ENERGY TRANSITIONS

Vaclav Smil

MADRID

2013

What comes next?

Forecasting compulsion

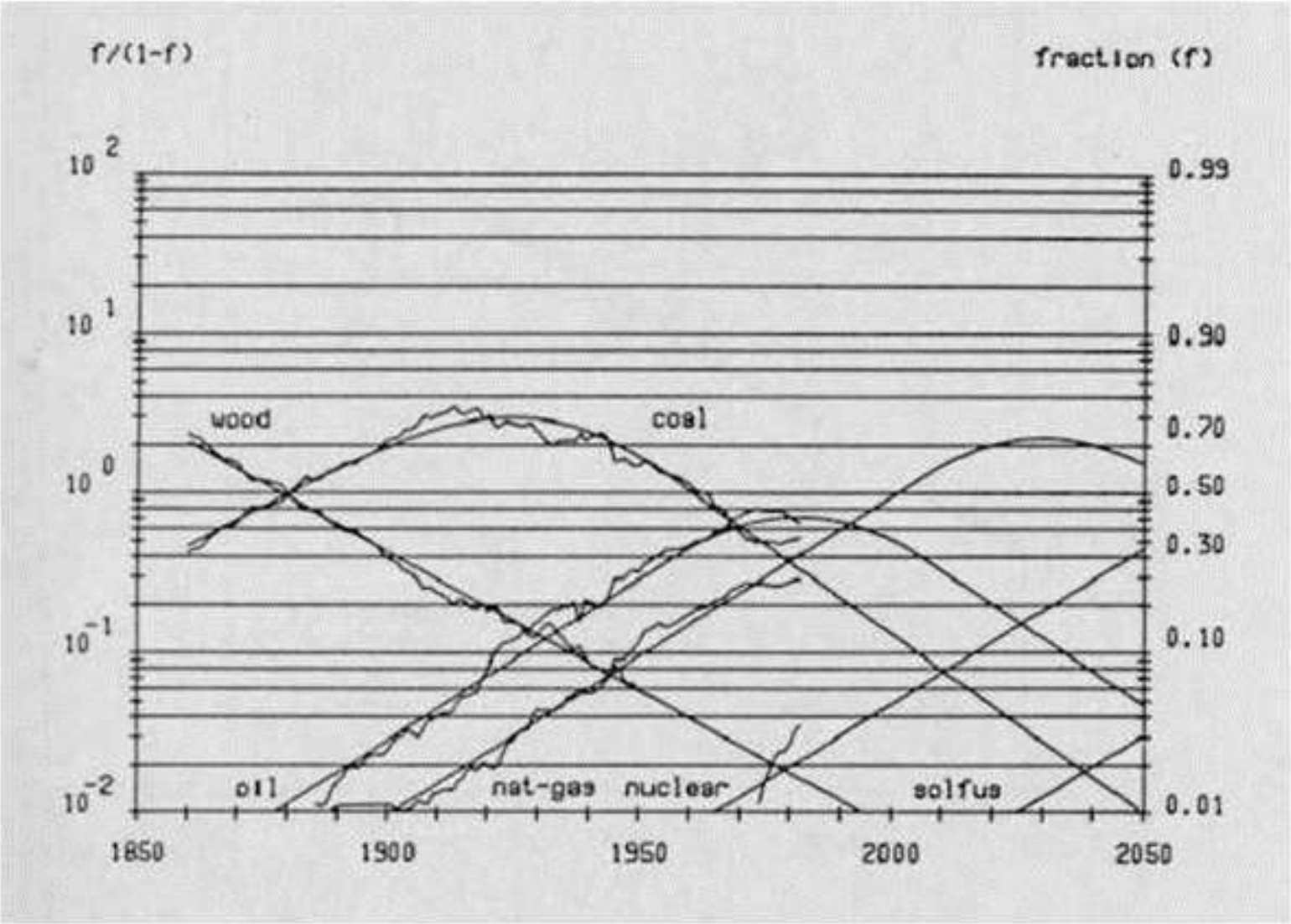
Quest for models

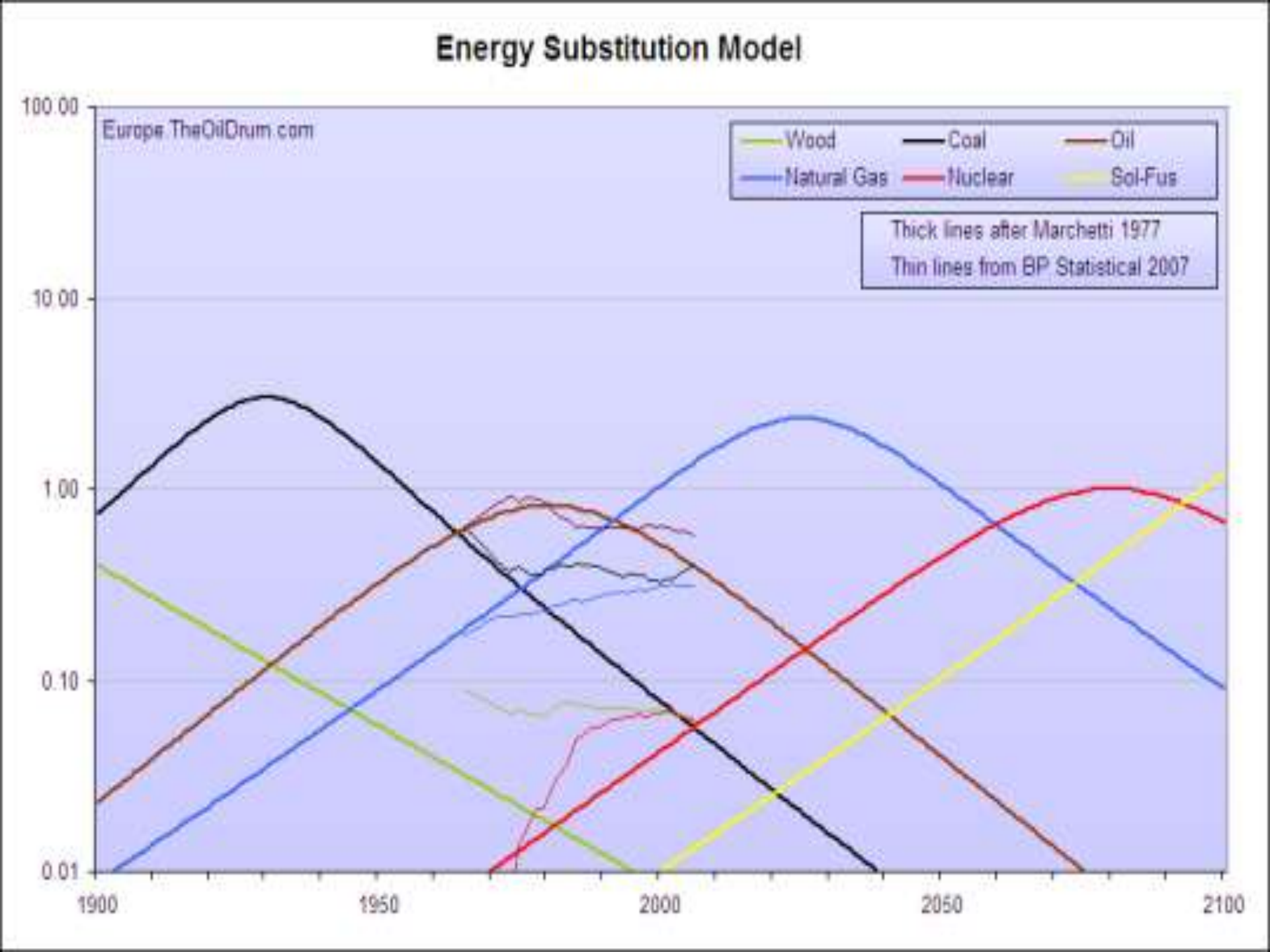
Fisher-Pry model (1971) developed to study the market penetration (adoption) of new techniques (simple two-variable substitutions)

Adoption tends to follow a logistic curve, market fraction (f) of a new technique expressed as f/1-f and plotted on a semi-log graph will appear as a straight line allowing apparently highly reliable forecasts

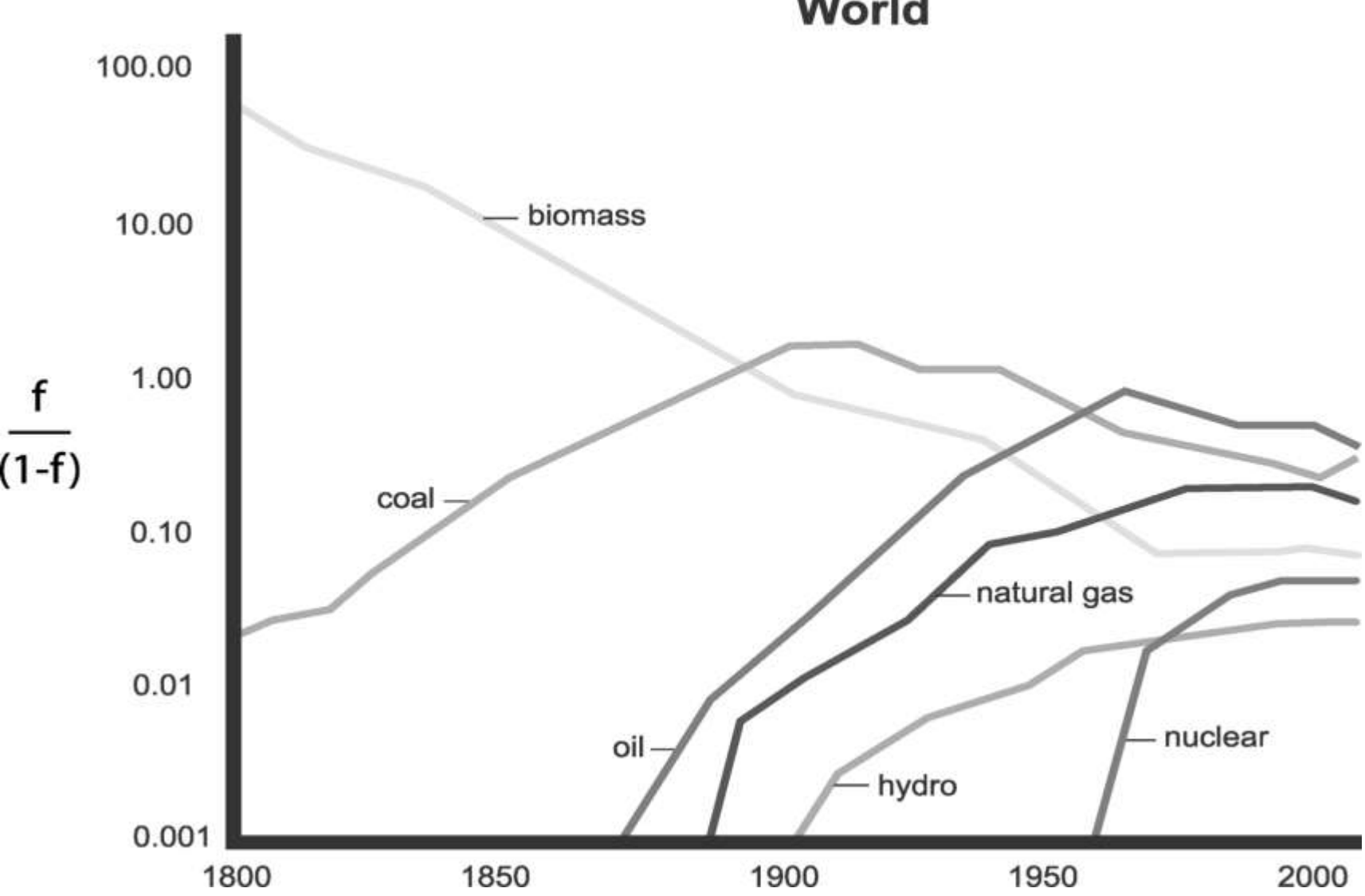
Applied to energy transitions by Marchetti (1977), widely cited

