Computing within Limits

Barath Raghavan
USC

Where Are We Headed?

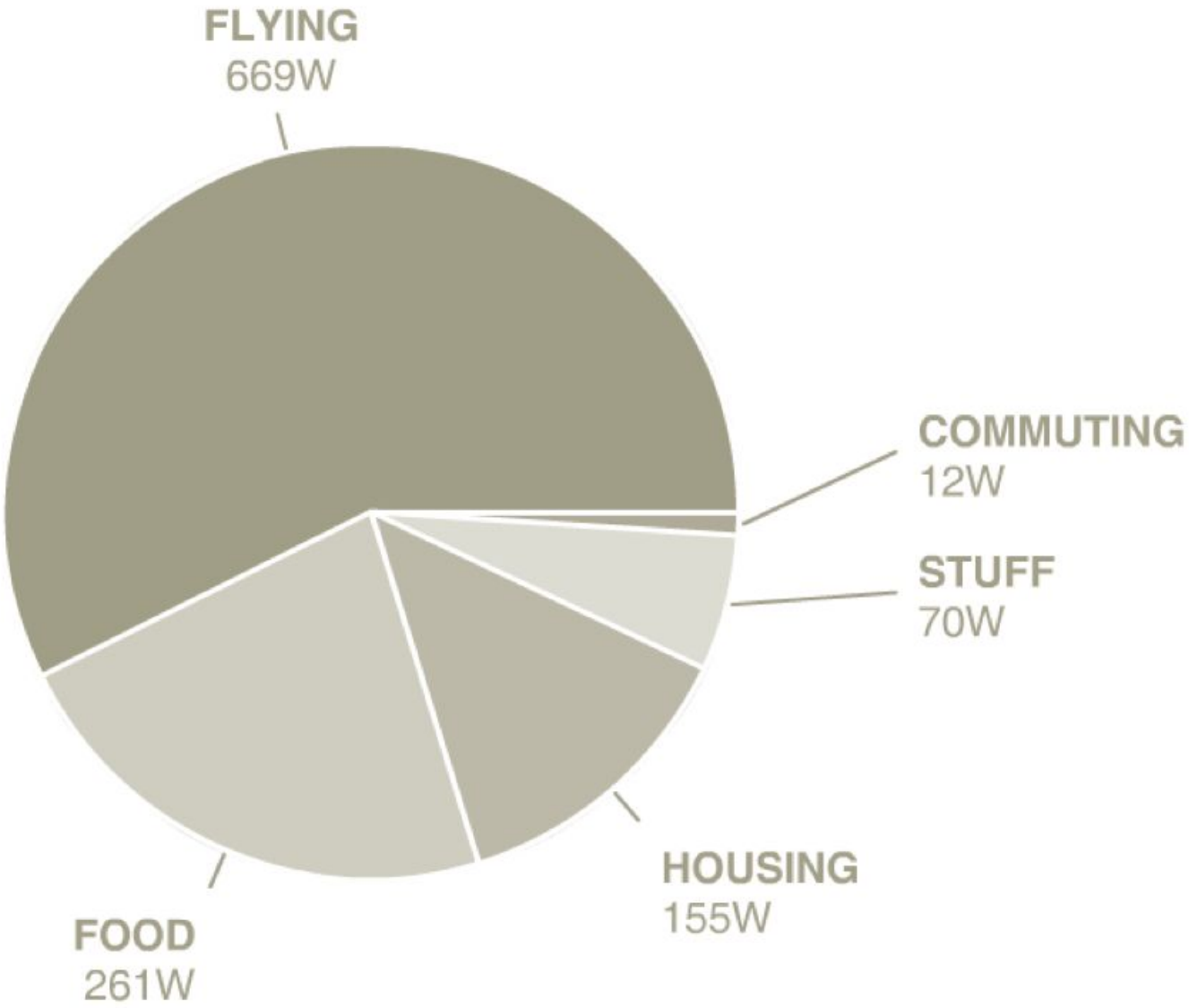
What Can Be Done?

What Should Be Done?

LIMITS

HOW DO WE USE ENERGY?

WHAT ARE THE CONSEQUENCES?


FLYING
669W
COMMUTING
12W
STUFF
70W
HOUSING
155W
FOOD
261W

OIL

Why do we use oil?

