What Can World Models Tell Us About *Peak Oil Supply* and *Global Warming*?

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The Chain Letter I

- Let us consider the model of a simple ***chain letter***.
- The following rules are set to govern this (artificial) model:
  - ❖ A chain letter is received with two addresses on it, the address of the sender, and the address of the sender's sender.
  - ❖ After receiving the letter, a recipient sends ***$1*** to the sender's sender. He or she then sends the letter on to 10 other people, again with two addresses, his (or her) own as the new sender, and the sender's address as the new sender's sender.
  - ❖ The letter is only mailed within the U.S.
  - ❖ Every recipient answers the letter exactly once. When a recipient receives the same letter for a second or subsequent time, he (or she) simply throws it away.

The Chain Letter II

- Special rules are needed to provide initial conditions.
  - ❖ The originator sends the letter to 10 people without sending money to anyone.
  - ❖ If a recipient receives the letter with only one address (the sender's address), he or she sends the letter on to 10 other people with two addresses (his or her own as the sender, and that of the originator as the sender's sender). No money is paid to anyone in this case.
- Every sender has 100 receiver's receivers, thus is expected to make ***$100***.
- Except for the first 11, who don't pay anything, every sender pays exactly ***$1***.
- Hence this is a wonderful (and totally illegal!) way of making money out of thin air.

The Chain Letter III

- We can model the chain letter easily as a discrete system.

$$I = 10 \cdot (1.0 - \frac{P}{P_{max}})$$

I is the average number of new infections per recipient.

$$R = I \cdot \text{pre}(R)$$

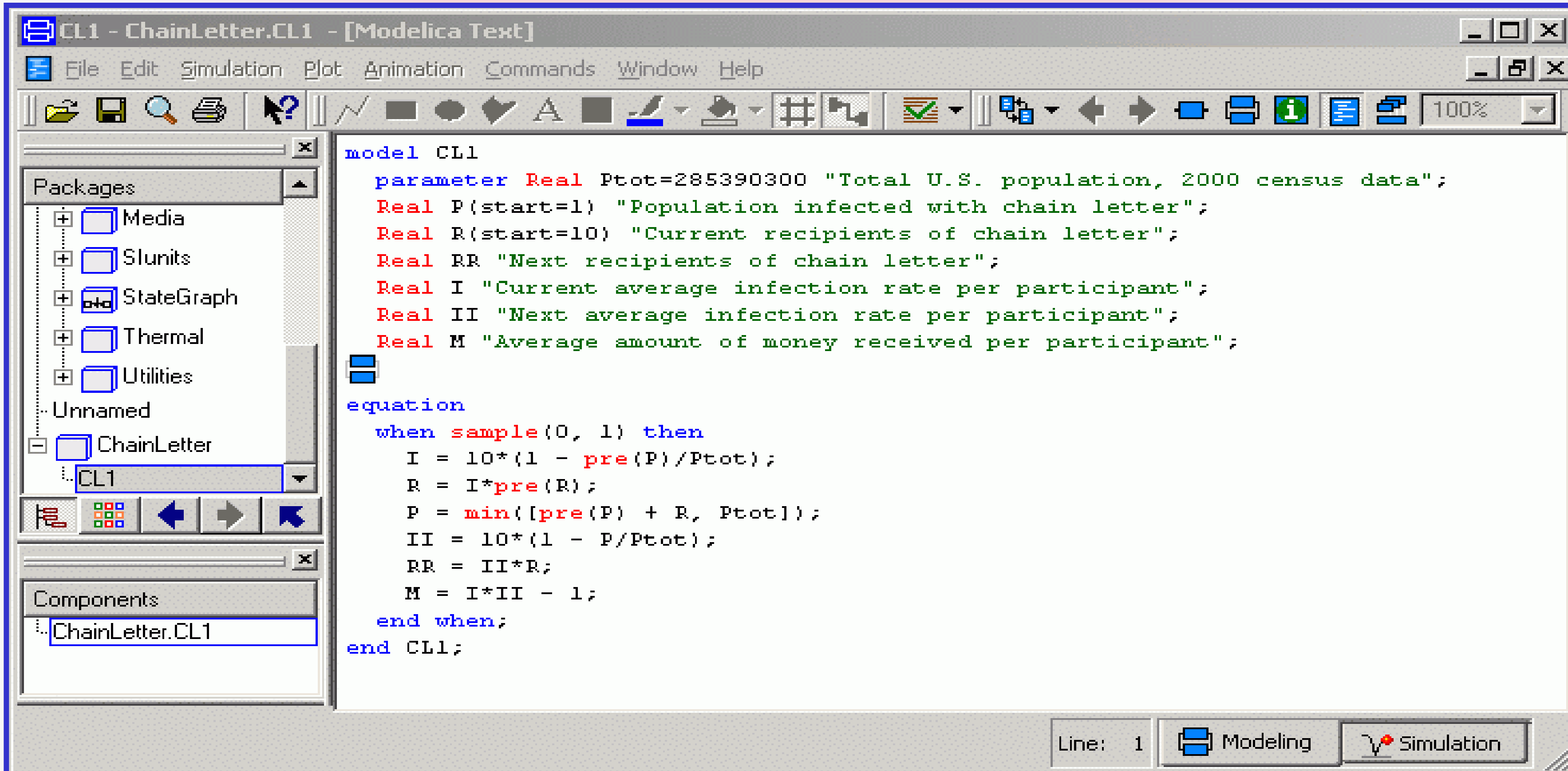
R, the number of new recipients, can be computed as the number of new infections per recipient multiplied by the number of recipients one step earlier.

$$P = \text{pre}(P) + R$$

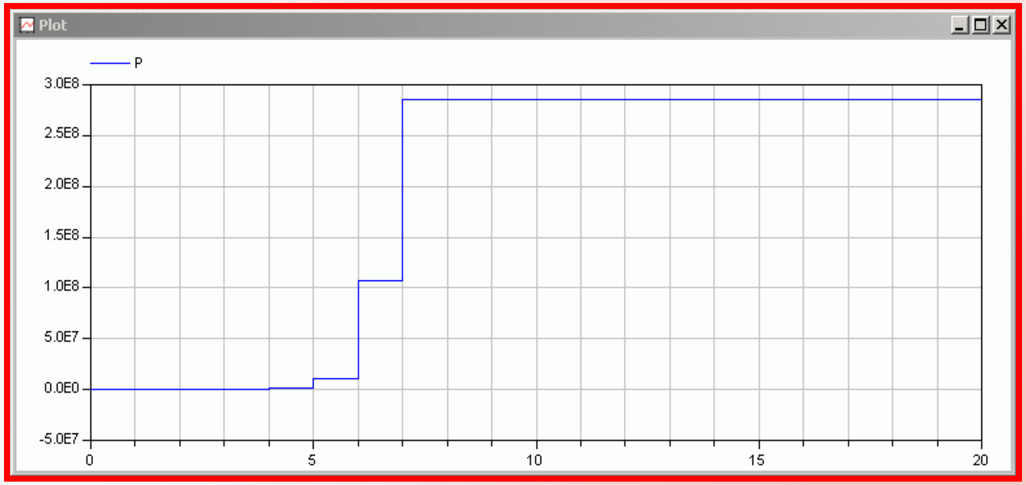
P, the number of already infected people, can be computed as the number of people infected previously plus the new recruits.

