Energy and Society

Development stages

- Pre-agricultural era (human power)
- Agricultural era (animal power)
- Mechanical power era
- Fossil fuels
- Electricity

Foraging society

- Energy needs covered by human body
- Sustained power 50-90 W, short-run power 100 W, maximum power 1000 W.
- Transformation efficiency:
  - Chemical energy food => muscles up to 99 %
  - Chemical energy => kinetic energy around 20-25 %

- Energy return on investment (EROI) up to 40, usually around 3, often around 1.
- Very low population density (0,1 person/sq. km)

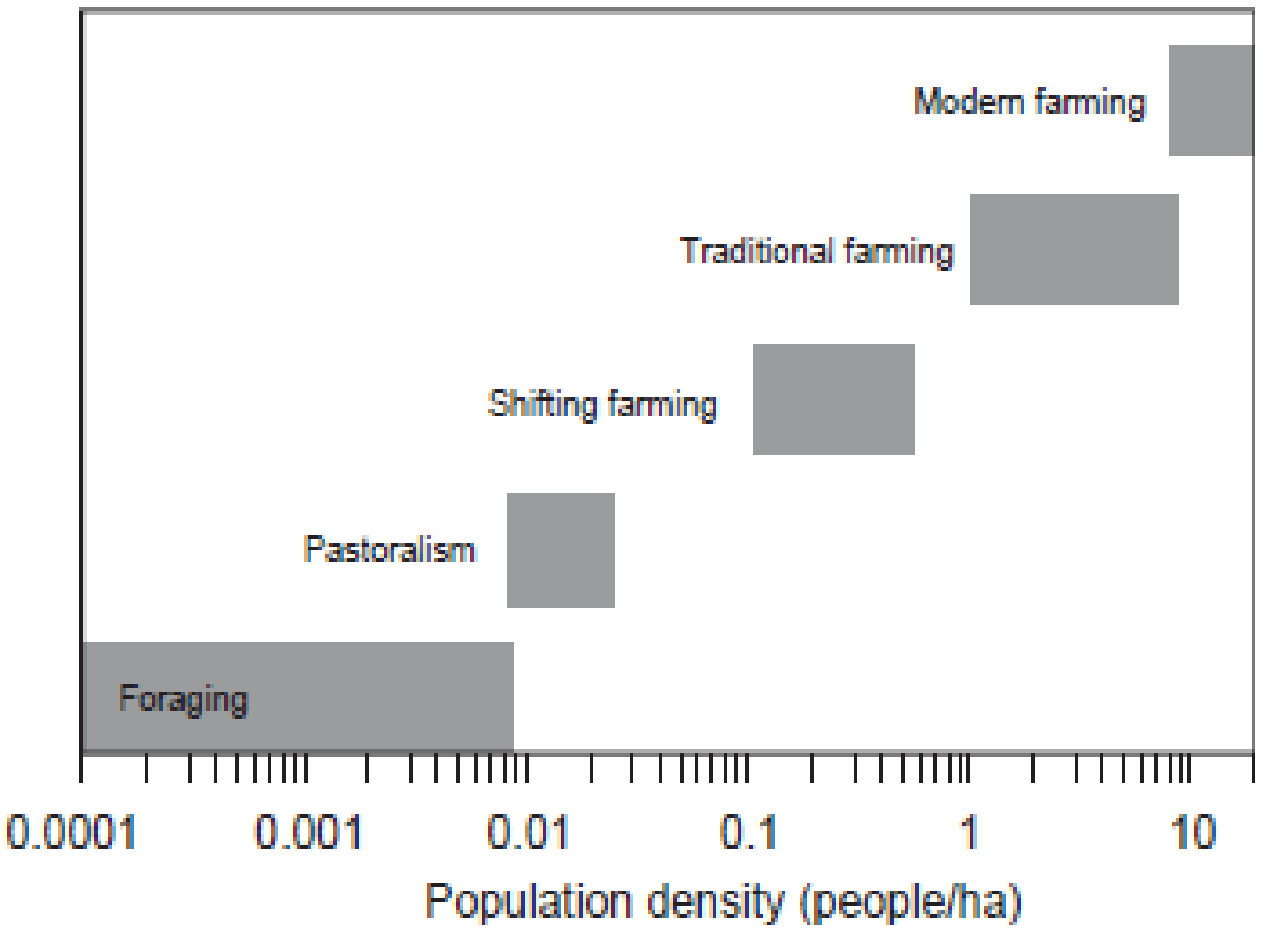
- Exosomatic sources of power: fire, body extensions (bows)

