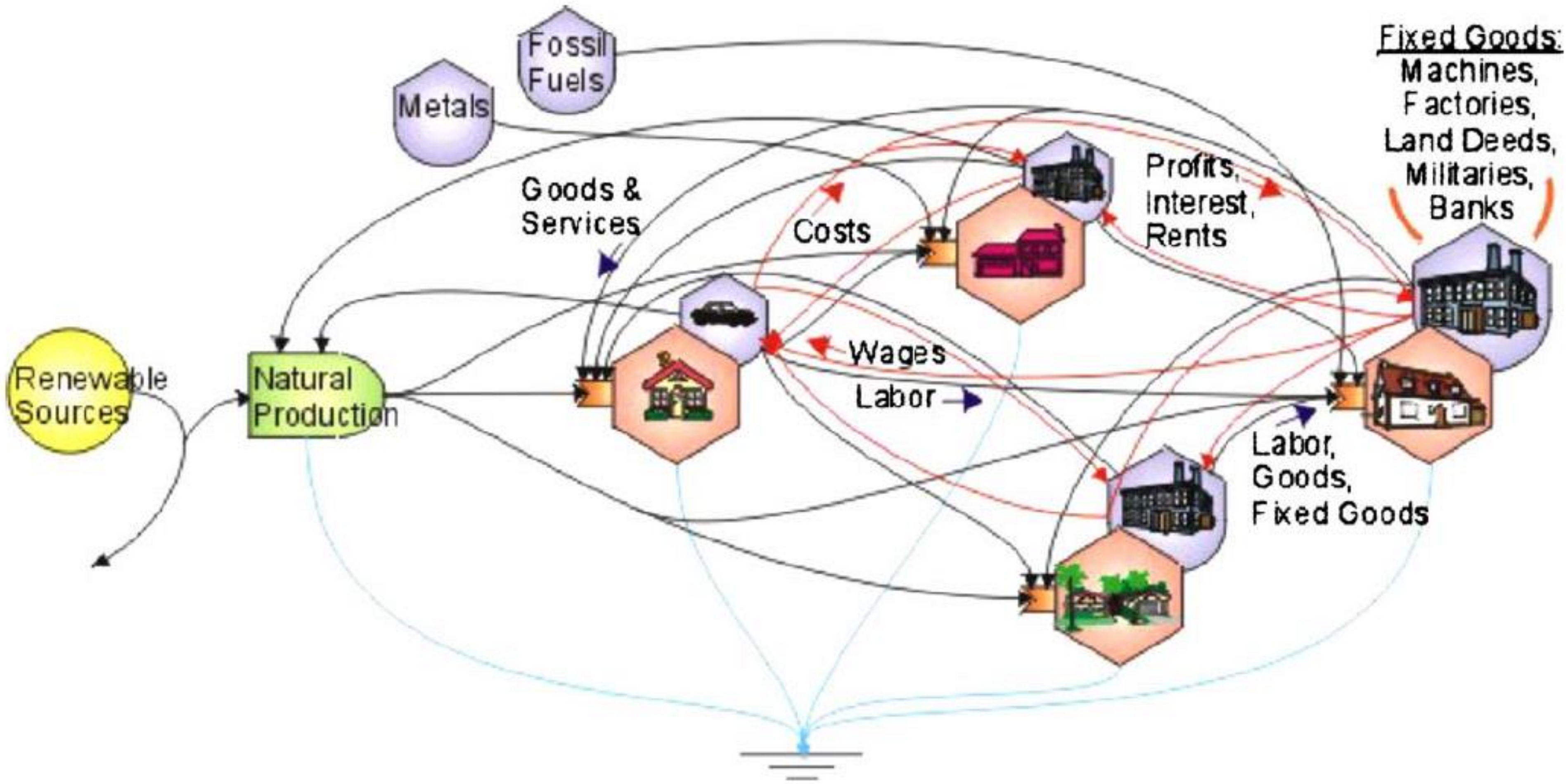
Information

Currency

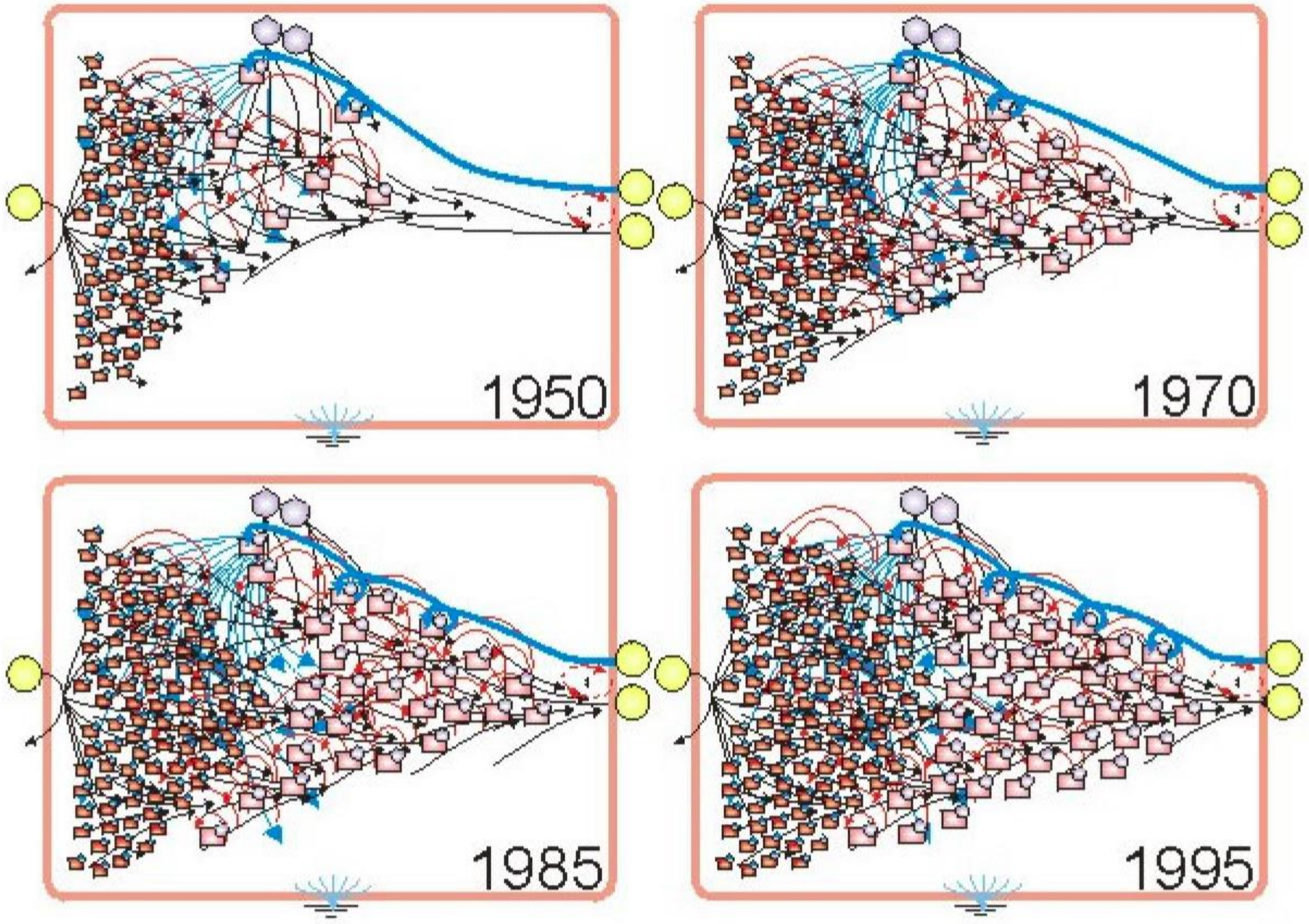