Easy to pump, transport, store

Stable at useful temperatures

Easily refined into numerous forms

High energy density

"Chemical fertilizers (made from natural gas), pesticides (made from petroleum), farm machinery, modern food processing and packaging and transportation have together transformed a system that in 1940 produced 2.3 calories of food energy for every calorie of fossil-fuel energy it used into one that now takes 10 calories of fossil-fuel energy to produce a single calorie of modern supermarket food."

Farmer in Chief, Pollan

heart valves • asphalt • crayons • parachutes • phones • dishwashing liquid • IV drips • tape • pop tarts • smoke detectors • strollers • candles • chicken nuggets • antiseptics • credit cards • deodorant • tupperware • ziplock bags • panty hose • air conditioners • shower curtains • shoes • volleyballs • floor wax • lipstick • synthetic clothing • coal extraction • bubble gum • car bodies • tires • paint • pens • markers • hair dryers • ammonia • eyeglasses • contacts • insect repellent • pesticides • hair coloring • movie film • ice chests • loudspeakers • basketballs • footballs • combs/brushes • linoleum • fishing rods • rubber boots • water pipes • motorcycle helmets • fishing lures • petroleum jelly • lip balm • antihistamines • golf balls • dice • insulation • trash bags • rubber cement • cold cream • umbrellas • ink • hearing aids • CDs/DVDs • mops • bandages • artificial turf • cameras • glue • shoe polish • caulking • stereos • flooring • toilet seats • car batteries • refrigerators • carpet • pharmaceuticals • solvents • nail polish • lighters • balloons • artificial flavoring • perfumes • toothpaste • toothbrushes • plastic forks • hair curlers • plastic cups/lids • electric blankets • oil filters • light switches • guitar strings • skis • upholstery • thermoses • plastic chairs • clingwrap • rubber bands • computers • gasoline • diesel • kerosene • heating oil • motor oil • jet fuel • bunker fuel

OIL DEPLETION

EFFICIENCY?

CLIMATE CHANGE

What Do Degrees °C Mean?

1 degree Ice-free arctic summer, polar ecosystem damage; coral reef bleaching; stronger hurricanes; erratic weather

2 degrees Lots of problems; 10-15% species extinction; most coral reefs bleached; permafrost melt begins; limit of no-return

3 degrees 20-80% loss of Amazon rainforest; extinction risk for polar species, 20-30% species extinction; continued permafrost melt; 1.1-3.2 billion more people with water stress; widespread coral loss

4 degrees End of ocean calcification; major global extinctions; decrease in food production; near-total deglaciation

5 degrees Many unknown impacts

[IPCC]

"The analysis within this paper offers a stark and unremitting assessment of the climate change challenge facing the global community. There is now little to no chance of maintaining the rise in global mean surface temperature at below 2°C, despite repeated high-level statements to the contrary. Moreover, the impacts associated with 2°C have been revised upwards (e.g. [20,21]), sufficiently so that 2°C now more appropriately represents the threshold between dangerous and extremely dangerous climate change."