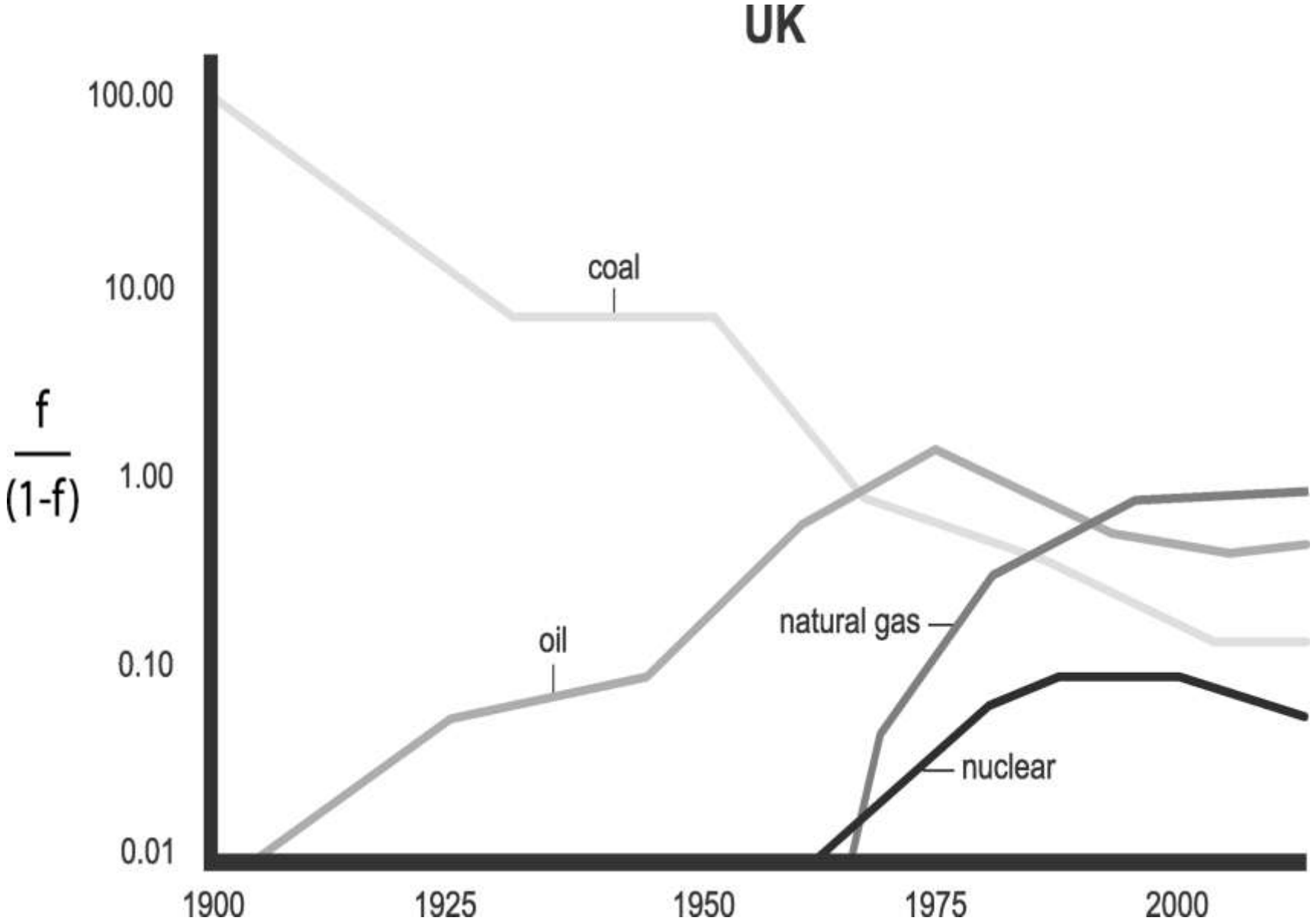
Marchetti's substitution model (1977)

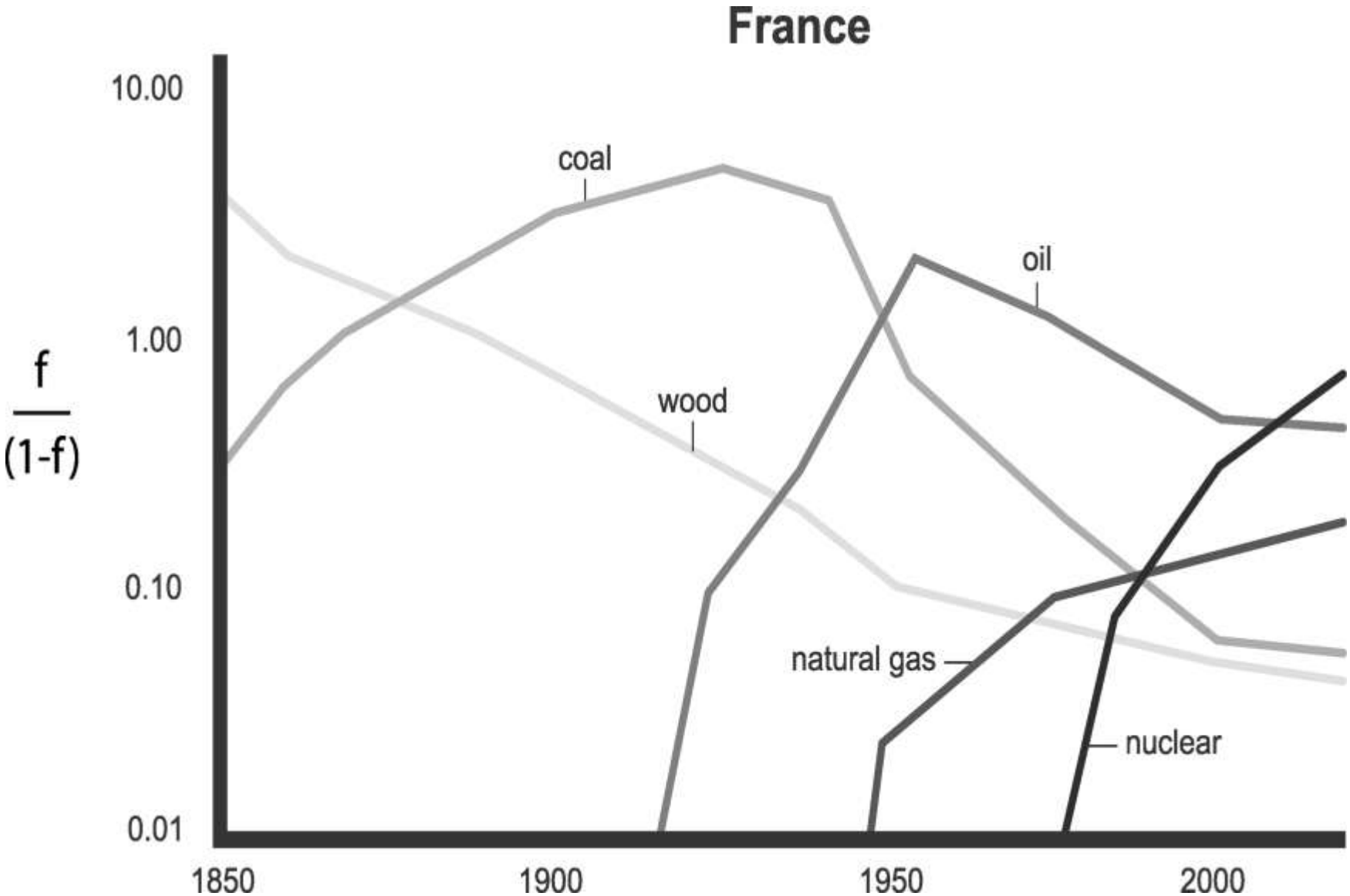


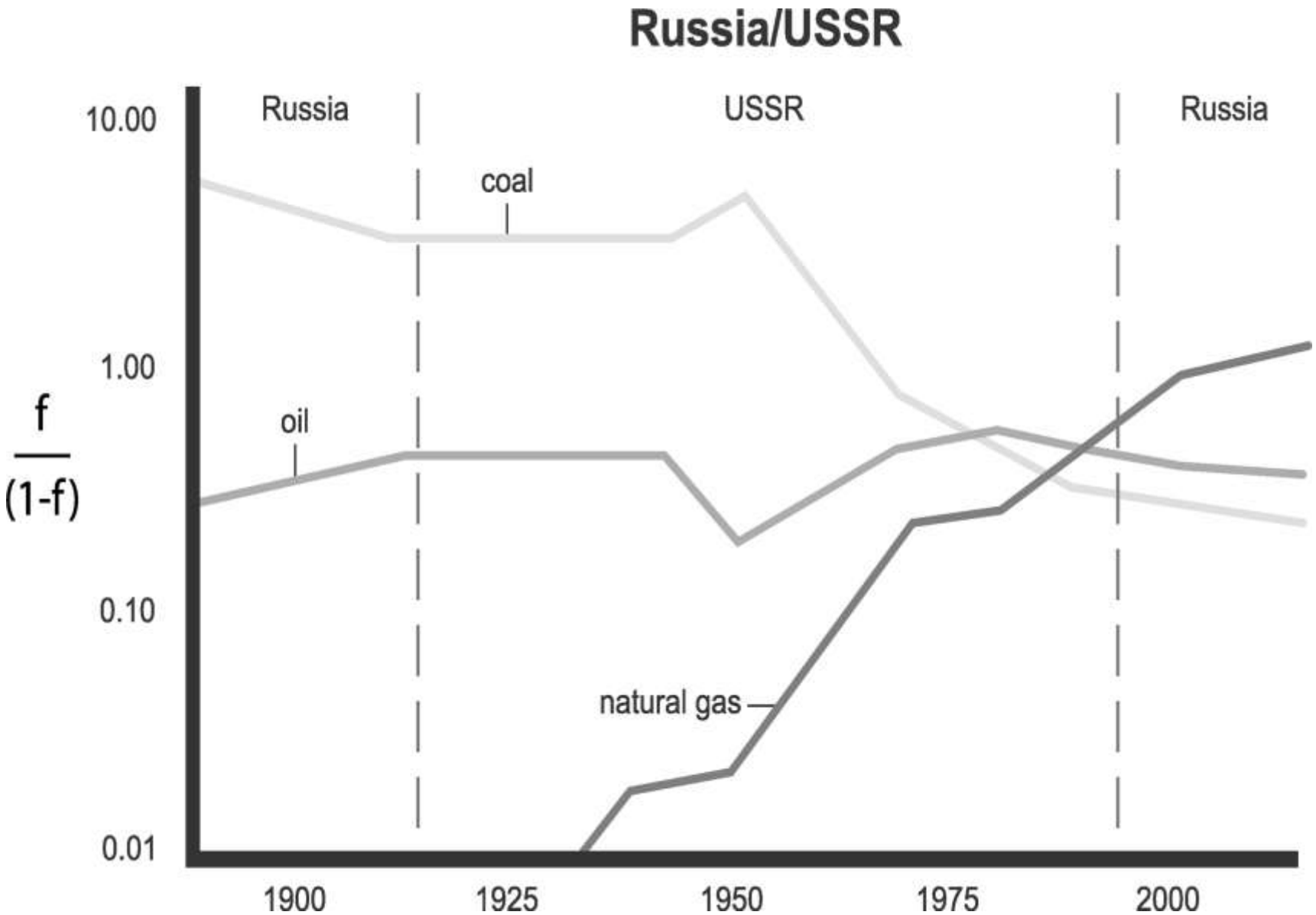

Energy Substitution Model
Europe TheOilDrum.com
Wood
Coal
Oil
Natural Gas
Nuclear
Sol-Fus
Thick lines after Marchetti 1977
Thin lines from BP Statistical 2007
100.00
10.00
1.00
0.10
0.01
1900
1950
2000
2050
2100