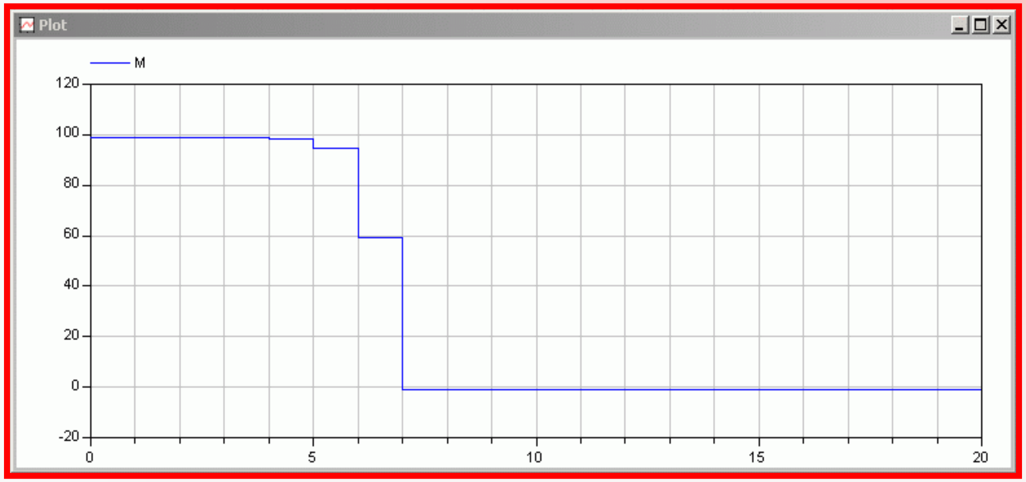
The Chain Letter IV

- We can easily code this model in ***Modelica***.



Simulation Results

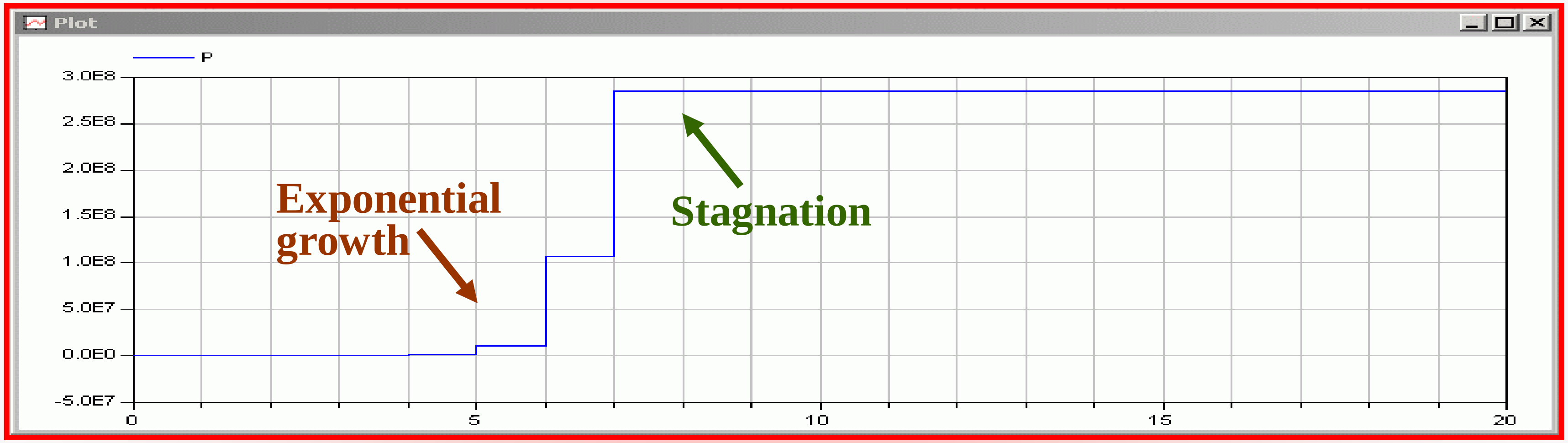


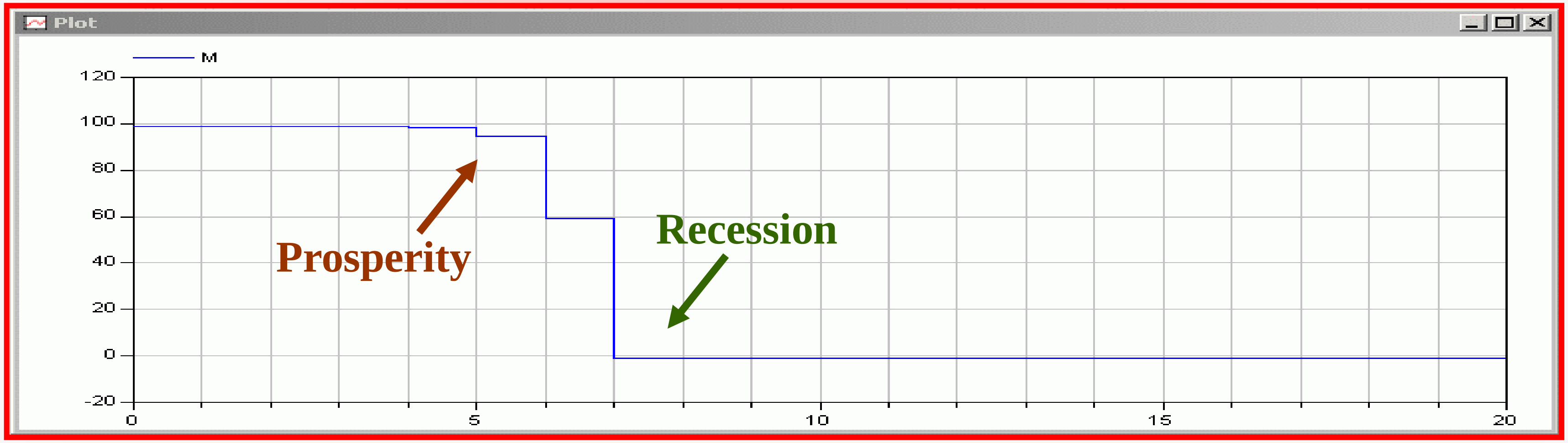


- Initially, every participant makes exactly ***$99*** as expected.
- However, already after seven generations, the entire U.S. population has been infected.
- Thereafter, everyone who still participates, loses ***$1***.

The energy conservation laws are not violated! No money is being made out of thin air! Those who participate early on, make money at the expense of the many who jump on the band wagon too late.