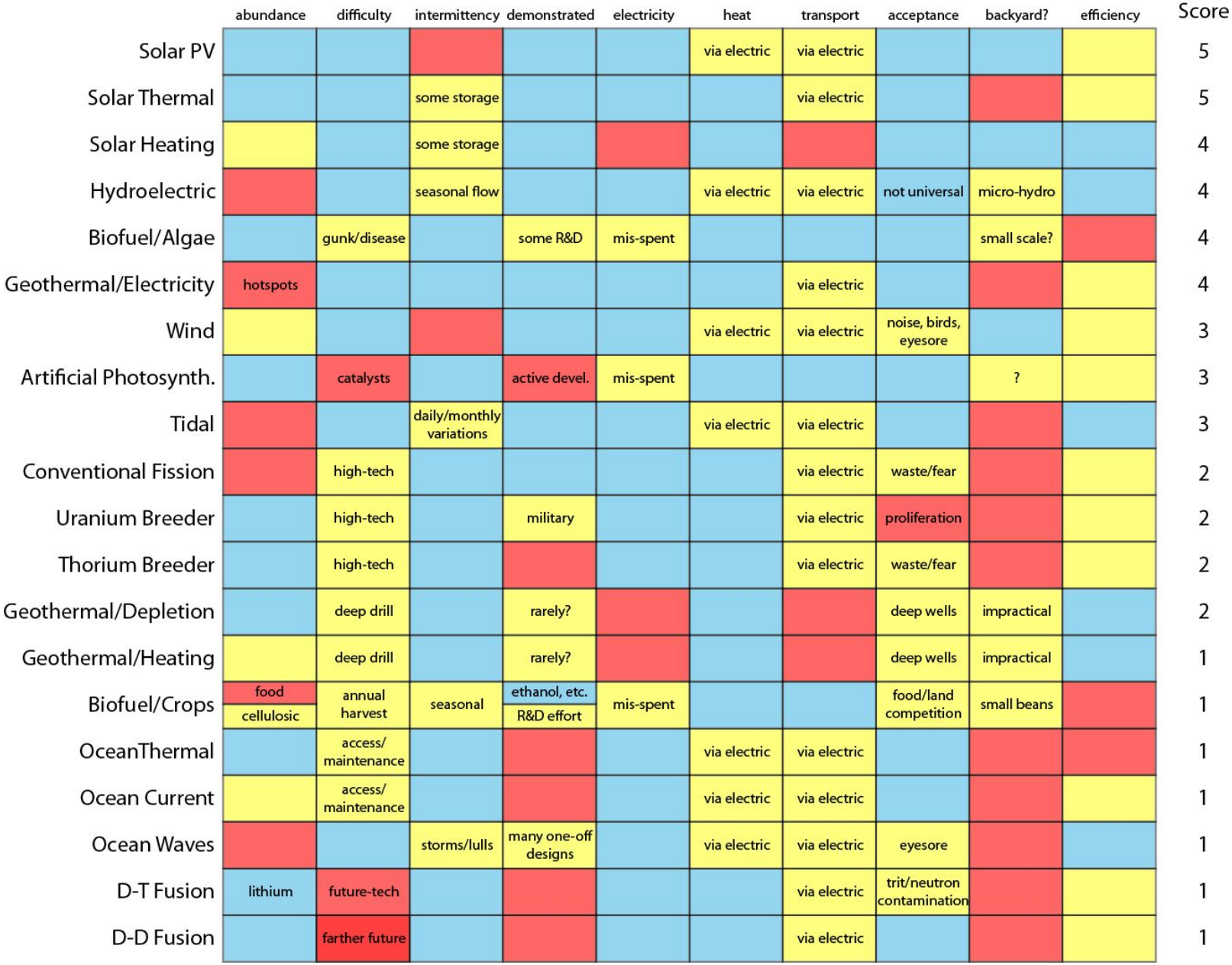
Beyond 'dangerous' climate change, Anderson and Bows (2011)

Change behavior

(use less)

Change sources

(find more)