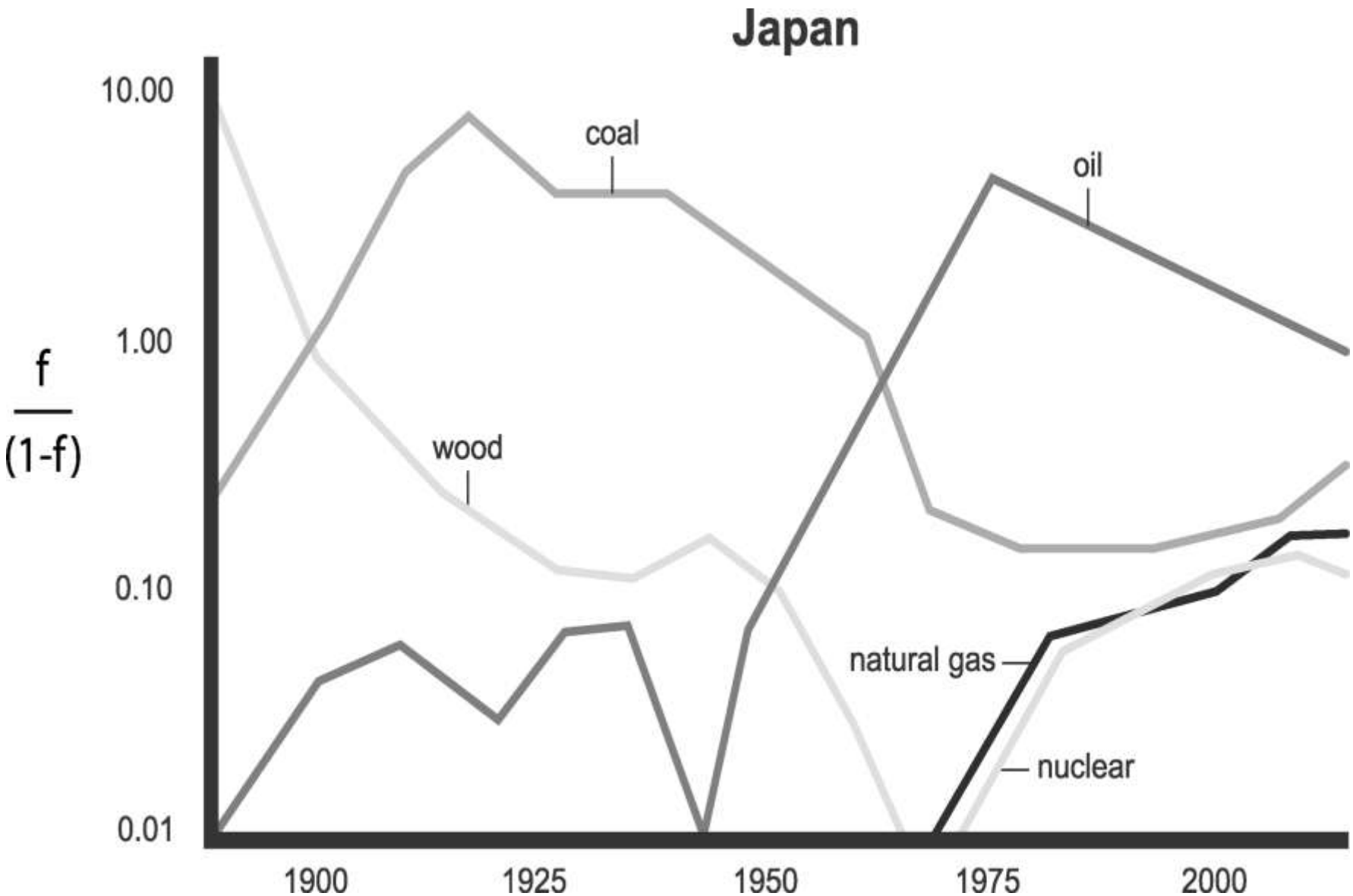
- Real world is far more complex
- The model is wrong
- Energy transition forecasts remain elusive

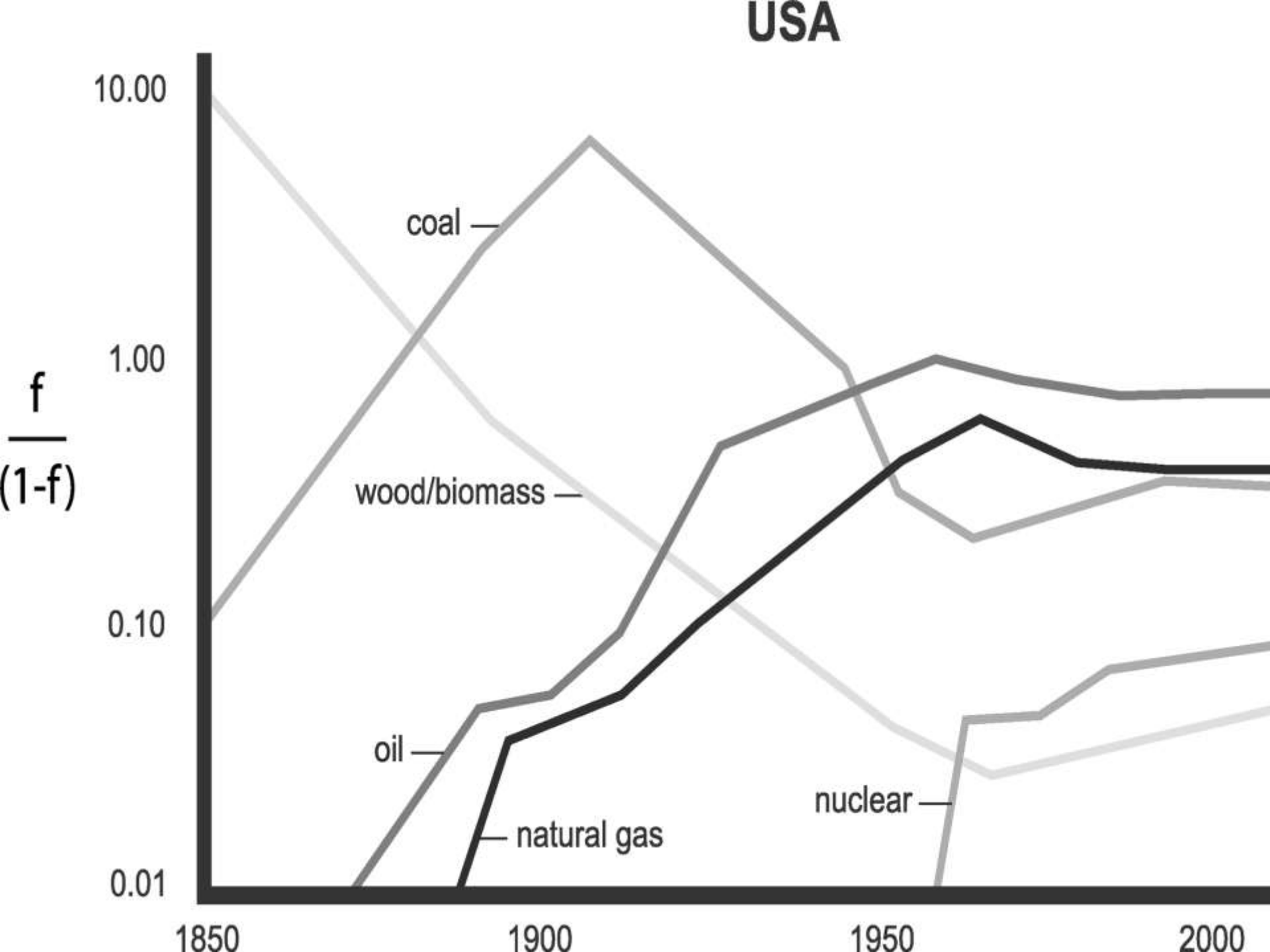

World
100.00
10.00
1.00
0.10
0.01
0.001
f
(1-f)
biomass
coal
oil
natural gas
hydro
nuclear
1800
1850
1900
1950
2000

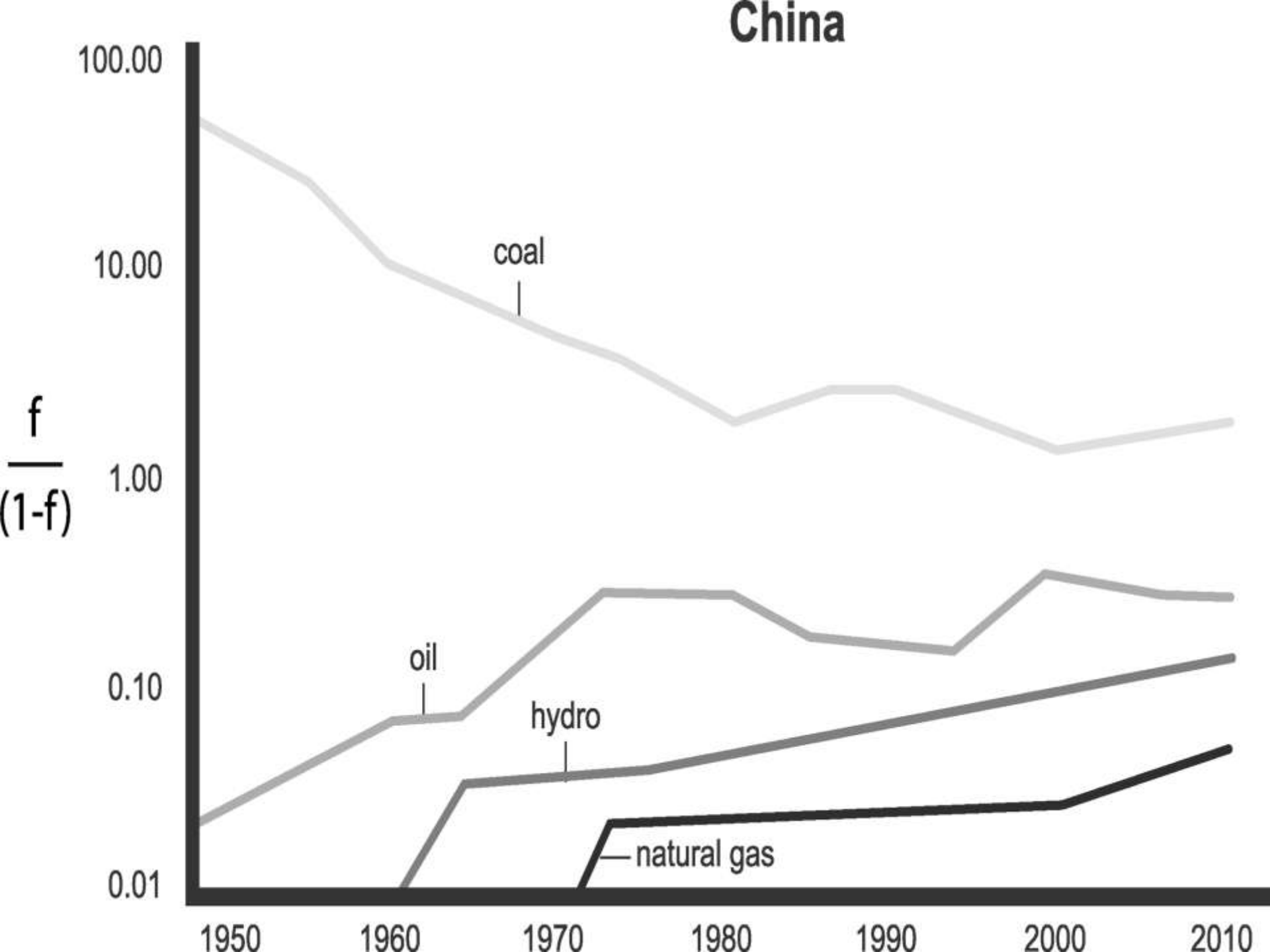

UK
100.00
10.00
1.00
0.10
0.01
f
(1-f)
coal
oil
natural gas
nuclear
1900
1925
1950
1975
2000


France
10.00
1.00
0.10
0.01
f
(1-f)
coal
oil
wood
natural gas
nuclear
1850
1900
1950
2000


Russia/USSR
Russia
USSR
Russia
coal
oil
natural gas
10.00
1.00
0.10
0.01
f
(1-f)
1900
1925
1950
1975
2000


Japan
10.00
1.00
0.10
0.01
f
(1-f)
coal
oil
wood
natural gas
nuclear
1900
1925
1950
1975
2000


USA
10.00
1.00
0.10
0.01
f
(1-f)
coal
wood/biomass
oil
natural gas
nuclear
1850
1900
1950
2000


China
100.00
10.00
1.00
0.10
0.01
f
(1-f)
coal
oil
hydro
natural gas
1950
1960
1970
1980
1990
2000
2010

Alternatives at a country level

- RENEWABLES

- Hydroenergy
- Geothermal energy
- Wind
- Solar radiation
- Ocean energy
- Biomass energies