Simulation Results





Exponential Growth and Ponzi Schemes

- Mailing out chain letters is illegal, when done by individuals.
- Unfortunately, our entire economy is based on the chain letter principle, which in economic circles is usually referred to as a ***Ponzi scheme***.
- Madoff failed, not because he was doing something out of the ordinary. He failed, because his Ponzi scheme was reaching its ***Limits to Growth***.

Social Security is a Ponzi Scheme

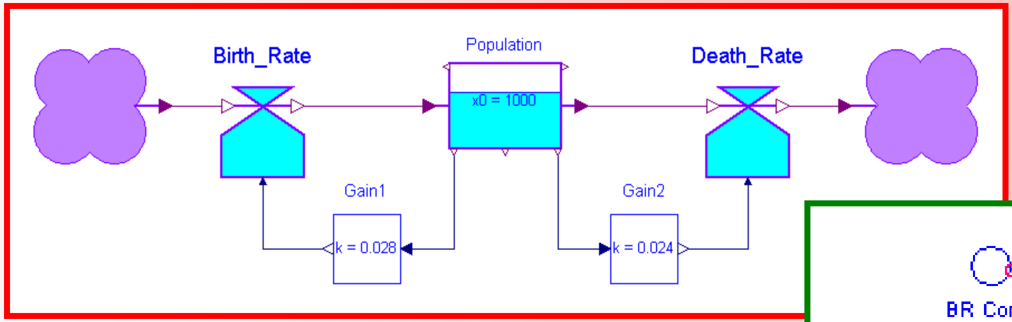
- When I pay social security taxes, my money is not being saved to guarantee retirement benefits for myself.
- The money is being spent immediately to pay out retirement benefits to those who are eligible to receive such benefits right now.
- Social security remains solvent as long as we can guarantee continued exponential growth of our population.
- When the population reaches its limits to growth, social security becomes insolvent, because it's a Ponzi scheme.

Our Banking System is a Ponzi Scheme

- When I deposit money in a bank account, I expect a fixed interest rate, i.e., my money is supposed to grow exponentially.
- In order to pay the promised interest on my deposit, the bank must re-invest my money in another scheme that makes it grow exponentially at a faster rate.
- This scheme works, until our economy reaches its limits to growth.
- At that time, our banks become insolvent, because they represent one colossal Ponzi scheme.

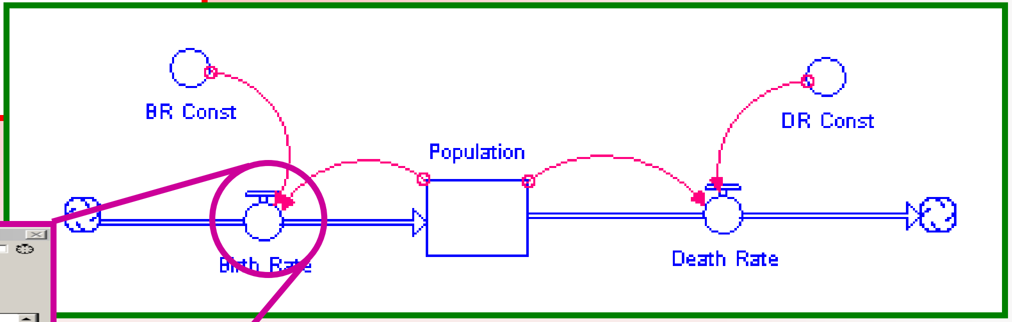
Short History of System Dynamics

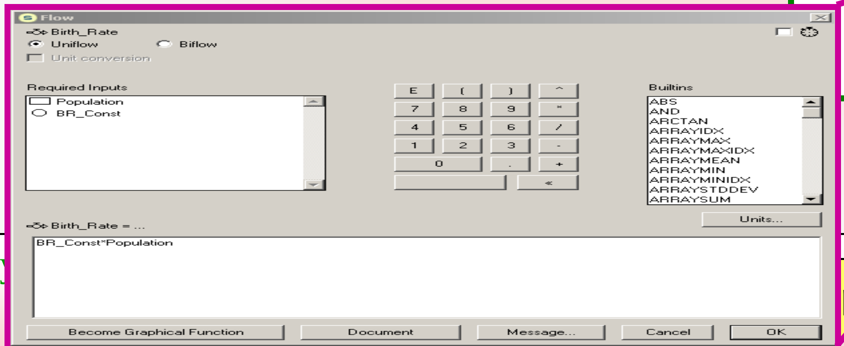
- The System Dynamics approach to modeling dynamic and in particular ill-defined systems was developed in the 1960s at M.I.T. by Jay Forrester.



Modelica

Stella





Short History of System Dynamics II

- Any System Dynamics modeling effort starts by defining the set of ***levels*** (stocks) and their ***rates*** (flows).

Levels	Rates: Inflows	Rates: Outflows
Population	Birth Rate	Death Rate
Money	Income	Expenses
Frustration	Stress	Affection
Love	Affection	Frustration
Tumor Cells	Infection	Treatment
Inventory on Stock	Shipments	Sales
Knowledge	Learning	Forgetting

- We then define a so-called "***laundry list***," specifying the set of influencing factors for each of the rate variables.

Birth Rate: ←

- Population
- Material Standard of Living
- Food Quality
- Food Quantity
- Education
- Contraceptives
- Religious Beliefs