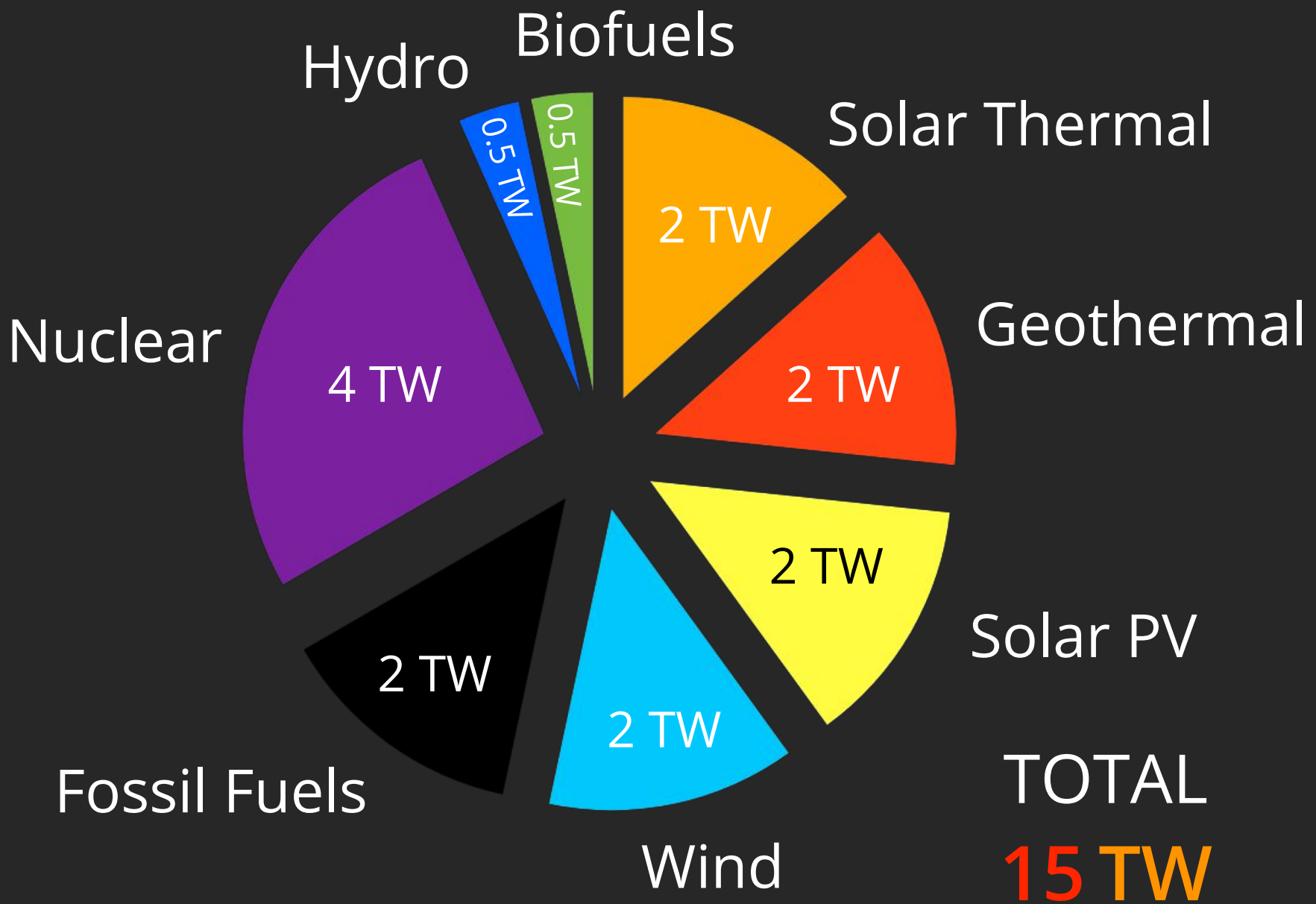

abundance
difficulty
intermittency
demonstrated
electricity
heat
transport
acceptance
backyard?
efficiency
Score
Solar PV
via electric
via electric
5
Solar Thermal
some storage
via electric
5
Solar Heating
some storage
4
Hydroelectric
seasonal flow
via electric
via electric
not universal
micro-hydro
4
Biofuel/Algae
gunk/disease
some R&D
mis-spent
small scale?
4
Geothermal/Electricity
hotspots
via electric
4
Wind
via electric
via electric
noise, birds, eyesore
3
Artificial Photosynth.
catalysts
active devel.
mis-spent
?
3
Tidal
daily/monthly variations
via electric
via electric
3
Conventional Fission
high-tech
via electric
waste/fear
2
Uranium Breeder
high-tech
military
via electric
proliferation
2
Thorium Breeder
high-tech
via electric
waste/fear
2
Geothermal/Depletion
deep drill
rarely?
deep wells
impractical
2
Geothermal/Heating
deep drill
rarely?
deep wells
impractical
1
Biofuel/Crops
food
cellulosic
annual harvest
seasonal
ethanol, etc.
R&D effort
mis-spent
food/land competition
small beans
1
OceanThermal
access/ maintenance
via electric
via electric
1
Ocean Current
access/ maintenance
via electric
via electric
1
Ocean Waves
storms/lulls
many one-off designs
via electric
via electric
eyesore
1
D-T Fusion
lithium
future-tech
via electric
trit/neutron contamination
1
D-D Fusion
farther future
via electric
1

[Murphy]

	abundance	difficulty	intermittency	demonstrated	electricity	heat	transport	acceptance	backyard?	efficiency	Score
Petroleum	for now										8
Natural Gas	for now						buses, trucks via electric			for heat elec/transport	8
Coal	for now						via electric (and trains?)				7

[Murphy]

I was promised a Mr. Fusion



Power Profile for 2030-2035 [Griffith09]