LOWER CONSUMPTION

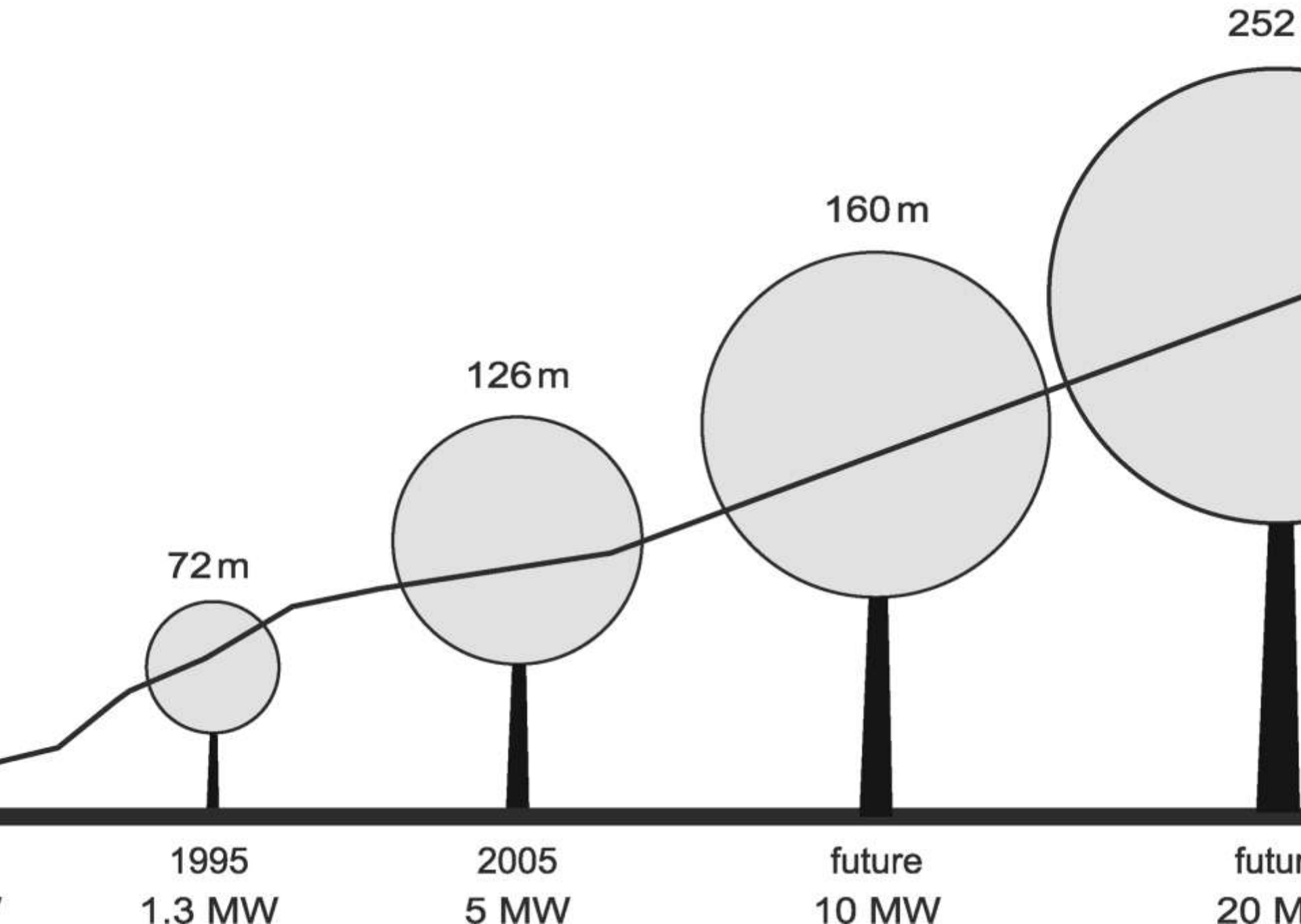
INCREASED IMPORTS

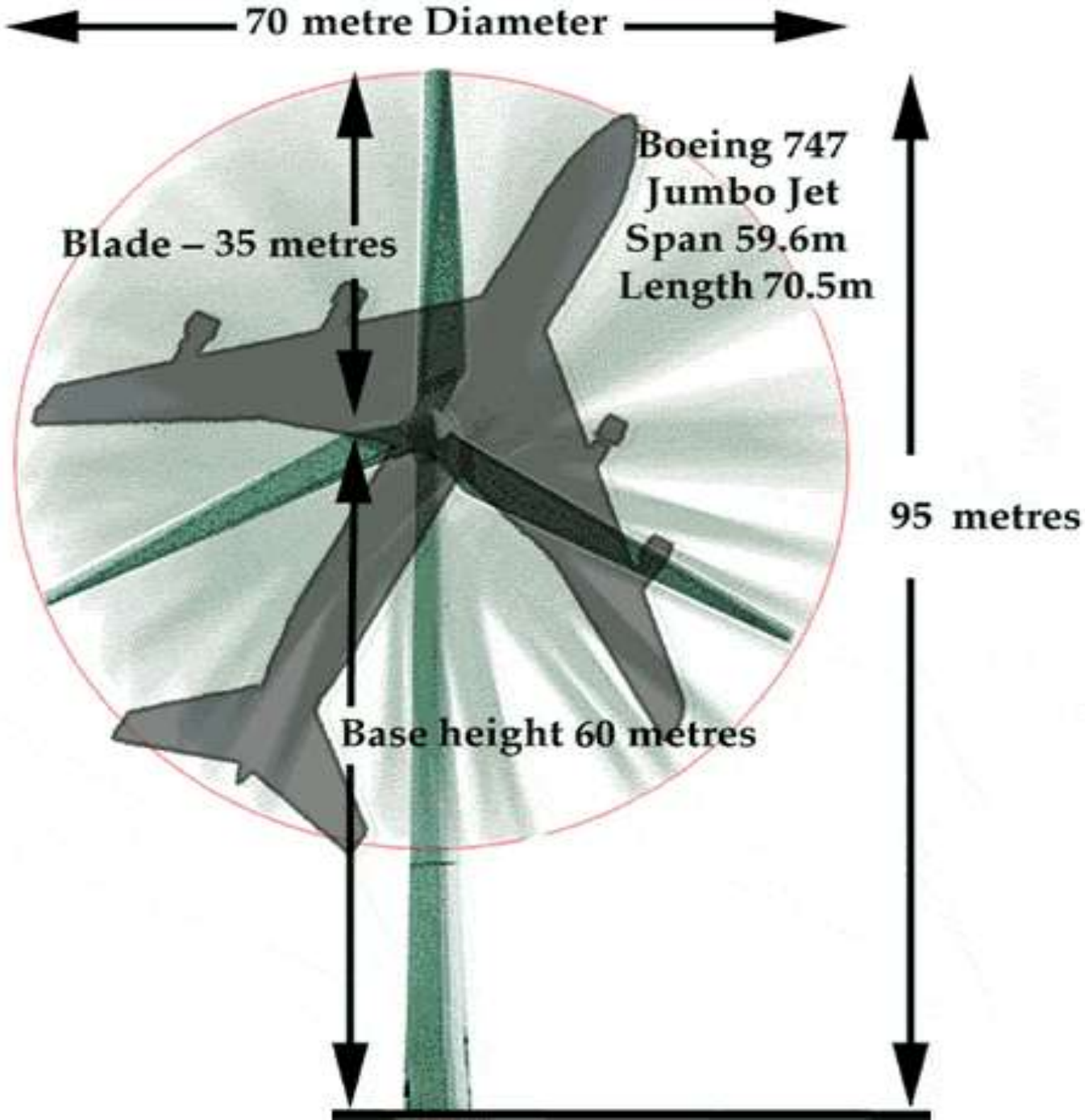
NUCLEAR ELECTRICITY

HYDROGEN

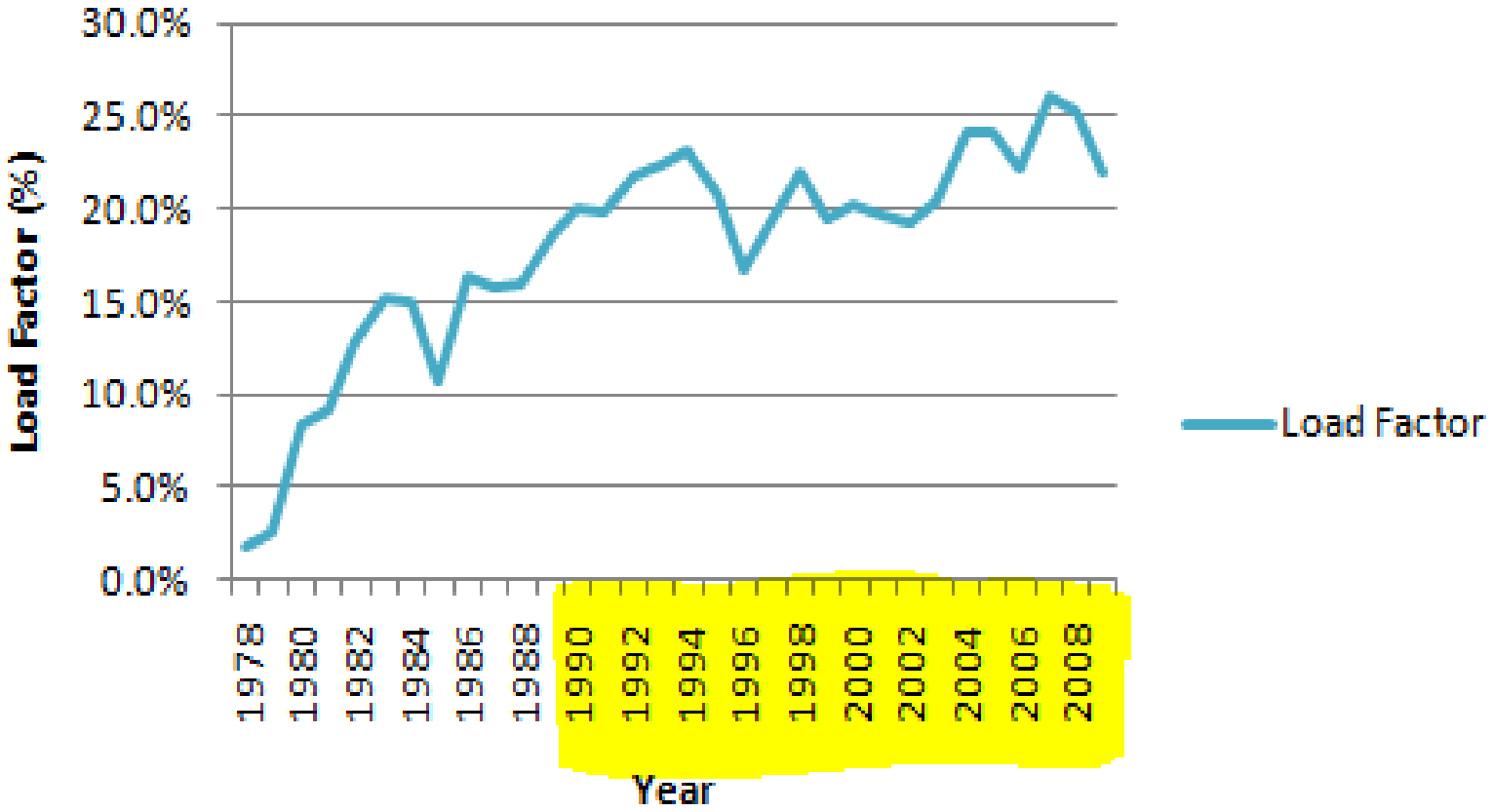
CHALLENGES OF RENEWABLES

- Intermittent flows
- Low power densities
- Low capacity factors
- Need for long-distance HV transmission
- Biofuels competing with food and reducing biodiversity