Short History of System Dynamics III

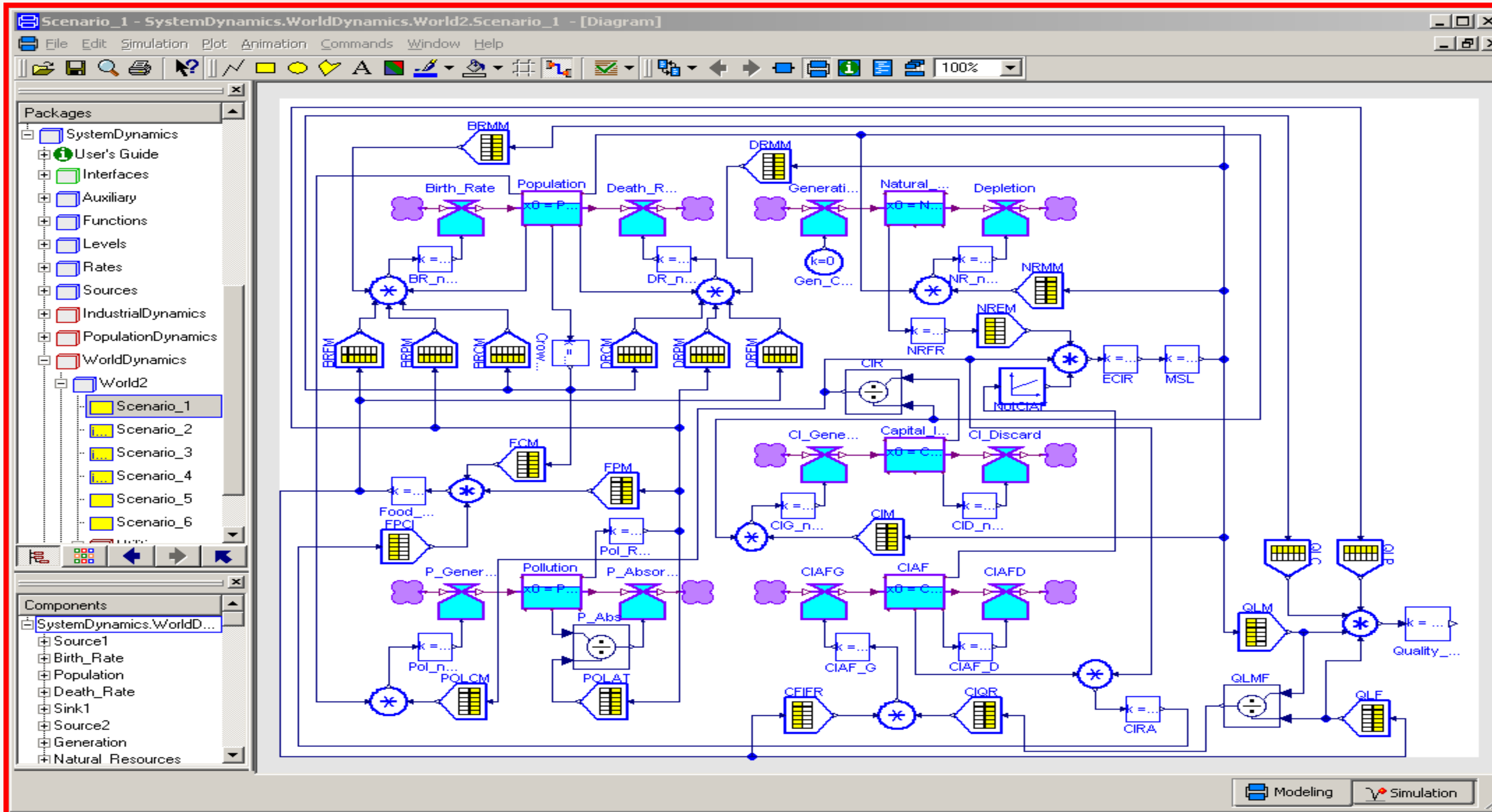
- Each laundry list defines a potentially non-linear function in the input variables.

$$Birth\_rate = f\,(Population,\ Pollution,\ Food,\ Crowding,\ Material\_Standard\_of\_Living)$$

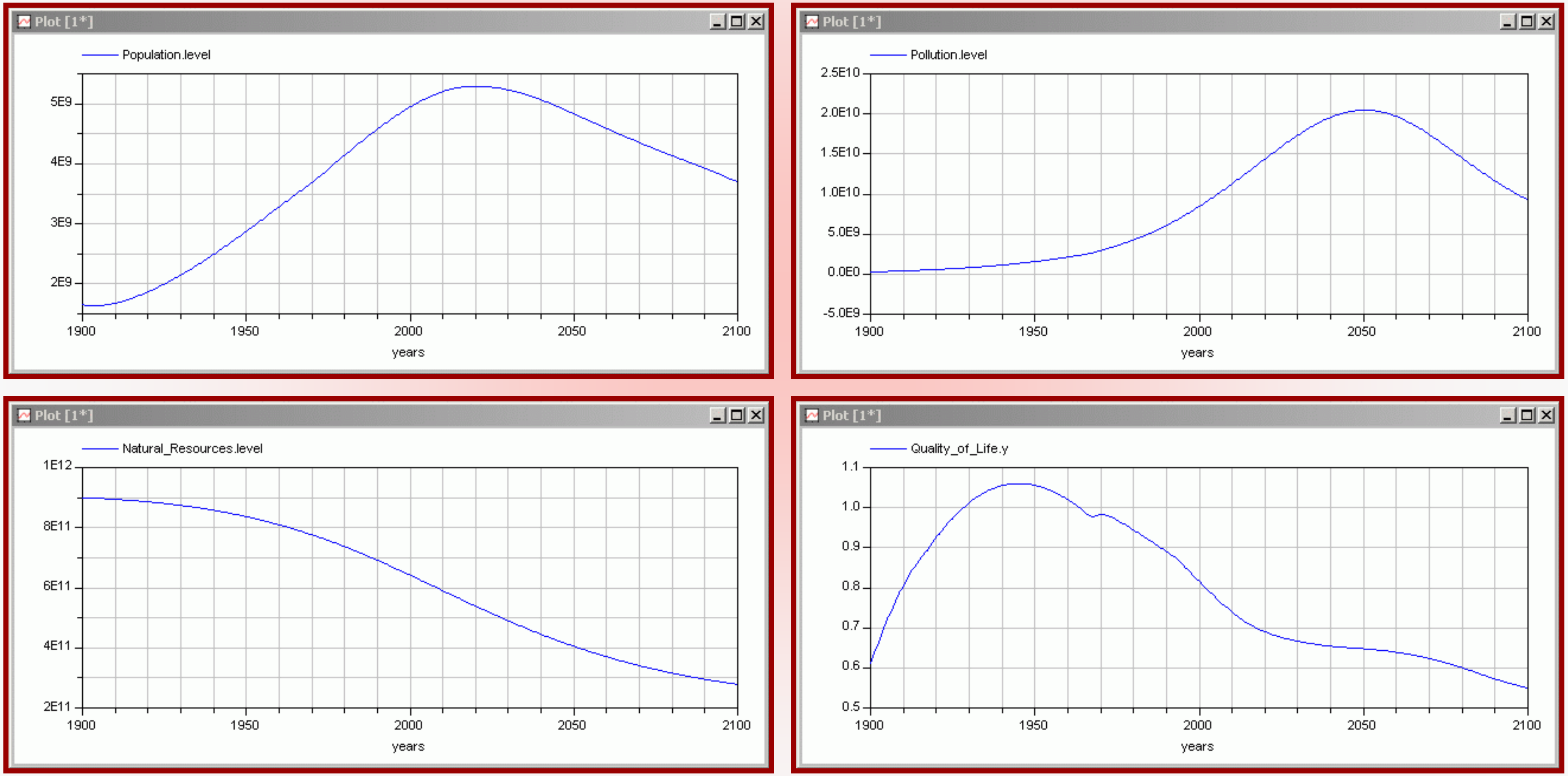
- We extract the normal value and apply any structural insight that we may possess about what the equation must look like, and then replace one multi-valued function by a product of single-valued functions, ignoring the interactions among the input variables.

$$Birth\_rate = BRN \cdot Population \cdot f_1\,(Pollution) \cdot f_2\,(Food) \cdot f_3\,(Crowding) \cdot f_4\,(Material\_Standard\_of\_Living)$$