Agricultural society

- Very slow pace of transition (never finished)
- Greater population density (20-30 persons/sq. km)

- First exosomatic sources of power:
  - Oxes (200-500 W)
  - Charcoal (29 MJ/kg, no smoke)
- Metallurgy: low efficiency, high energy intensity (until 1750)

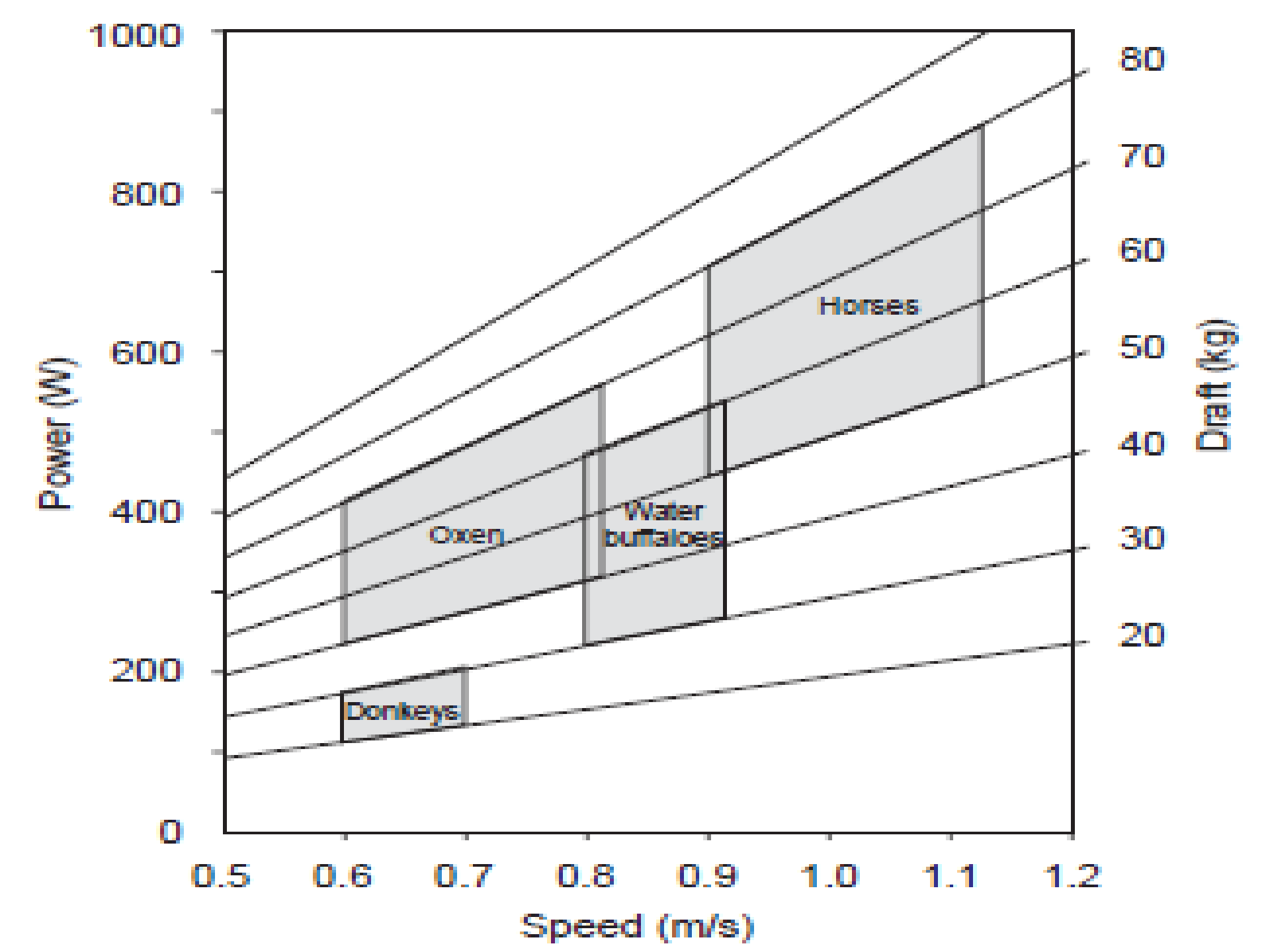
- Mechanical propulsion (windmills)