Concentrated Flows

Greater transformity
Less material

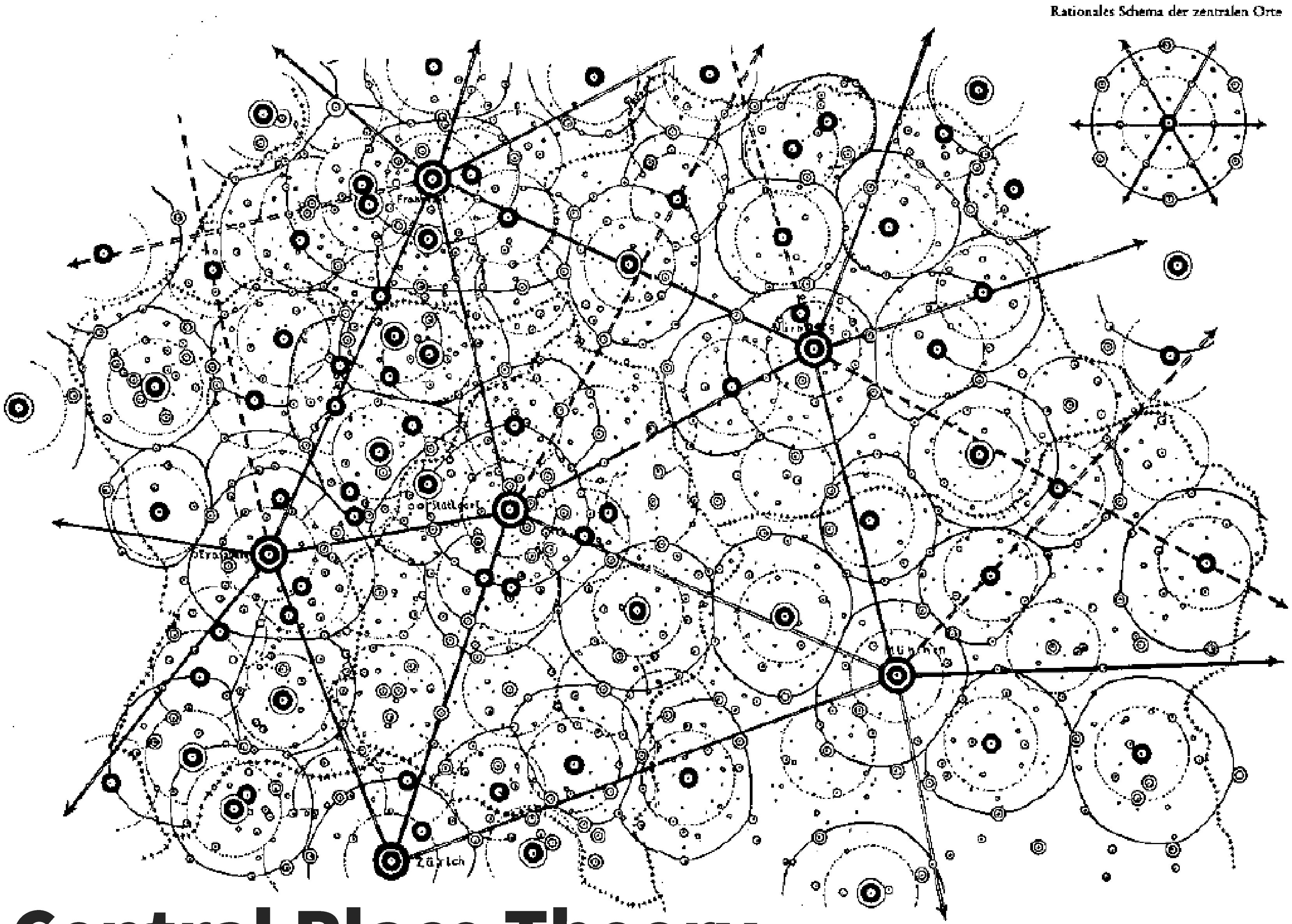
Location (site) **within socio-economic hierarchies**