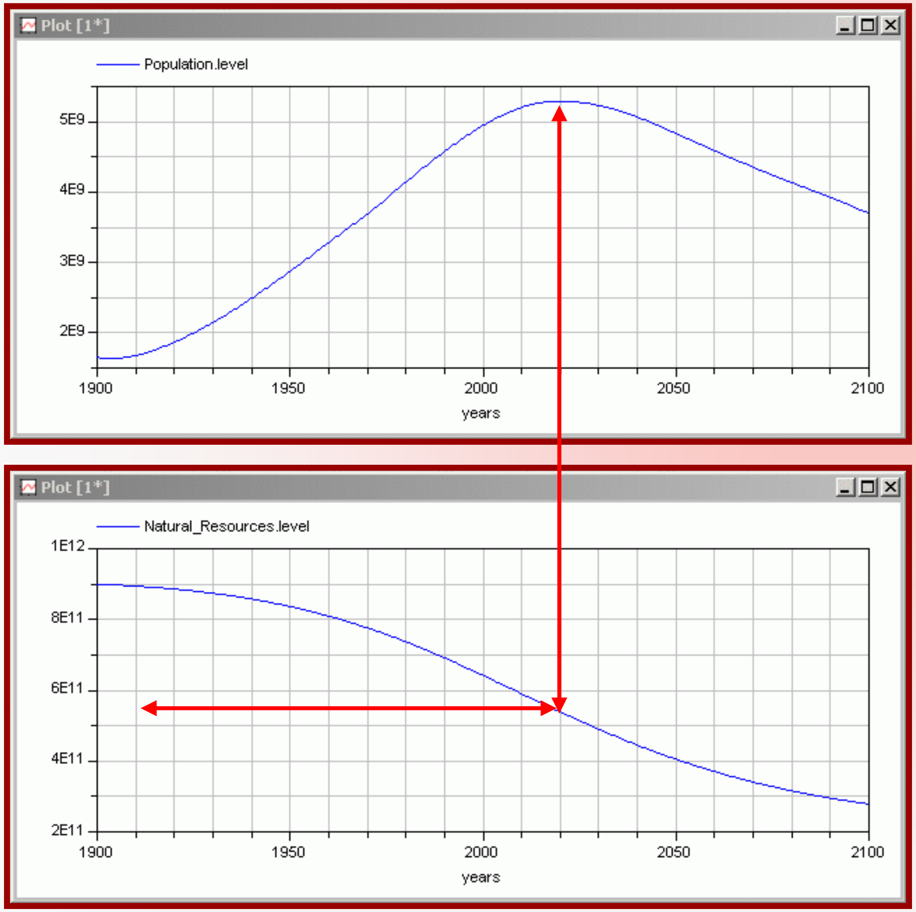
Forrester’s World2 Model [1971]



Forrester's World2 Model II



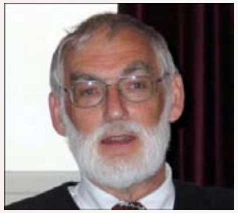
Forrester's World2 Model III



The model shows nicely the ***limits to growth***. The population peaks at about the year 2020 with a little over 5 billion people.

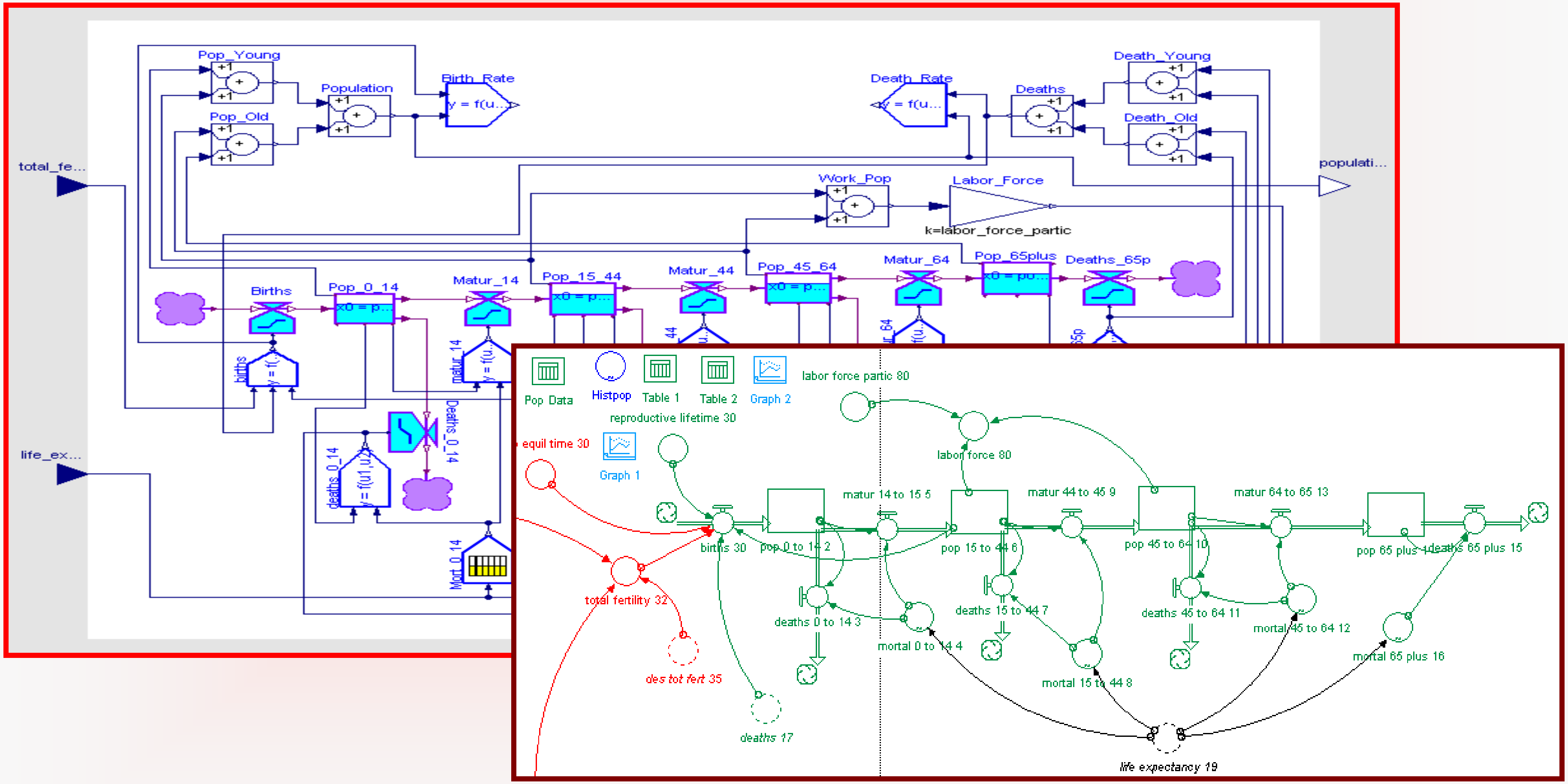
It turns out that, as the *natural resources* shrink to a level below approximately $5 \cdot 10^{11}$, this generates a strong damping effect on the population.