Modern farming
Traditional farming
Shifting farming
Pastoralism
Foraging
0.0001
0.001
0.01
0.1
1
10
Population density (people/ha)

Progress in the Middle Ages

- Organic prime movers still dominant
- Increased efficiency in energy transformation (treadwheels, horseshoes, fodder, breeding)

- Non-organic prime movers
  - Watermills (England, 11th century)
  - Wind power: sails (+ compass, heavy cannons, rear stear = colonization)
  - Fuel scarcity (England at 1710s: 12 000 tons of wood/year)

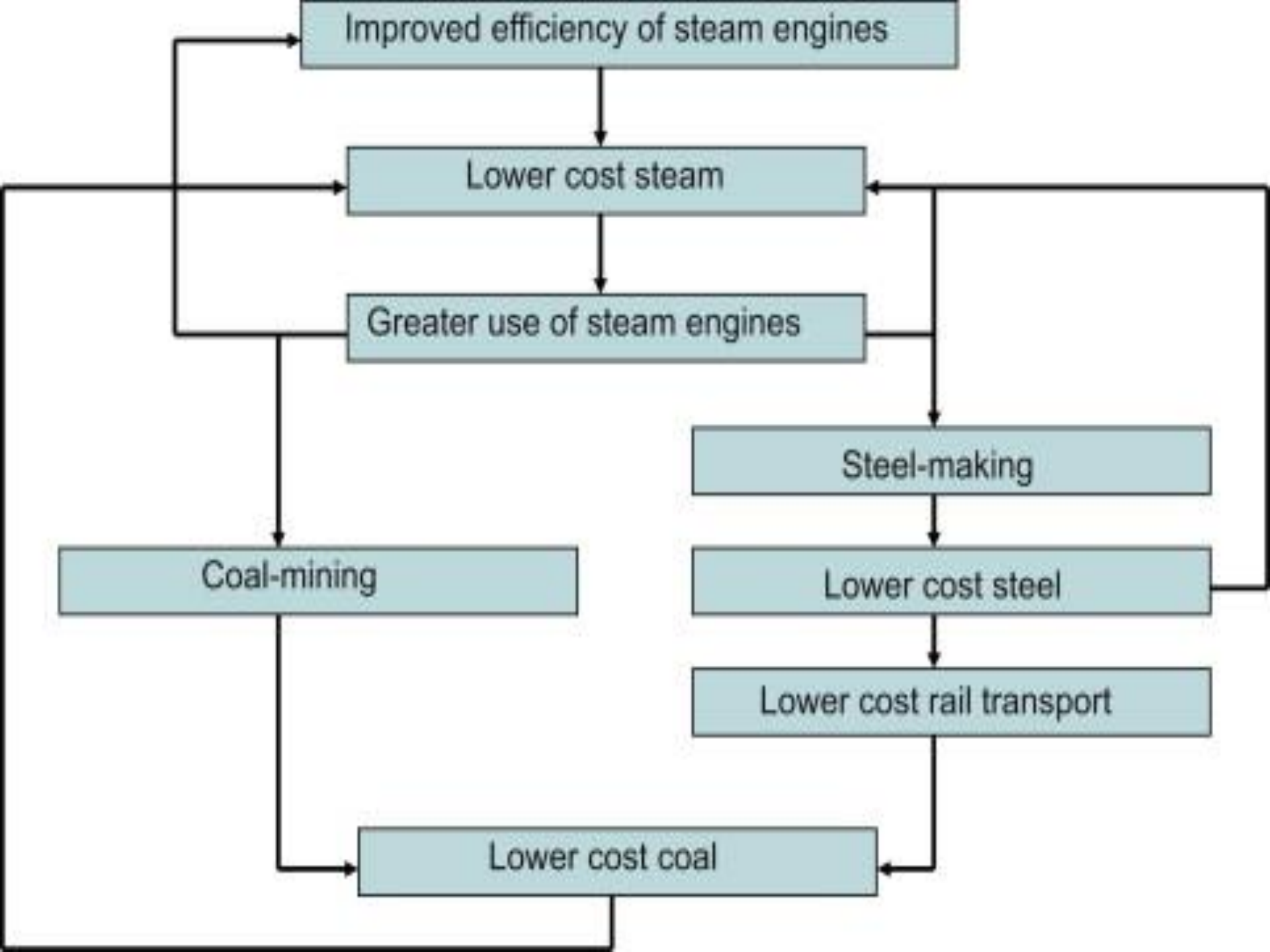

1000
800
600
400
200
0
Power (W)
80
70
60
50
40
30
20
Draft (kg)
Horses
Oxen
Water buffaloes
Donkeys
0.5
0.6
0.7
0.8
0.9
1.0
1.1
1.2
Speed (m/s)

Towards modernity: steam engine

- Europe: 1800-1950: Five distinct prime movers: humans, animals, watermills/turbines, windmills, steam engines

- Fossil fuels: peat replacing wood in Holand (17th Century)
- Steam engine (Newcomen, Watt)
  - 20 kW
  - Efficiency 5%
- Inland transport revolution
- „Industrial revolution“ powered by watermills and steam (positive feedback)

- 1870: mechanical power outweighs organic power in the U. S.
- 1900: North Sea windmills: 100 MW of installed capacity


Improved efficiency of steam engines
Lower cost steam
Greater use of steam engines
Steel-making
Coal-mining
Lower cost steel
Lower cost rail transport
Lower cost coal

Towards modernity: electricity

- Production, transport, and use of electricity introduced between 1880-1900
- Basics laid by T. A. Edison in early 1880s
- G. Westinghouse and N. Tesla: alternating current
- Ch. Parsons: steam turbine
- W. Stanley: transformer
- N. Tesla: electric motor

- 20th century: evolution of power industry
- USA 1930s: 80% of all mechanical power

- Profound change in work and personal life

Towards modernity: internal combustion engine