Abel, "Systems diagrams for visualizing macro-economics," 2004


1950
1970
1985
1995

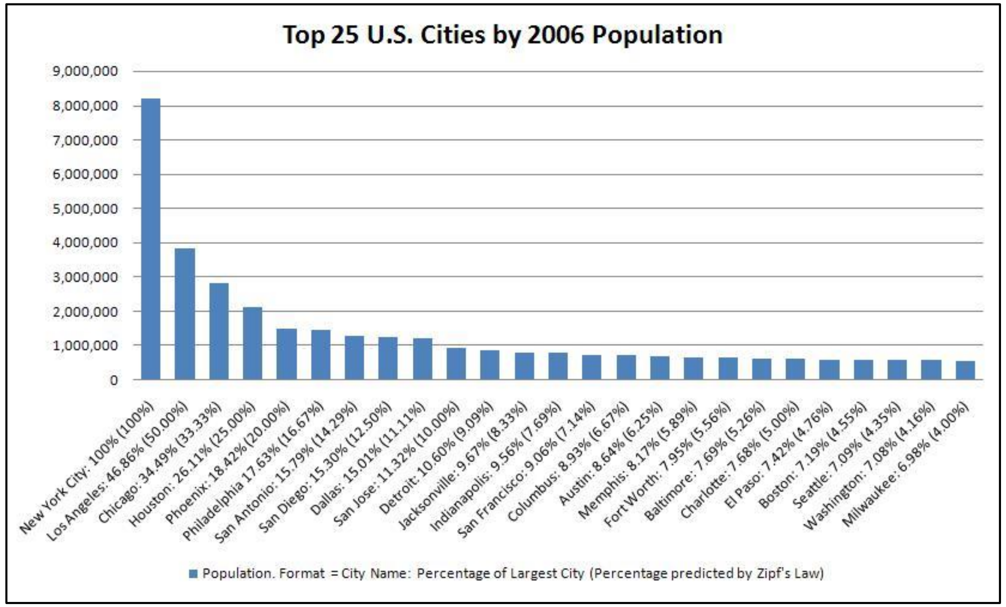
City size