Meadows' World3 Model [1972]

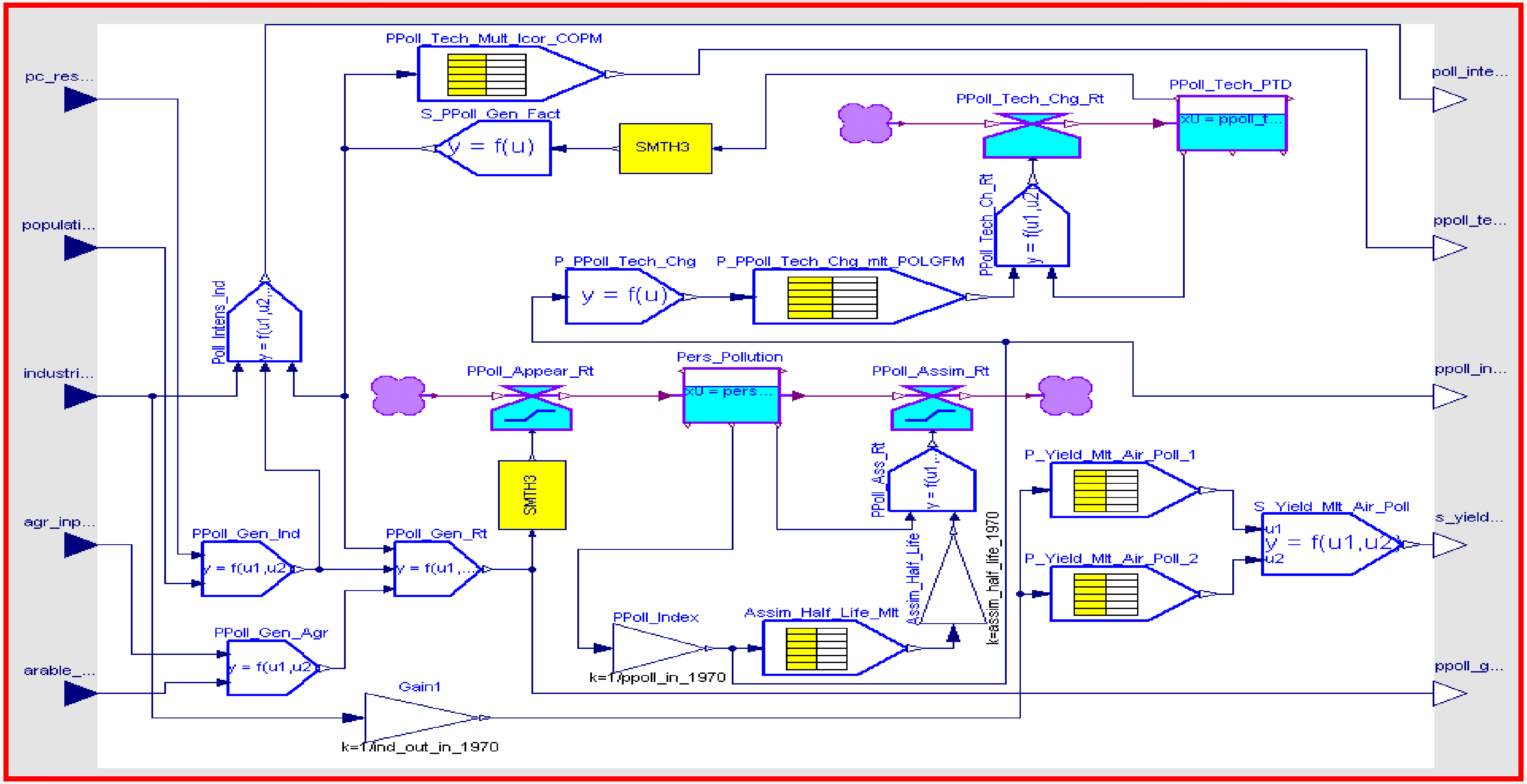


- One year after Forrester, Meadows (also from M.I.T.) published his own world model that he coined ***World3***.
- The World3 model is considerably more complex than the earlier World2 model. It no longer fits on a single screen.
- Contrary to Forrester, Meadows didn't publish the equations governing his model in his book: ***Limits to Growth***. He only published the simulation results obtained from his model.
- He published the model itself in a separate book: ***Dynamics of Growth in a Finite World***. That book appeared two years later.
- Meadows' model is considerably more sound than Forrester's model, and consequently, it can answer more questions in a more reliable fashion.