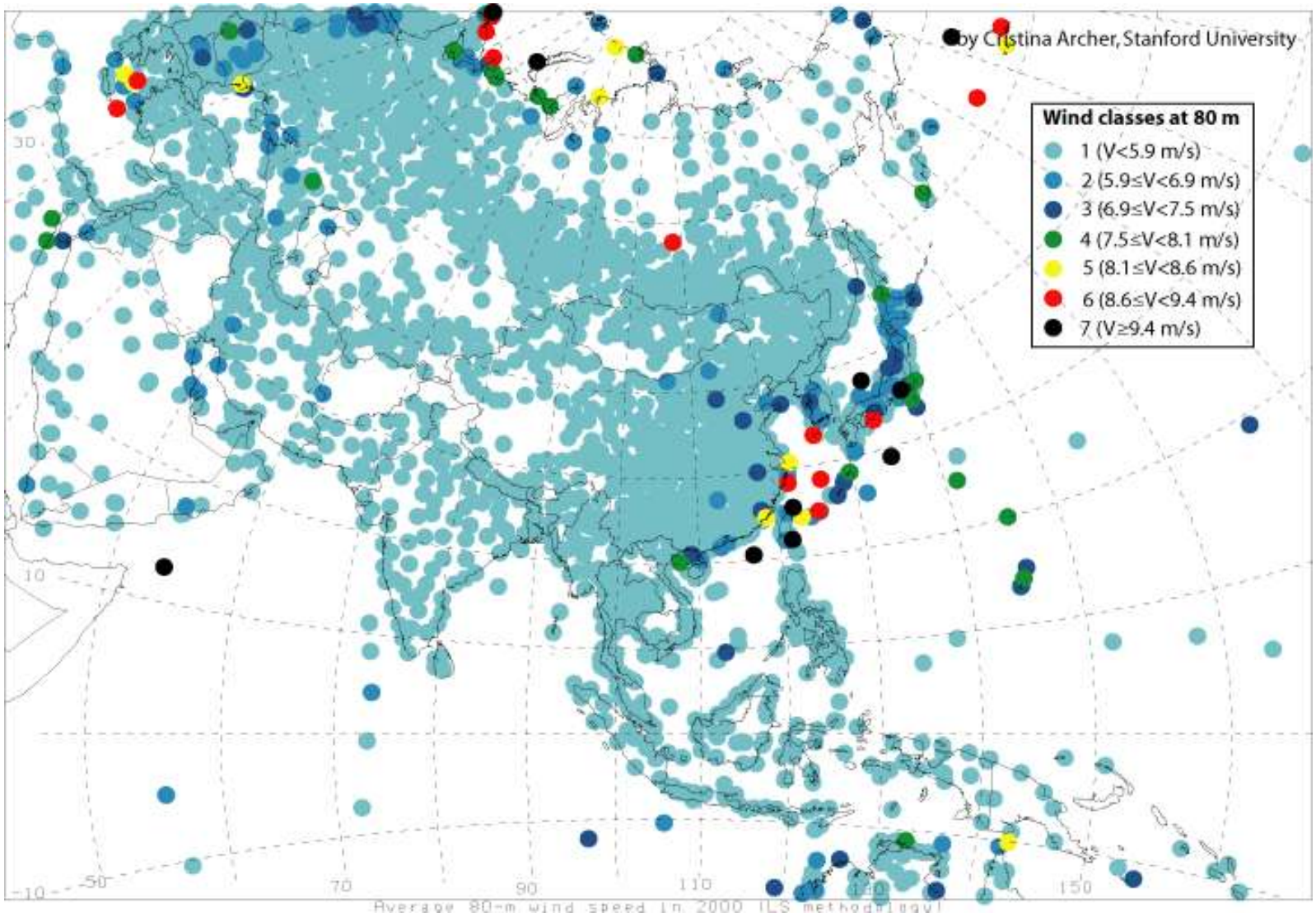

252
160 m
126 m
72 m
1995
1.3 MW
2005
5 MW
future
10 MW
futur
20 M


70 metre Diameter
Boeing 747
Jumbo Jet
Span 59.6m
Length 70.5m
Blade – 35 metres
95 metres
Base height 60 metres

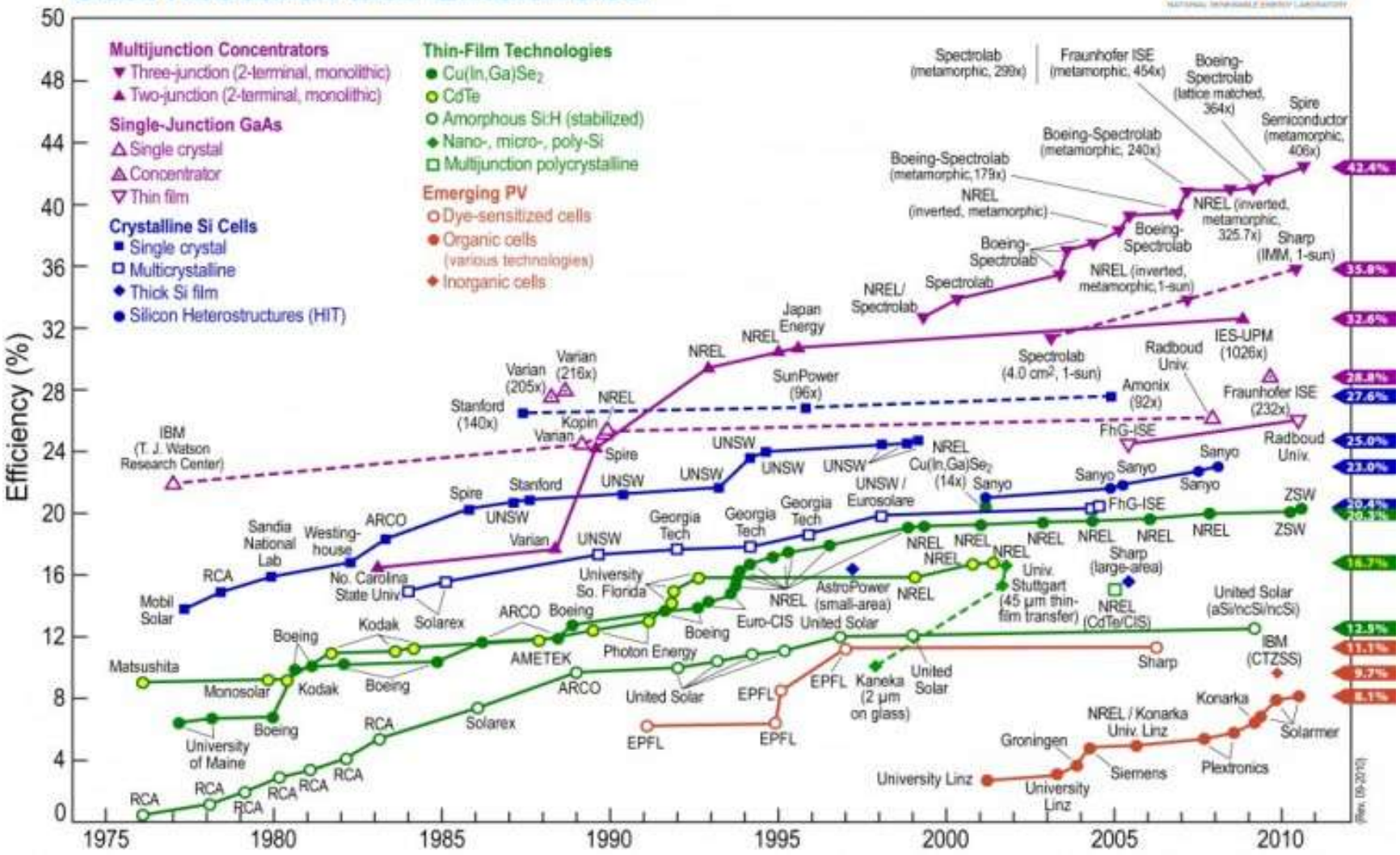
Wind Power Load Factor Denmark



A calm continent: Asia's wind classes at 80 m



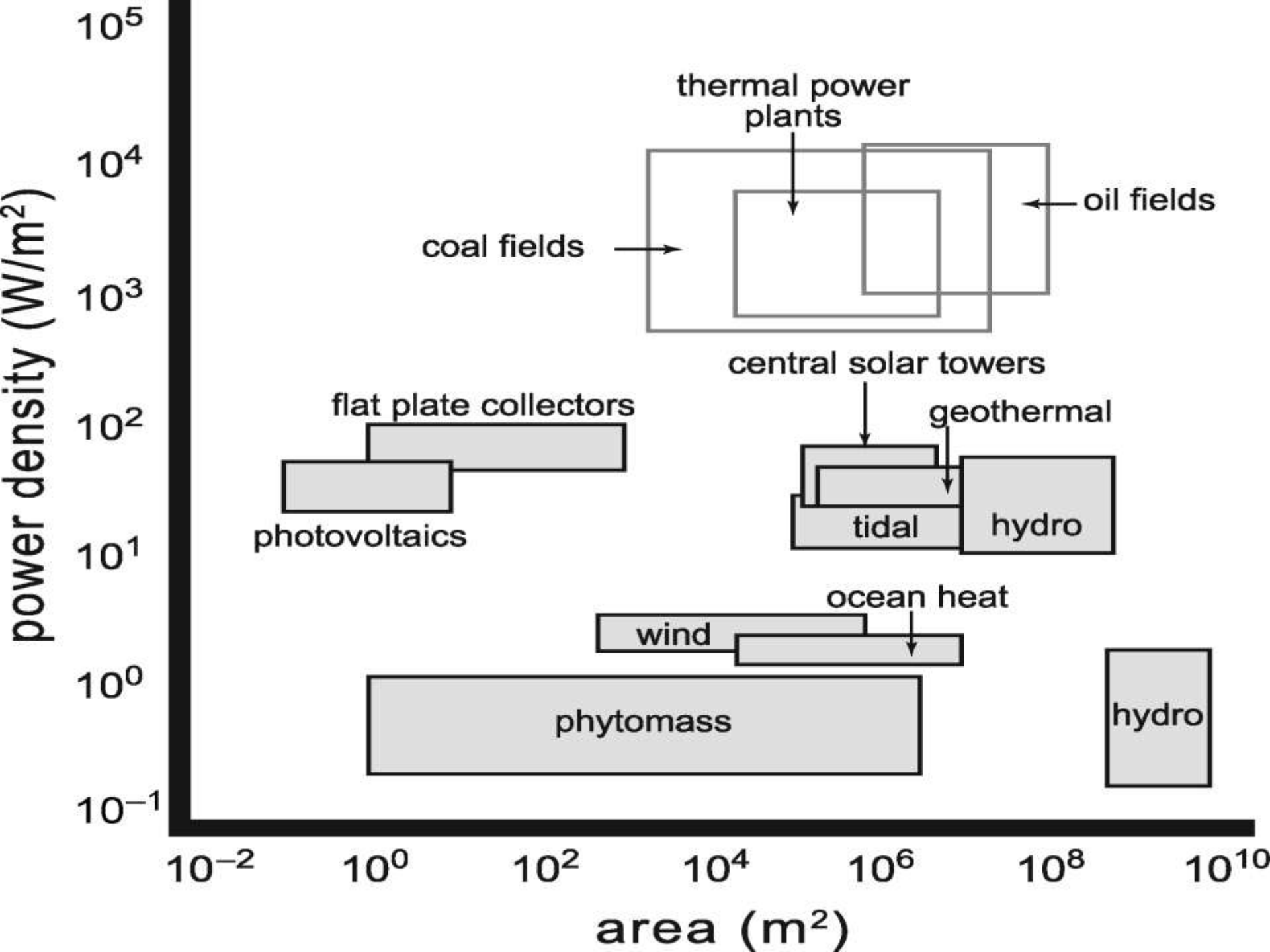
Best Research-Cell Efficiencies



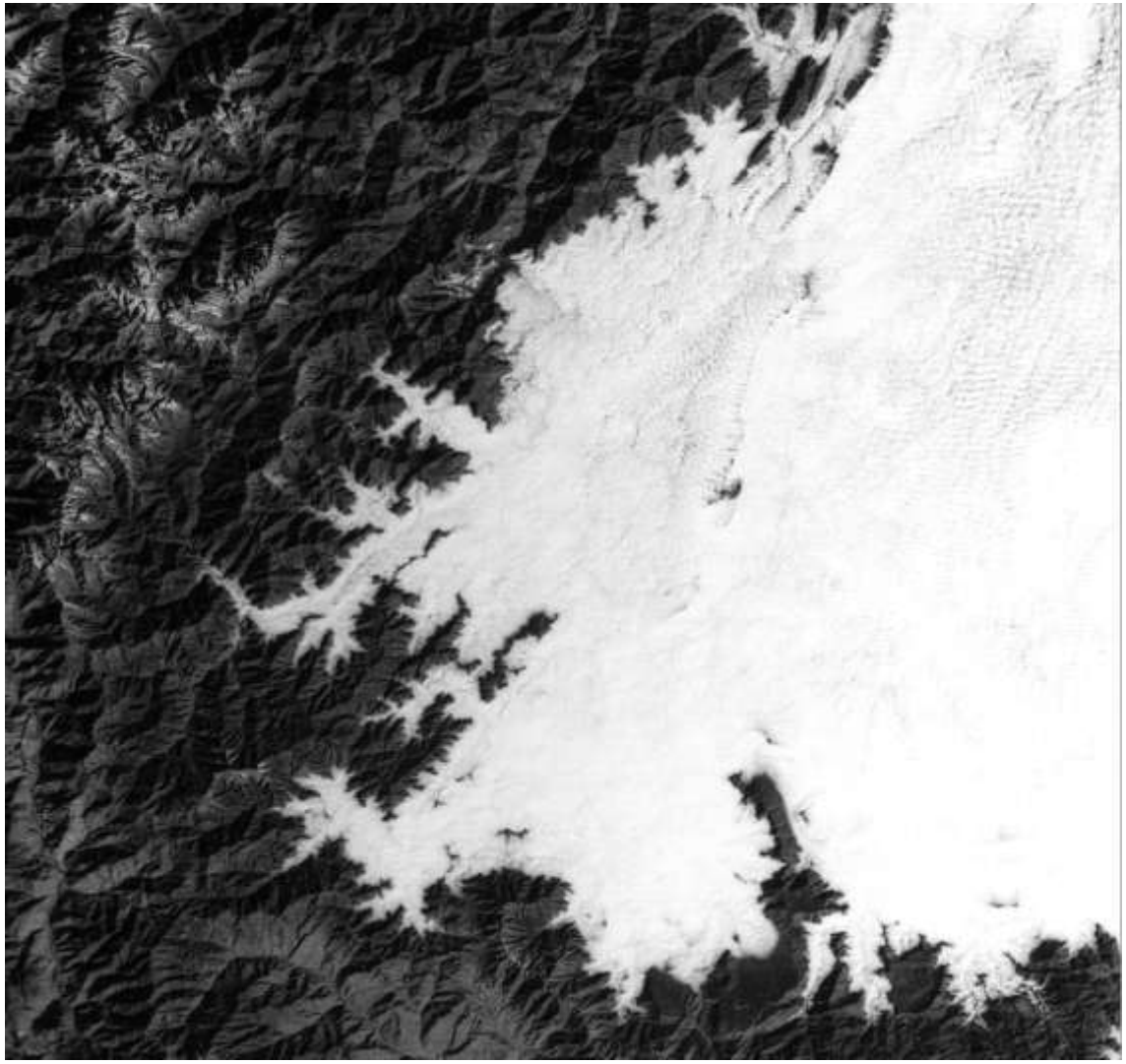
PHOTOVOLTAICS

Olmedilla de Alarcón, Spain's largest photovoltaic electricity-generating plant. Installed capacity of 60 peak MW, annual generation of 85 GWh, capacity factor of 16%.