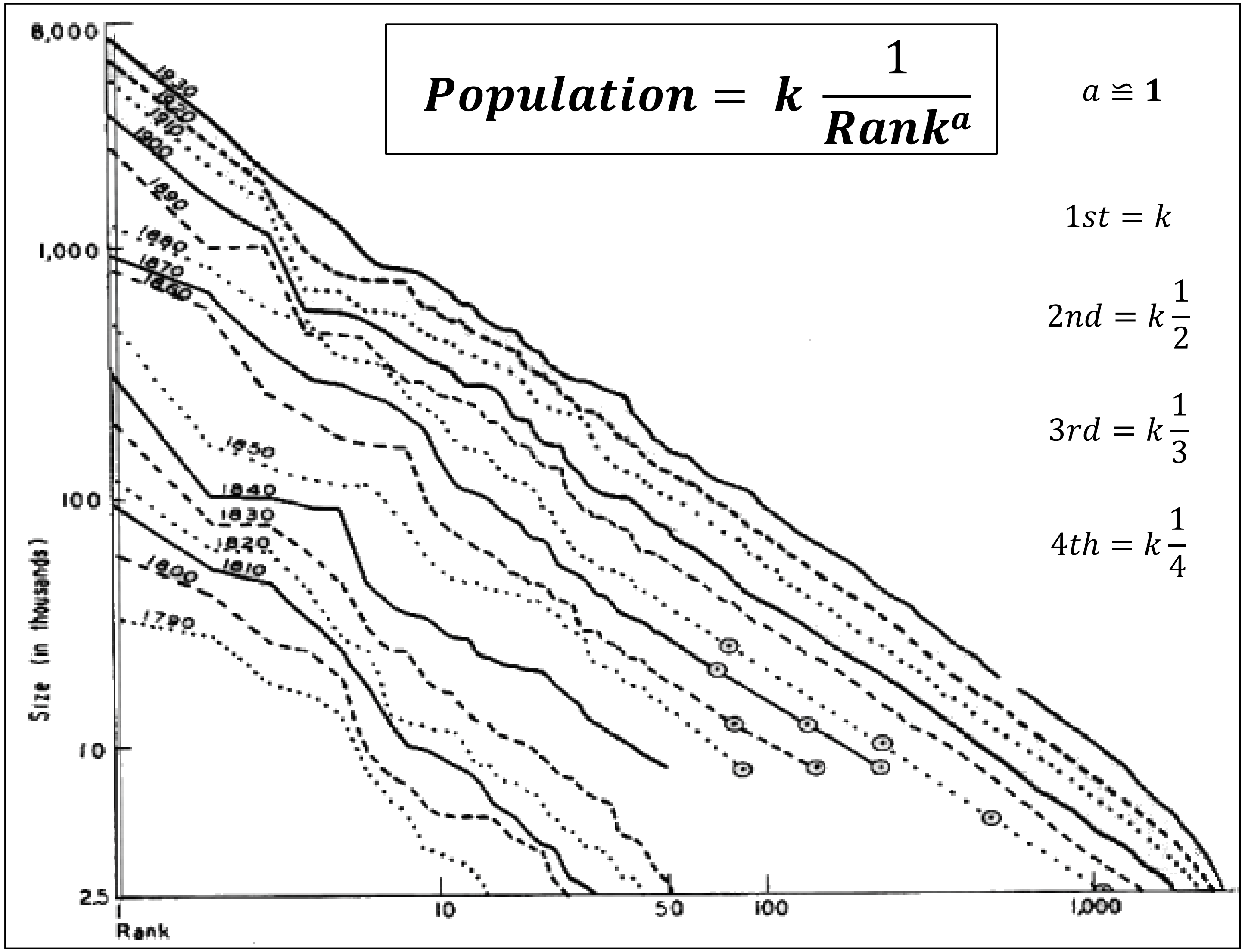


Central Place Theory

Christwaller, 1950

Zipf distribution, “Rank-Size Rule” for US Cities





$$Population = k \frac{1}{Rank^a}$$