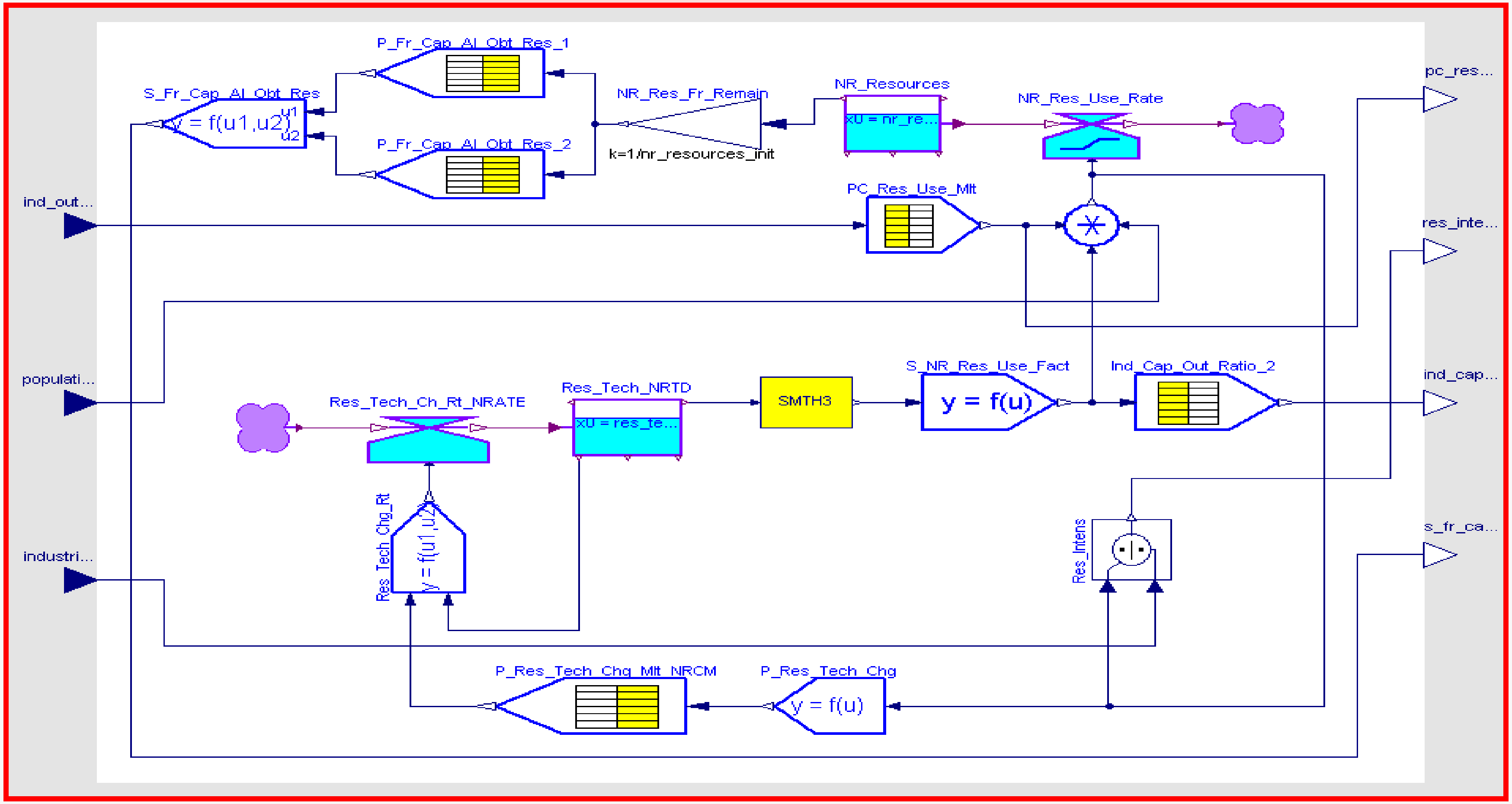
Population Dynamics



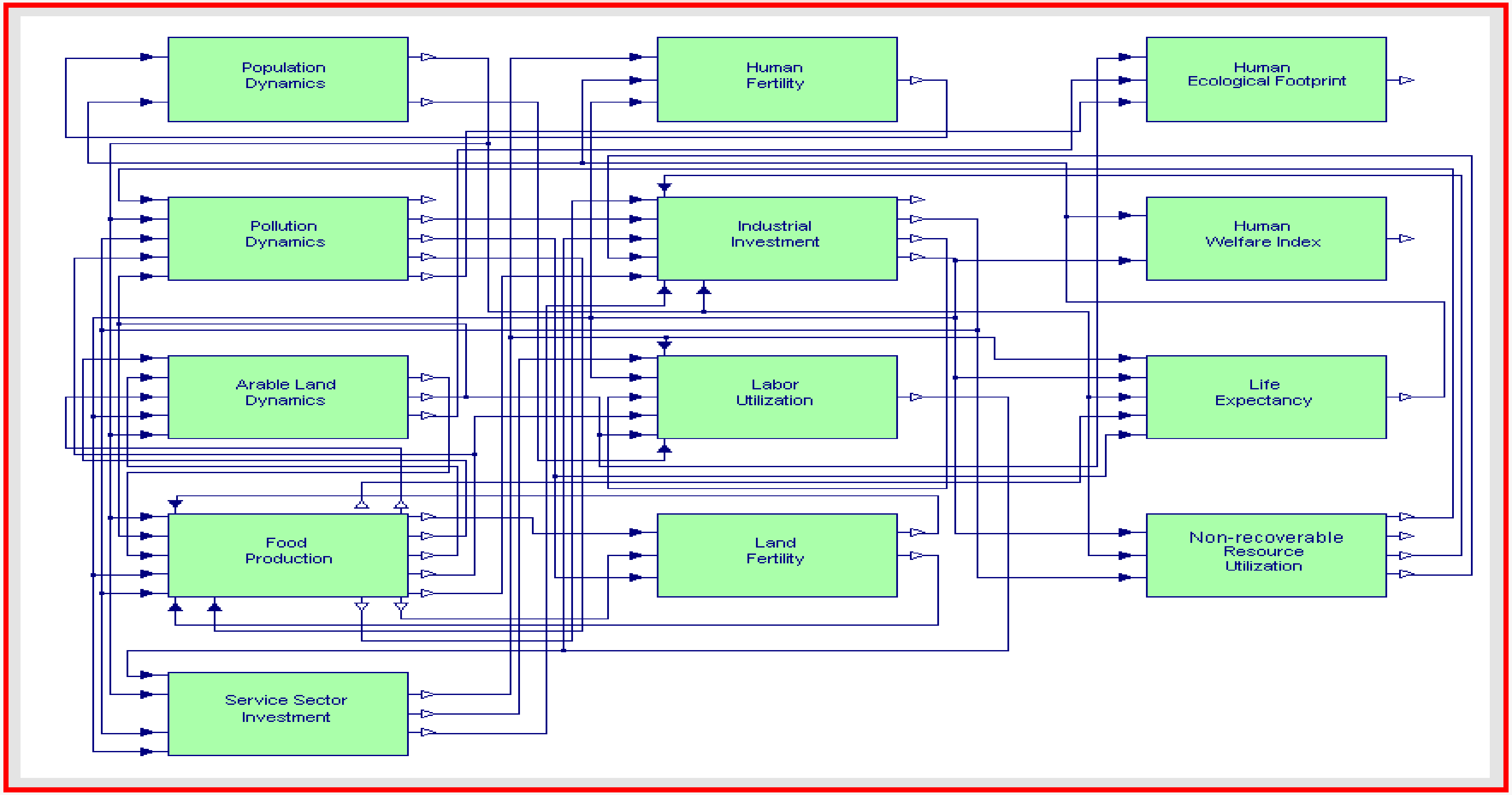
Pollution Dynamics



Resource Utilization Dynamics

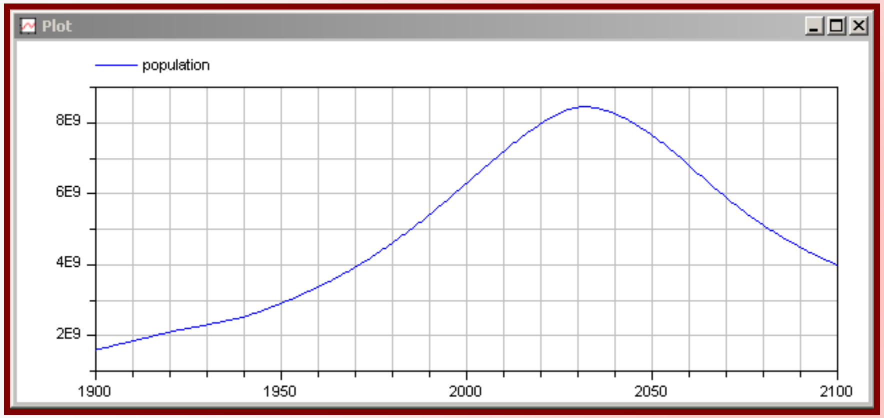


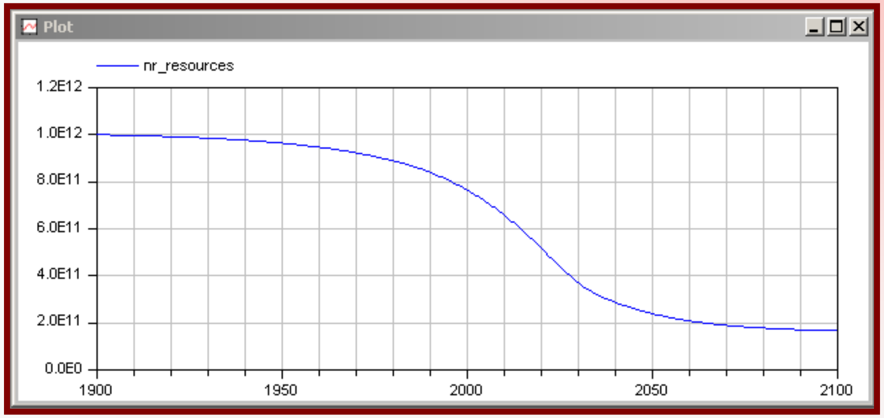
Overall World3 Model



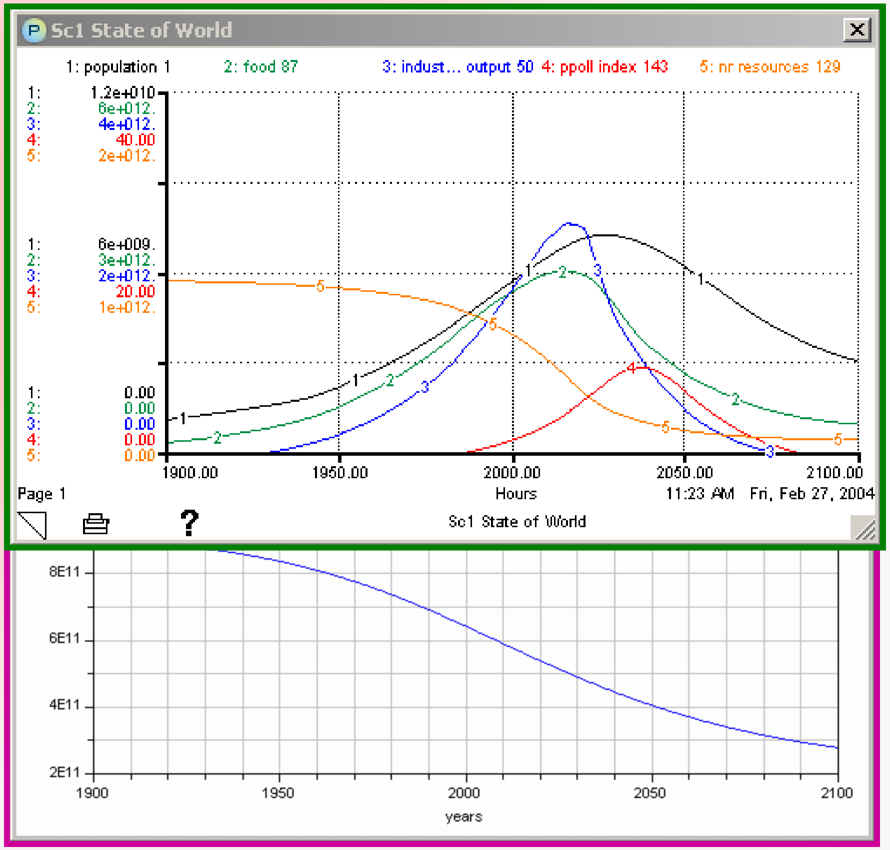
Simulation Results

World3





World2 *Stella*



Analysis of Simulation Results

- Although ***World2*** and ***World3*** use a completely different set of state variables with different interactions between them, the results are almost identical.
- The simulation results don't seem to be very sensitive to the selection of state variables and interactions in the model.
- This essentially is bad news in the given situation.
- Meadows published three versions of his model: in 1972, in 1992, and in 2004 (based on simulations of 2002).
- The revised versions added a few components, but the primary difference between them is the year, interventions take place. It makes no sense to optimize over the past.
- As time progresses, the window of opportunity for affecting the outcome is shrinking.

Different Scenarios

- Both in ***World2*** and ***World3***, the limits to growth are initially caused by resource depletion.
- Meadows (like Forrester before him) proposed to lift that limit by assuming that there are more resources available than earlier thought.
- In both models, the limits to growth are now caused by excessive pollution.
- Both models show that excessive pollution is much worse than resource depletion. It leads to massive die-off.
- Hence measures are proposed to limit the amount of pollutants generated. Now the limits to growth are caused by food scarcity.