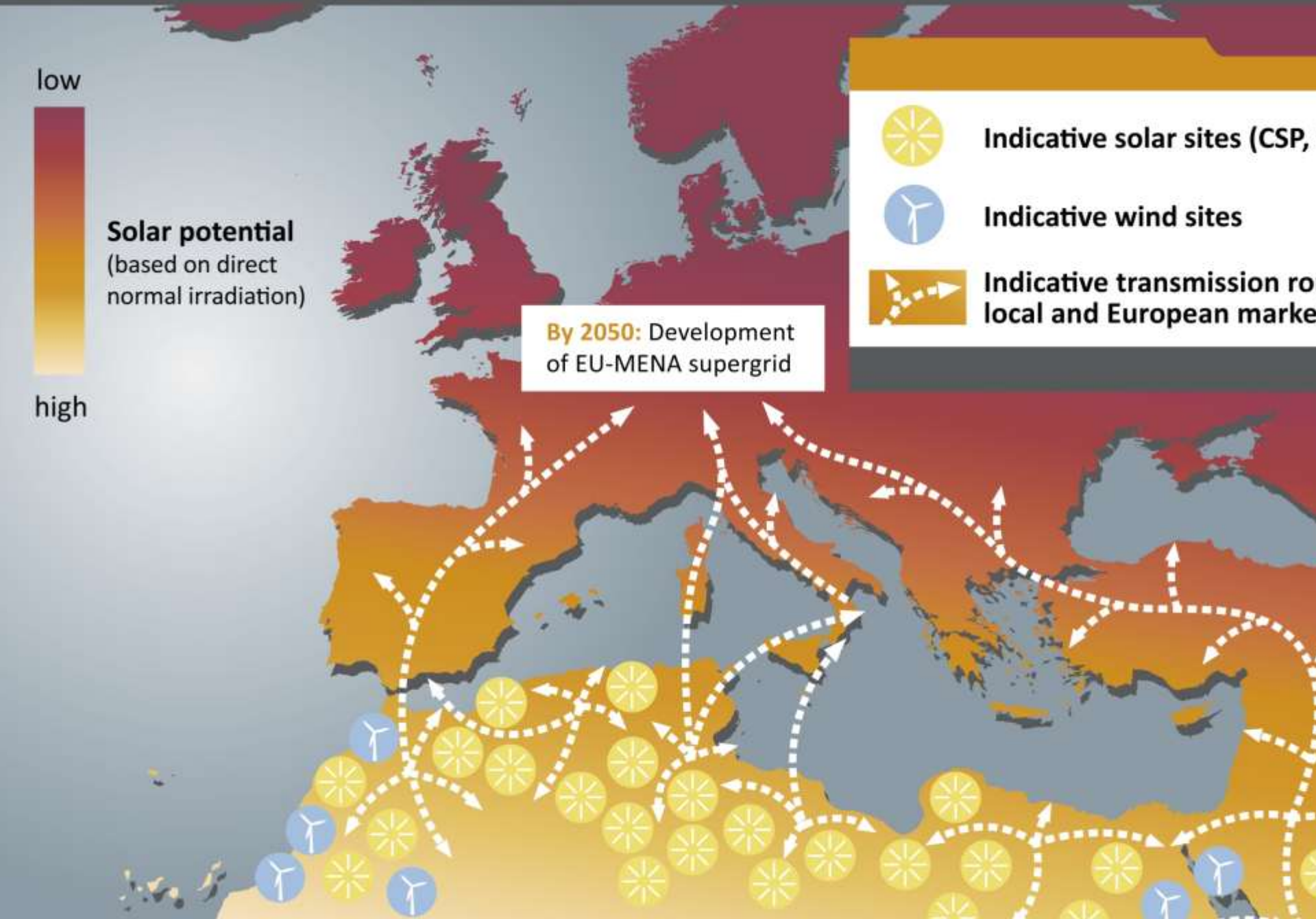
Gemasolar power density 6.8 W/m^2


thermal power plants
oil fields
coal fields
central solar towers
flat plate collectors
geothermal
photovoltaics
tidal
hydro
ocean heat
wind
phytomass
hydro
power density (W/m²)
area (m²)
10⁵
10⁴
10³
10²
10¹
10⁰
10⁻¹
10⁻²
10⁰
10²
10⁴
10⁶
10⁸
10¹⁰

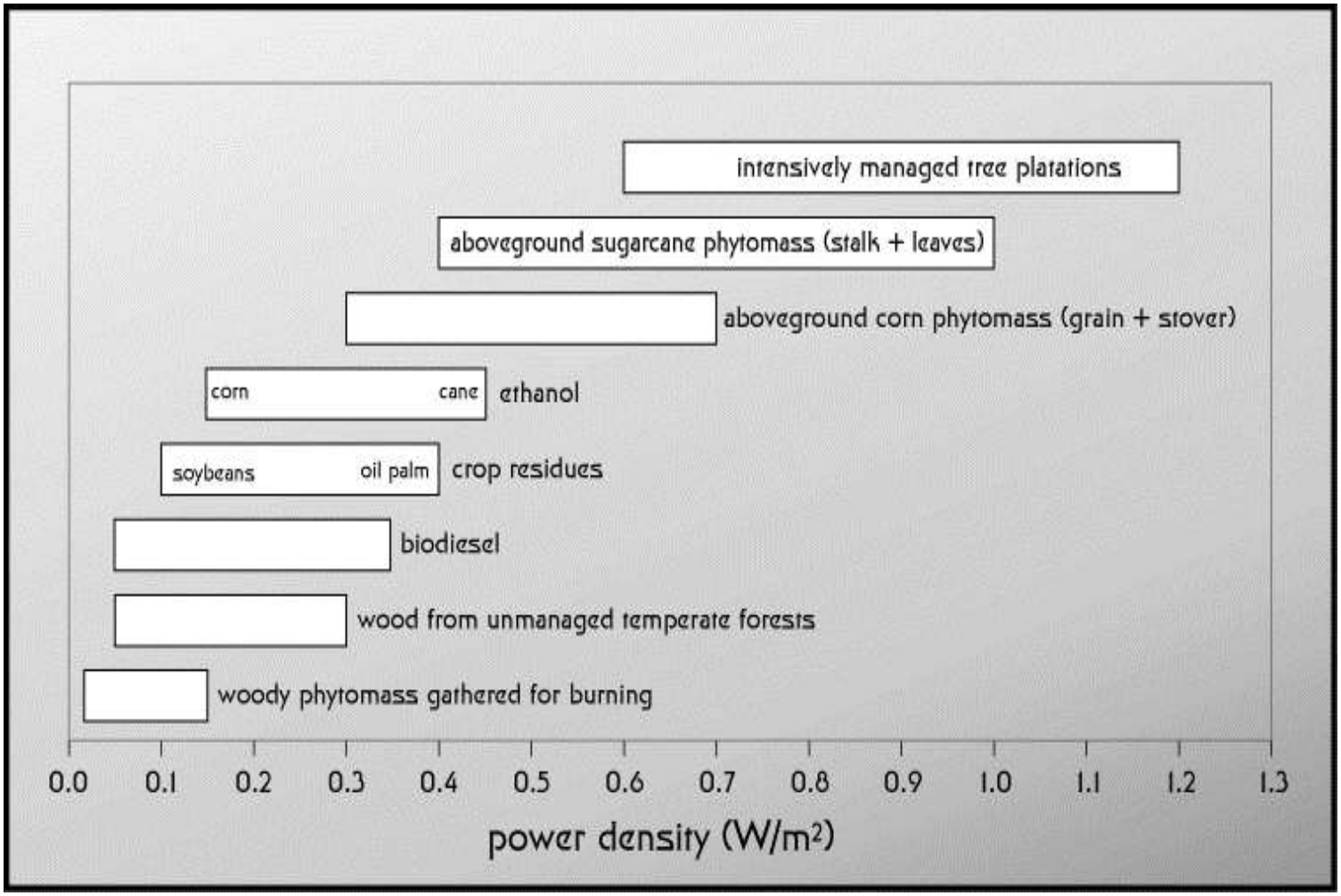
China’s cloud-filled Sichuan Basin



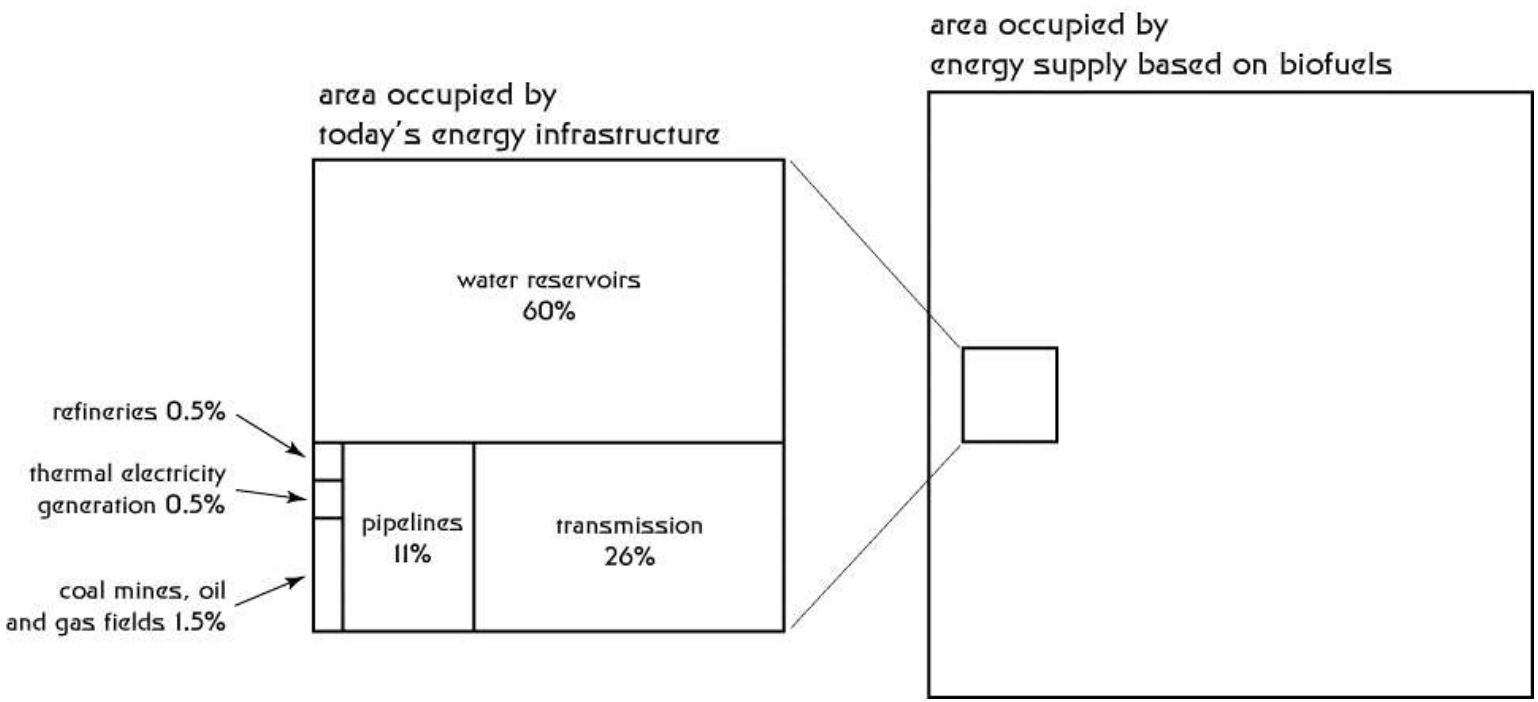
Dii: Power generation from sun and wind energy in the deserts of the Middle East and No