$$a \cong \mathbf{1}$$

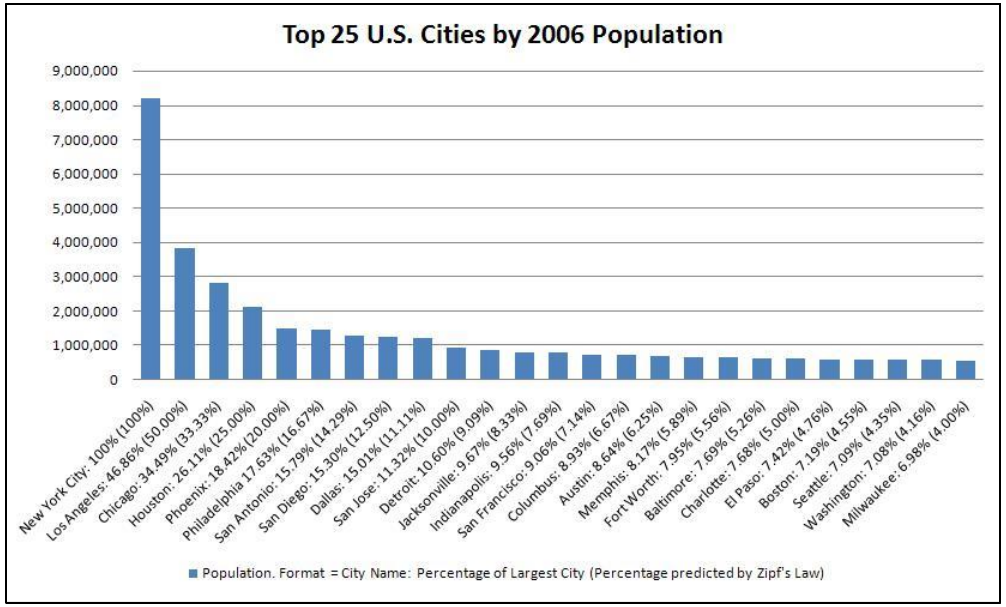
$$1st = k$$

$$2nd = k\frac{1}{2}$$

$$3rd = k\frac{1}{3}$$

$$4th = k\frac{1}{4}$$