- 1890s:
  - Spark ignition engine (G. Daimler), carburator (W. Maybach), electrical ignition (K. Benz).
  - Compression ignition engine (R. Diesel)
- Three waves of automobile dissemination

- Aviation
  - 1904: the Wright brothers
  - 1961: Yuri Gagarin
  - 1969: Neil Armstrong, Boeing 747

- Fossil fuels-based transportation drives demand for oil, later on utilized in a variety of industries


PAN AM

Prime Mover	Sustained Power (W)
Working child	30
Small woman	60
Strong man	100
Donkey	150
Small ox	300
Typical horse	600
Heavy horse	800
Early small tractor *(1920)*	10,000
Ford's Model T *(1908)*	15,000
Typical tractor *(1950)*	30,000
Honda Civic *(2000)*	79,000
Large tractor *(2000)*	225,000
Large diesel engine *(1917)*	400,000
Large marine diesel engine *(1960)*	30,000,000
Four gas turbines of Boeing 747 *(1970)*	60,000,000

Energy-intensive society

- Mechanization of agriculture and industry

- Geometrical growth of available power:

Foraging societies	100 W (human)
Early antiquity	300 W (ox)
Ancient Rome	2 kW (watermill)
The Middle Ages	5 kW (watermill)
17th century	8 kW (watermill
18th century	100 kW (Watt‘s steam engine)
Early 20th century	10 MW (water turbine)
Early 21st century	1,5 GW (gas turbine)

- Last 10,000 years:
  - Maximum power of the prime movers has increased 15,000,000x
  - 99% of this change occurred in 20th century
  - Still a modest number compared to yield of weapons used

Energy-intensive society

- Increased quality of life
- Great differences among societies/nations
  - 10% consumes 40% of all primary energy
  - 50% consumes 10% of all primary energy
- Anthropocene

Conclusions

- Development stages reflect the power, efficiency, and flexibility of employed prime movers
- Harnessing more energy leads to greater complexity of society