Power densities of biomass production



Biofuel land claims



Nautilus, New York 1954

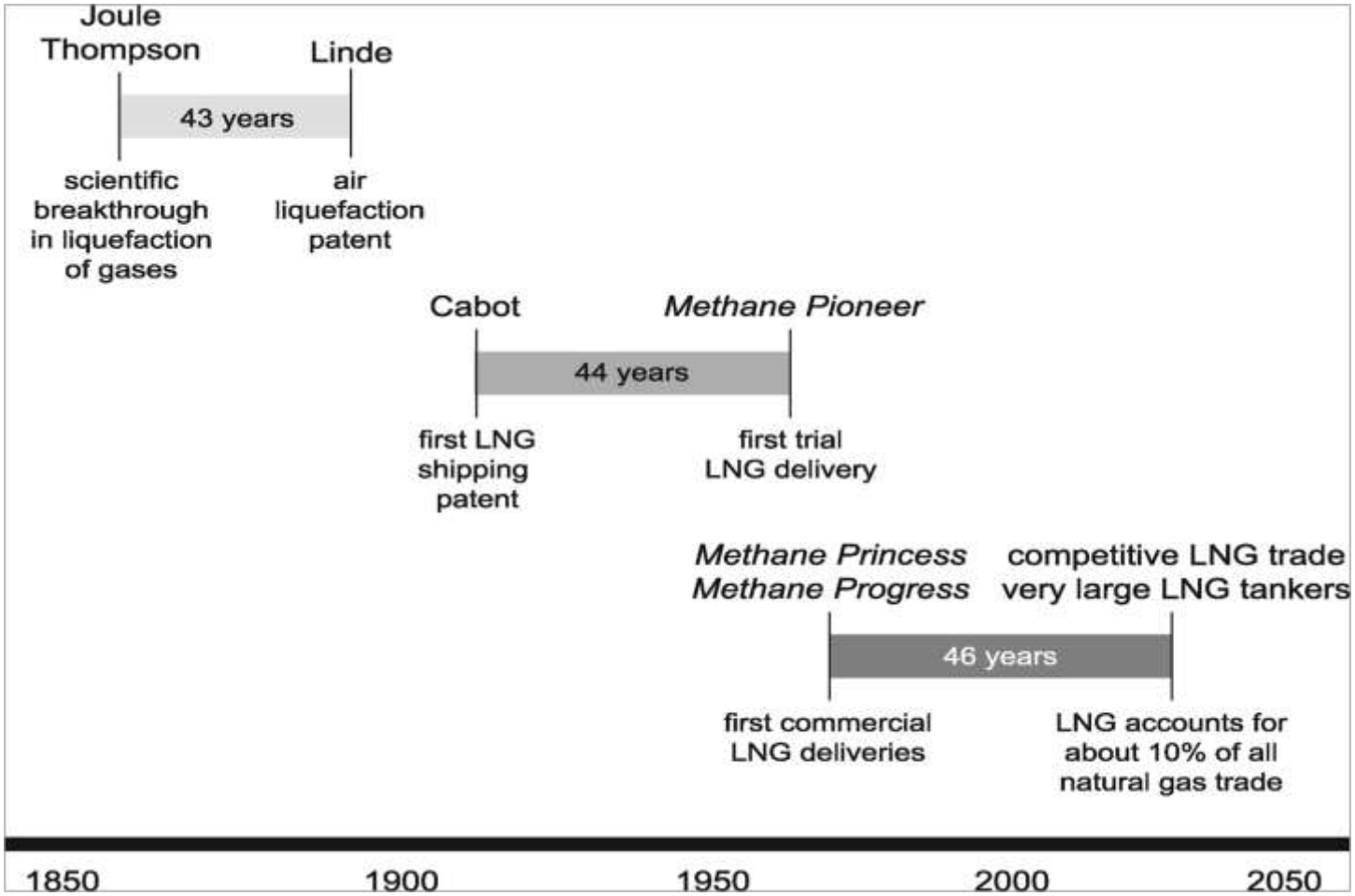
Success: France >75% electricity from fission

Failure: Fukushima reactor buildings, March 24 2011

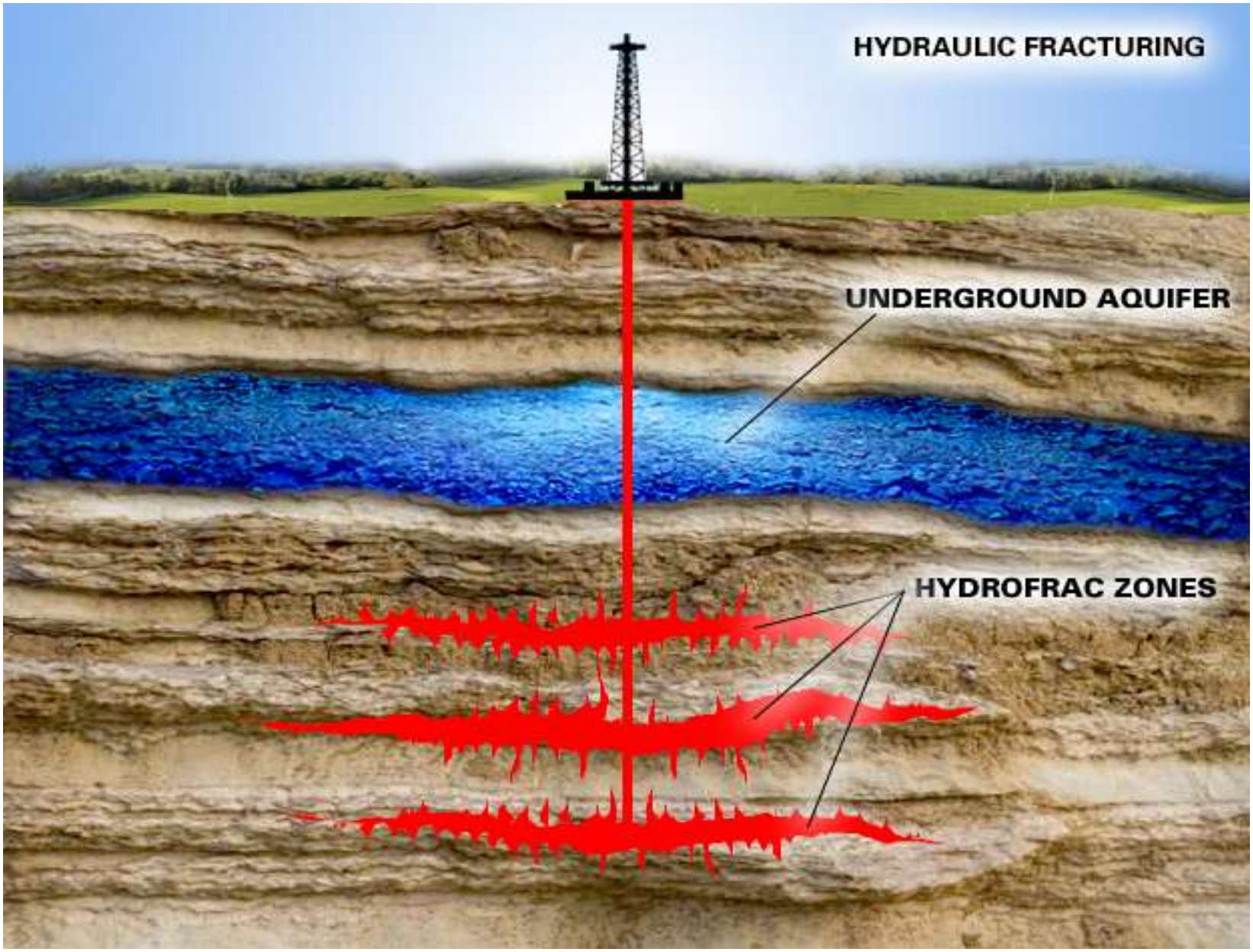
ASCENT OF LNG

- Long technical gestation
- Decades of high costs and fixed contracts
- Technical advances and lower shipping costs
- Eventual increase of sellers and buyers
- Poised to become a global commodity
- Derailed by the US shale gas

Evolution of LNG transportation

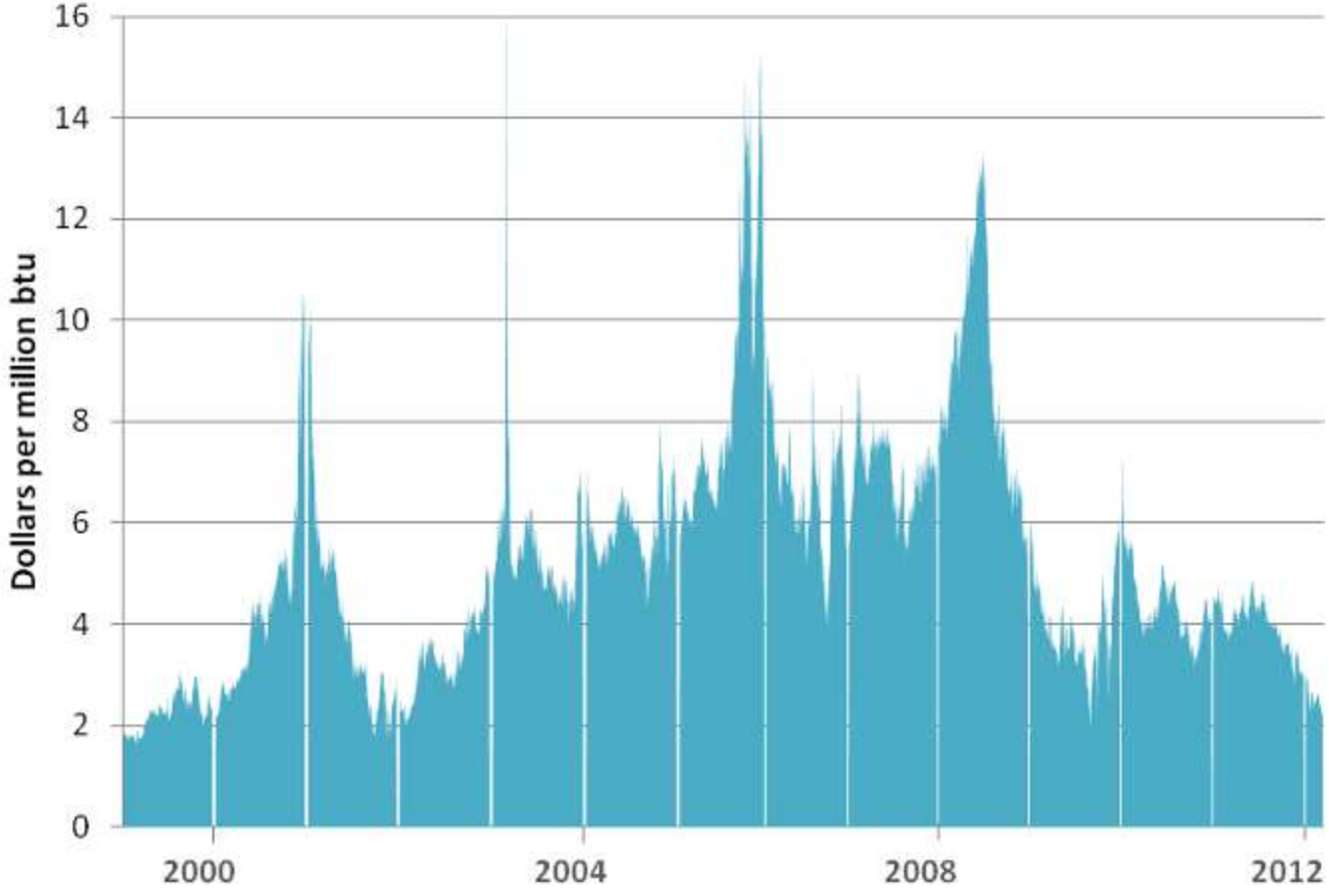


Mozah, Qatar's Q-Max LNG carrier (266,000 m^3)