Zipf distribution, “Rank-Size” for US Cities



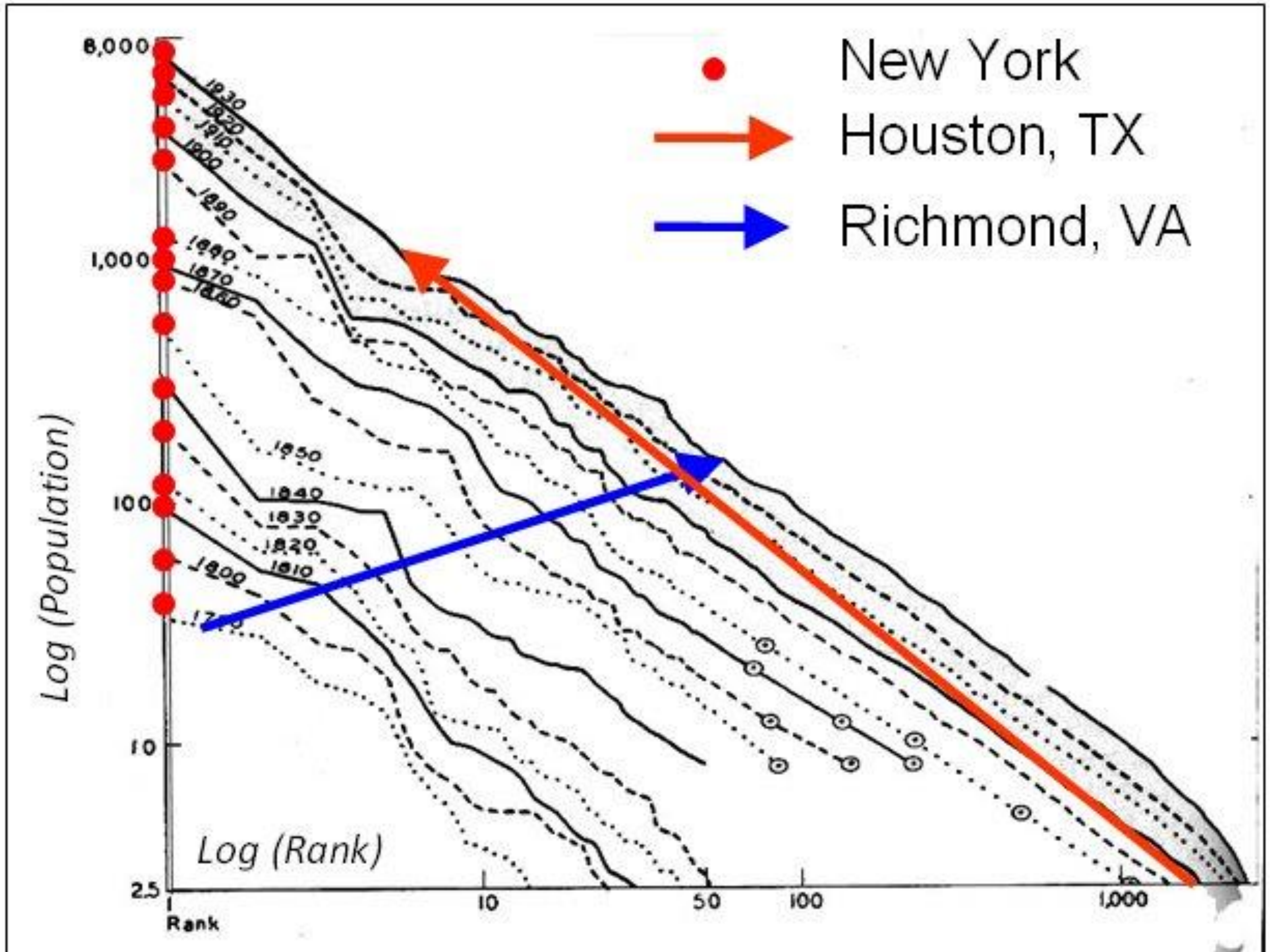
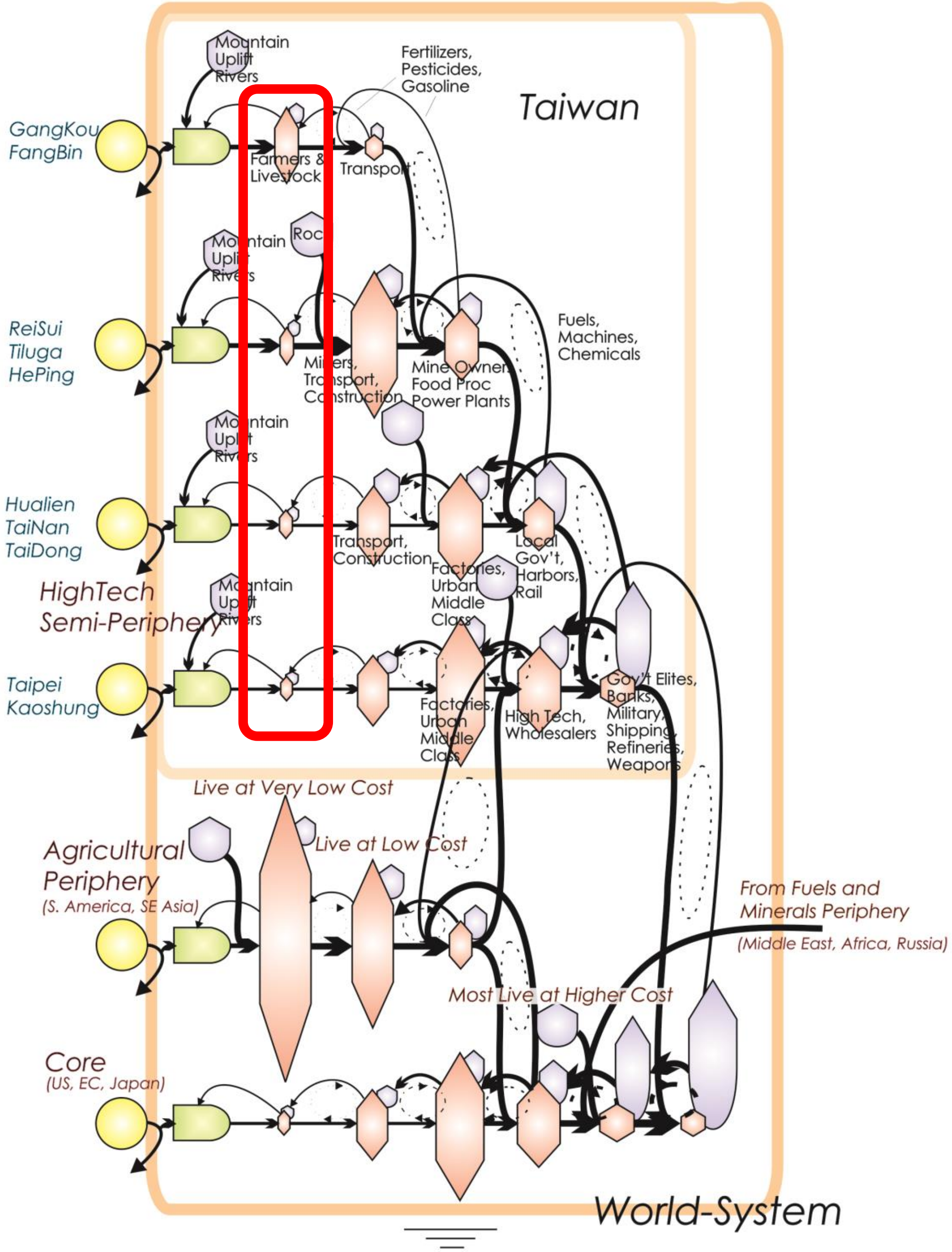
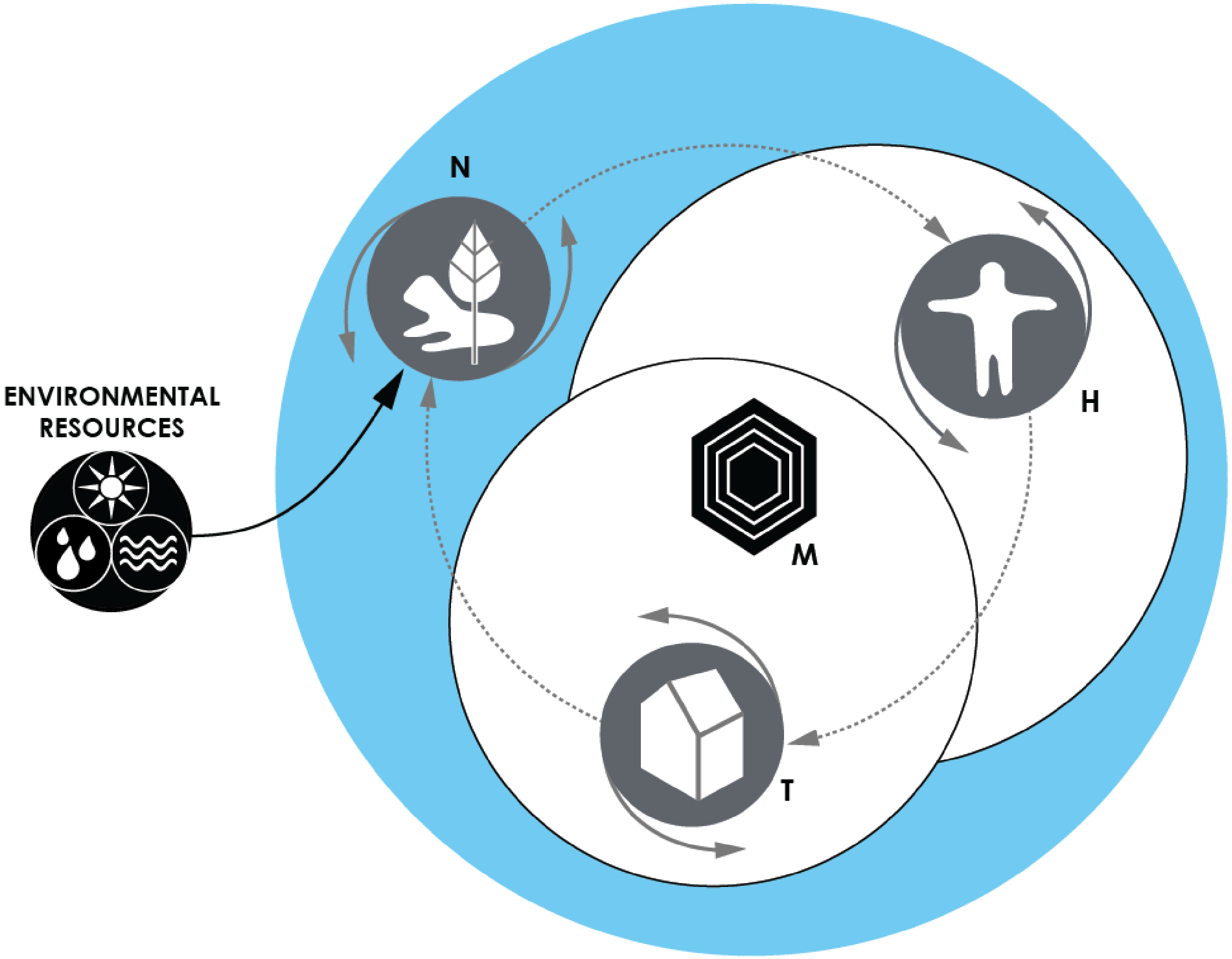