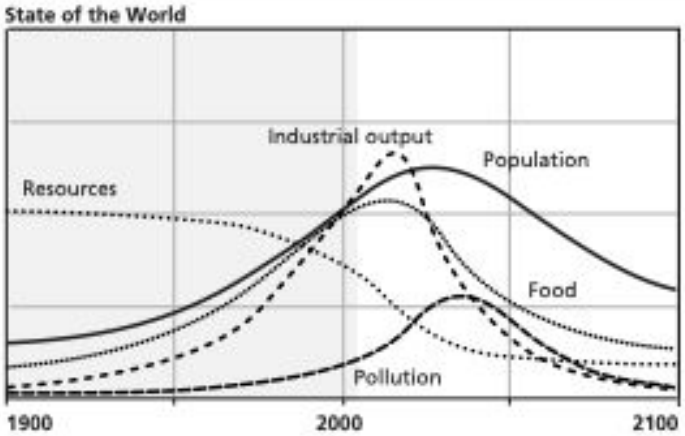
Source (New capacity)	How Much? (New capacity in 2030-2035 mix)	How Fast? (Manufacturing rate required, sustained over 20 years)
Solar PV	2 TW	100 m^2 photovoltaic / sec
Solar Thermal	2 TW	50 m^2 mirrors / sec
Wind	2 TW	12 x 100m turbines / hour
Nuclear	3 TW	3 x 1GW plants / week
Geothermal	2 TW	3 x 100MW turbines / day
Biofuel	0.5 TW	1250 m^3 oil algae / sec

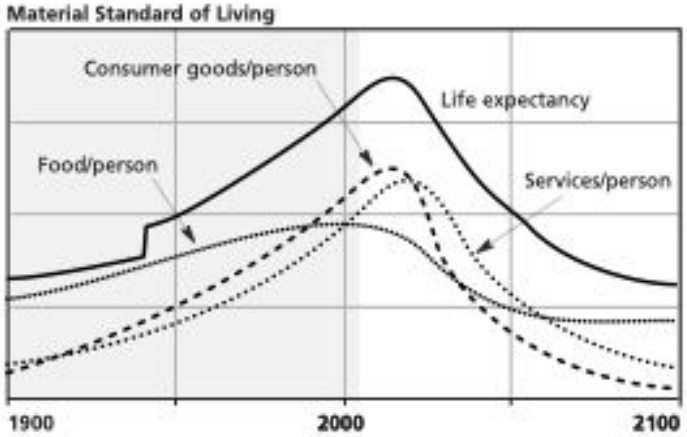
New Generating Capacity for 2030-2035 [Griffith09]

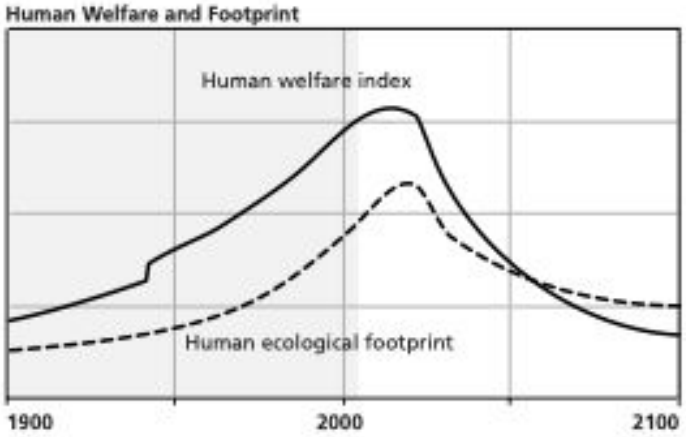
Source (New capacity)	How Fast? (Manufacturing rate required, sustained over 20 years)	Capacity (Optimistic estimate of manufacturing potential)
Solar PV	100 m^2 PV/sec	35 m^2 PV/sec
Solar Thermal	50 m^2 mirrors/sec	large?
Wind	12 x 100m turbines/hr	5 turbines/hr
Nuclear	3 x 1GW plants/wk	0.5 plants/wk
Geothermal	3 x 100MW turbines/day	3 turbines/month
Biofuel	1250 m^3 oil algae/sec	2 m^3 oil algae/sec

Energy transition: ~20 year crash program required.

Crash program: ~50% short by 2030s.