HYDRAULIC FRACTURING
UNDERGROUND AQUIFER
HYDROFRAC ZONES

Natural gas price volatility 1999-2012

Spot price at U.S. Henry Hub



PERILS OF FORECASTING

Scientific American **in 1913**

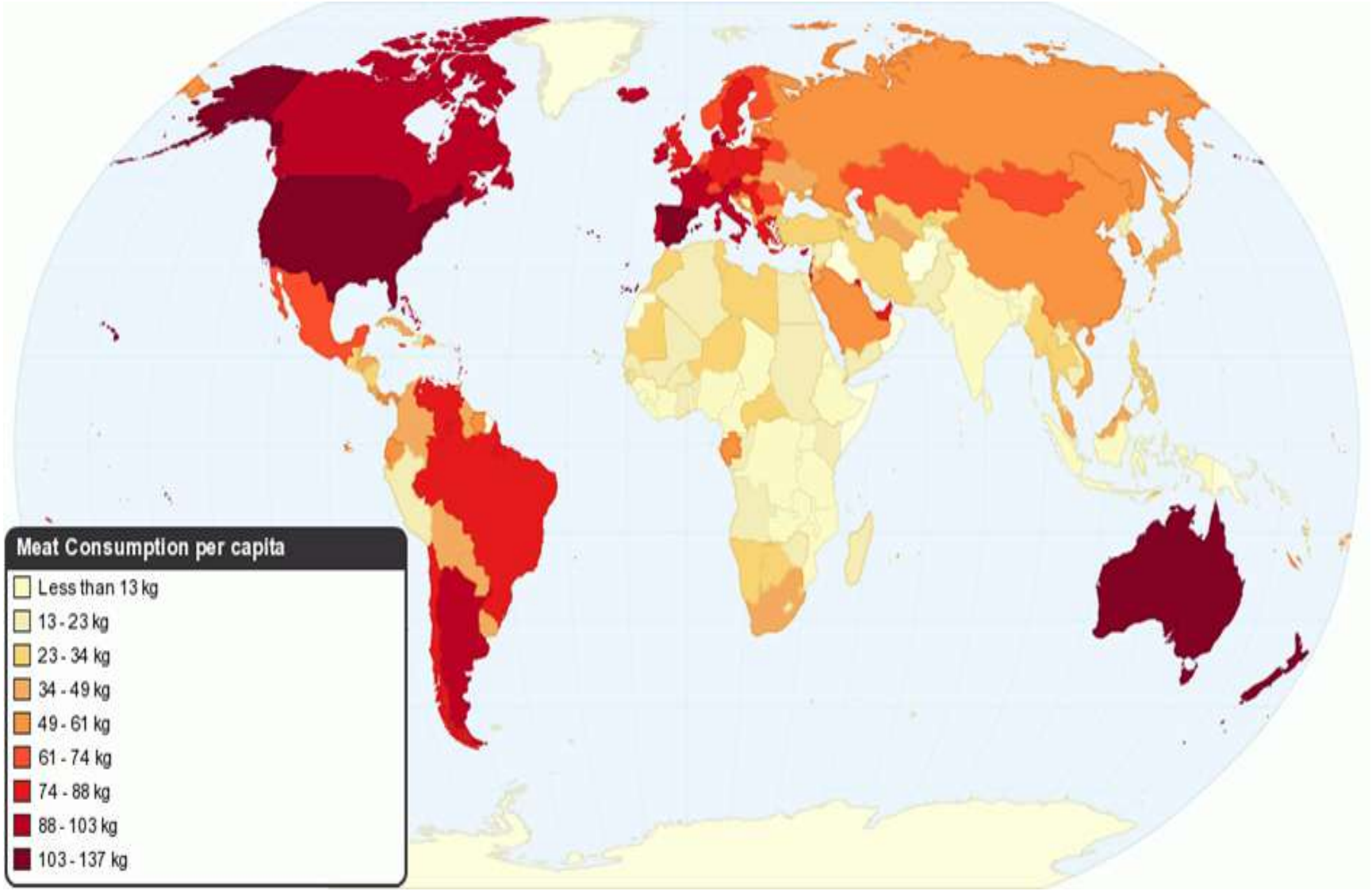
"elevated sidewalks will solve city transportation problems because the vehicular and the pedestrian traffic will be then free to develop itself along its own lines"

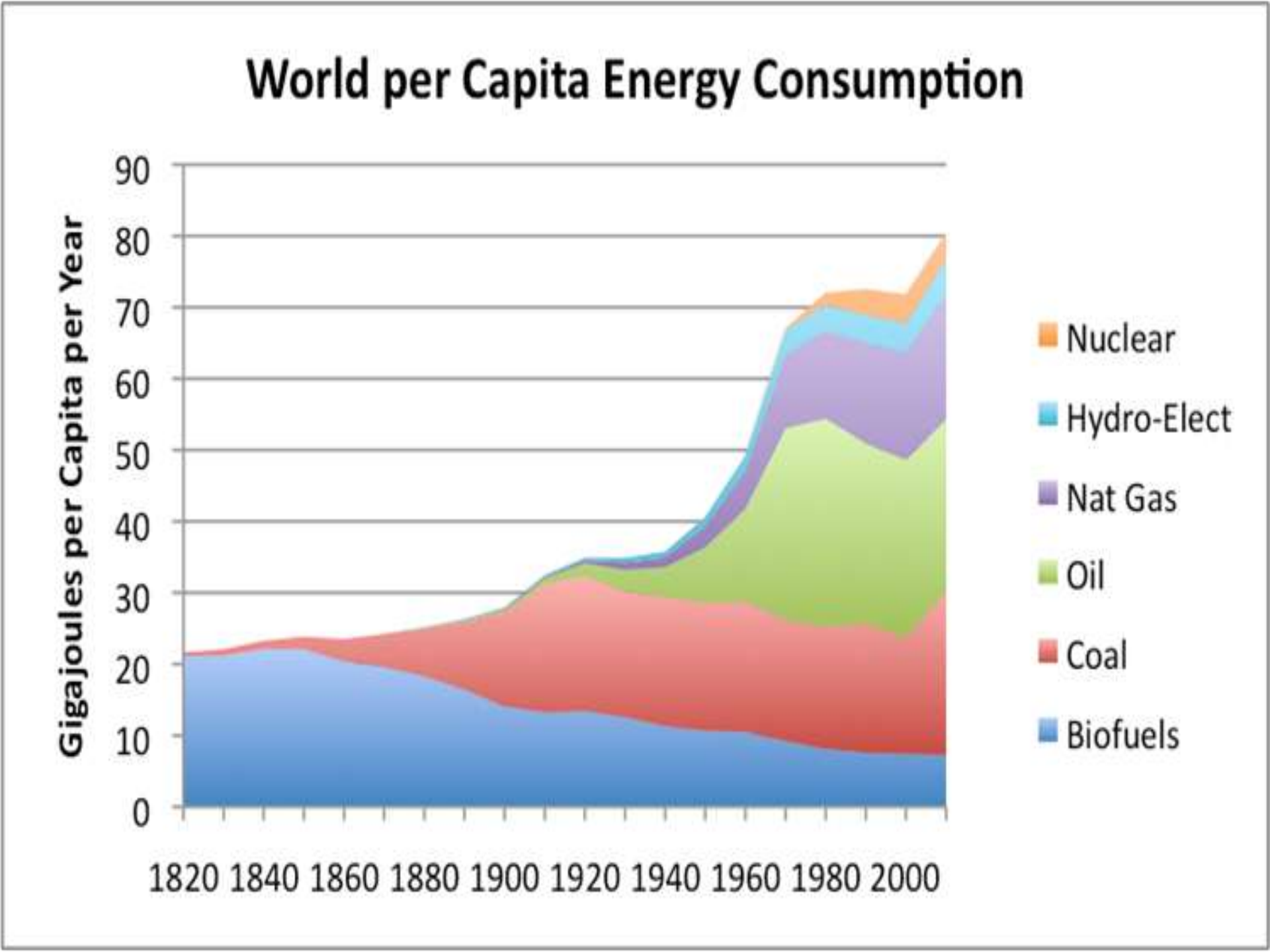
A century later . . .

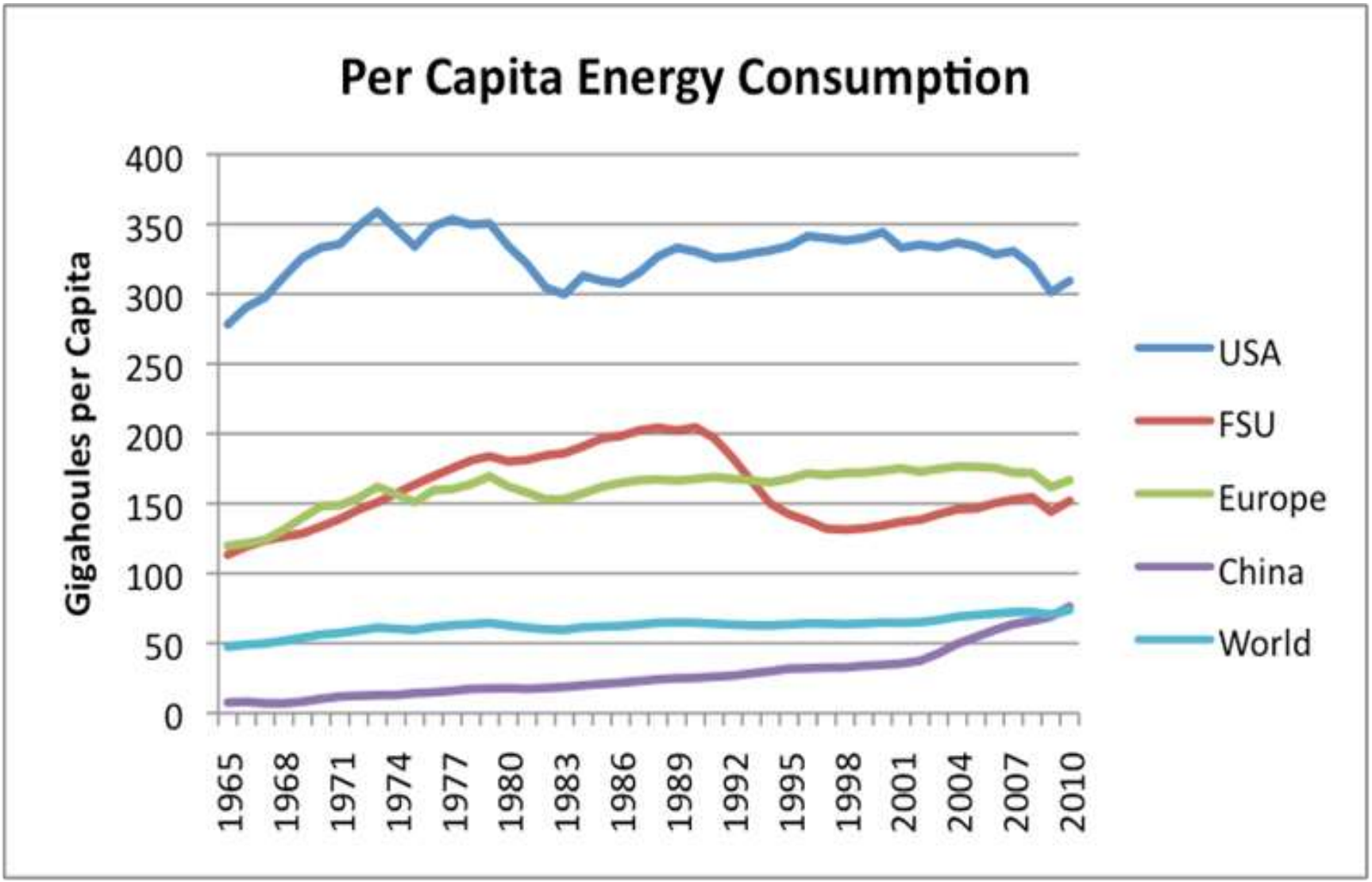
We have done the very opposite of the 1913 vision as we have raised our highways, some in massive, multiple, disorienting contortions with sidewalks buried deep beneath them.

May this be the best the West ever gets?

- Aging populations
- Weak economic growth and recessions
- Stagnant or declining per capita energy consumption
- Concerns about global environmental change
- Affluent economies may have reached a temporary plateau to be followed by . . . ?


Meat Consumption per capita
Less than 13 kg
13 - 23 kg
23 - 34 kg
34 - 49 kg
49 - 61 kg
61 - 74 kg
74 - 88 kg
88 - 103 kg
103 - 137 kg


World per Capita Energy Consumption
Gigajoules per Capita per Year
90
80
70
60
50
40
30
20
10
0
1820 1840 1860 1880 1900 1920 1940 1960 1980 2000
Nuclear
Hydro-Elect
Nat Gas
Oil
Coal
Biofuels


Per Capita Energy Consumption
Gigahoules per Capita
400
350
300
250
200
150
100
50
0
1965
1968
1971
1974
1977
1980
1983
1986
1989
1992
1995
1998
2001
2004
2007
2010
USA
FSU
Europe
China
World