Fig. 10–2. U. S. A. 1790–1930. Communities of 2500 or more inhabitants rank in the decreasing order of population size.

From George Kingsley Zipf (1949) ***Human Behavior and the Principle of Least Effort*** (Addison-Wesley, Cambridge, MA)


Beijing
North Korea
Aomori
Sea of Japan
Akita
Japan
Niigata
South Korea
Nagano
Mito
Nagoya
Tokyo
China
Gwangju
Busan
Fukuoka
Osaka
Oita
Chengdu
Wuhan
Shanghai
Nagasaki
Kumamoto
Kagoshima
East China Sea
Chongqing
Naha
A
Taiwan
Guangzhou
Hà Nội
Hong Kong
Macau
Laos
South China Sea
Manila
Vietnam
Cambodia
Philippines
Ho Chi Minh City
Phnom Penh
Sulu Sea
Celebes Sea


Mountain Uplift Rivers
Fertilizers, Pesticides, Gasoline
Taiwan
GangKou FangBin
Farmers & Livestock
Transport
ReiSui Tiluga HePing
Miners, Transport, Construction
Mine Owners, Food Proc, Power Plants
Fuels, Machines, Chemicals
Hualien TaiNan TaiDong
Transport, Construction
Factories, Urban Middle Class
Local Gov't, Harbors, Rail
HighTech Semi-Periphery
Taipei Kaoshung
High Tech, Wholesalers
Gov't Elites, Banks, Military, Shipping, Refineries, Weapons
Live at Very Low Cost
Live at Low Cost
Agricultural Periphery
(S. America, SE Asia)
From Fuels and Minerals Periphery
(Middle East, Africa, Russia)
Most Live at Higher Cost
Core
(US, EC, Japan)
World-System



H – Human
T – Technological
N - Natural

System Principle of Thermodynamics