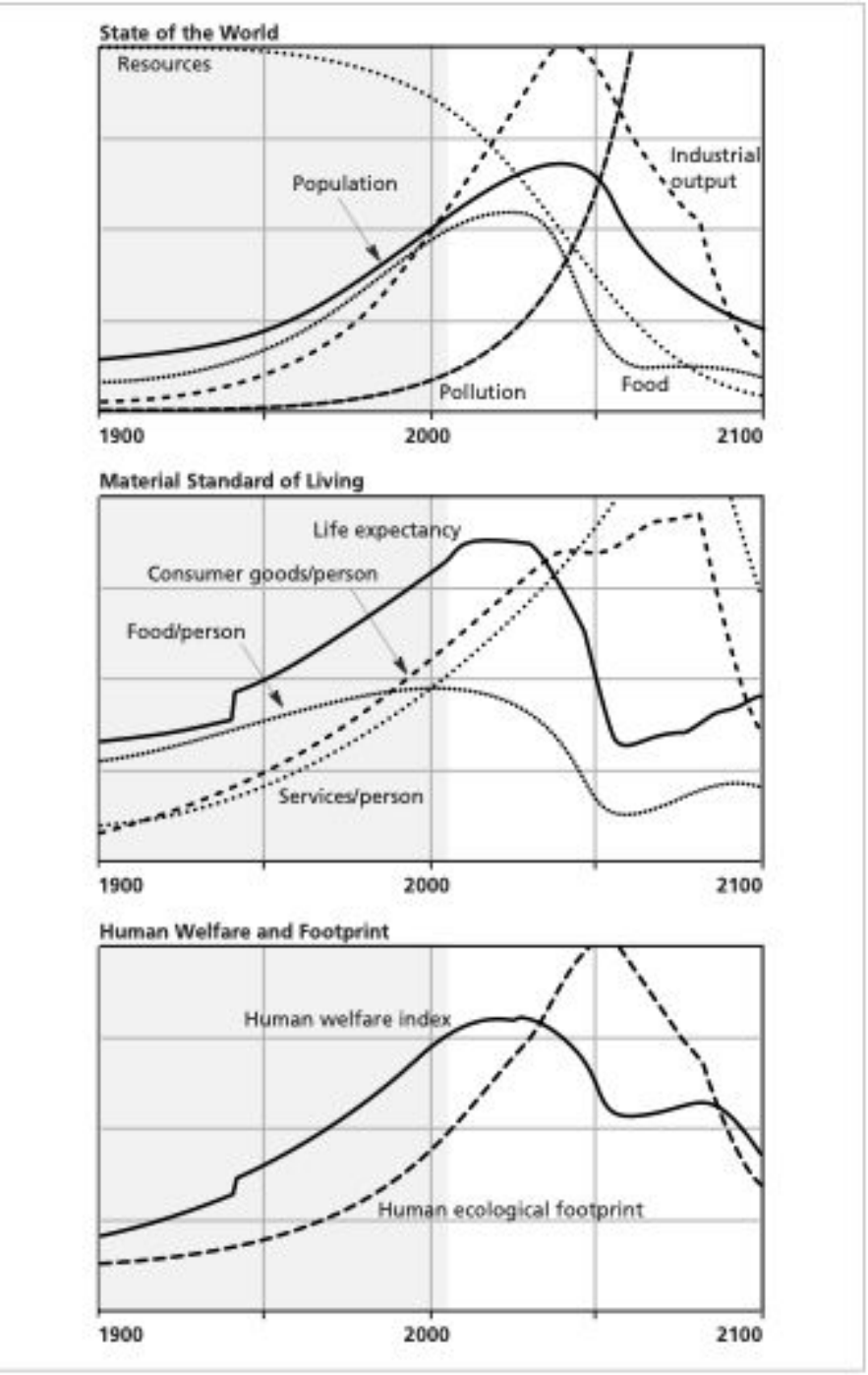
Scenario 1

Limits to Growth

Scenario 1:

Baseline,

resource crisis



Limits to Growth

Scenario 2:

More resources, pollution crisis

“We are grossly wasting our energy resources and other precious raw materials as though their supply was infinite. We must even face the prospect of changing our basic ways of living. This change will either be made on our own initiative in a planned and rational way, or forced on us with chaos and suffering by the inexorable laws of nature.”

[Carter74]

Where Are We Headed?

What Can Be Done?

What Should Be Done?

Sustainable Computing

Computing for Sustainability

Sustainable Computing

5%

Computing for Sustainability

95%

Agriculture

Transportation

Power Generation

Manufacturing

Consumption

Production

Finance

Governance

Culture

Perspective

Flexibility

Wisdom

"Not: Industry is the cause of all problems, or the cure.
Nor: Government is the cause or the cure.
Nor: Environmentalists are the cause or the cure.
Nor: Any other group [economists come to mind] is the cause or the cure.

But: All people and institutions play their role within the large system structure. In a system that is structured for overshoot, all players deliberately or inadvertently contribute to that overshoot. In a system that is structured for sustainability, industries, governments, environmentalists, and most especially economists will play essential roles in contributing to sustainability."

[Meadows04]