Reactions

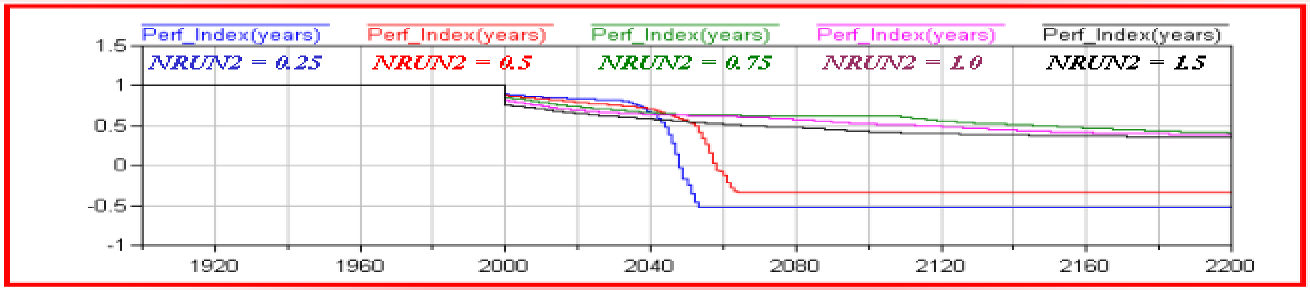
- Both ***World Dynamics*** and ***Limits to Growth*** received immediately lots of attention. Both books were sold millions of times and were translated into many languages.
- Because of the attention that these books had found, and because the message wasn't palatable, lobbyists quickly started denouncing the results. These were essentially the same agents that today denounce climate change.
- The methods were defamed as pseudo-science, and the authors were both ridiculed and vilified.
- The defamation campaign turned out to be utterly successful. Forrester and Meadows were shunned by "serious" scientists for many years, and their message was buried. No public funding was henceforth made available for research relating to global dynamics.

Sustainability

- All indicators point to the assumption that we are already now consuming the remaining resources of this planet at a pace faster than the planet is able to re-grow them for us.
- Our material standard of living is no longer sustainable.
- In such a situation, it doesn't help to relieve a limiting factor. Doing so will make the situation only worse.
- In order to prevent the worst-case scenario, we'll have to reduce our consumption down to a sustainable level.
- The faster we do so, the better we'll be off in the long run.
- Unfortunately, there is no indication that this is what we are actually doing, or even, what we might be willing to consider doing.

Forrester's World2 Model

- I added a performance index rewarding a high material standard of living, while punishing massive die-off.

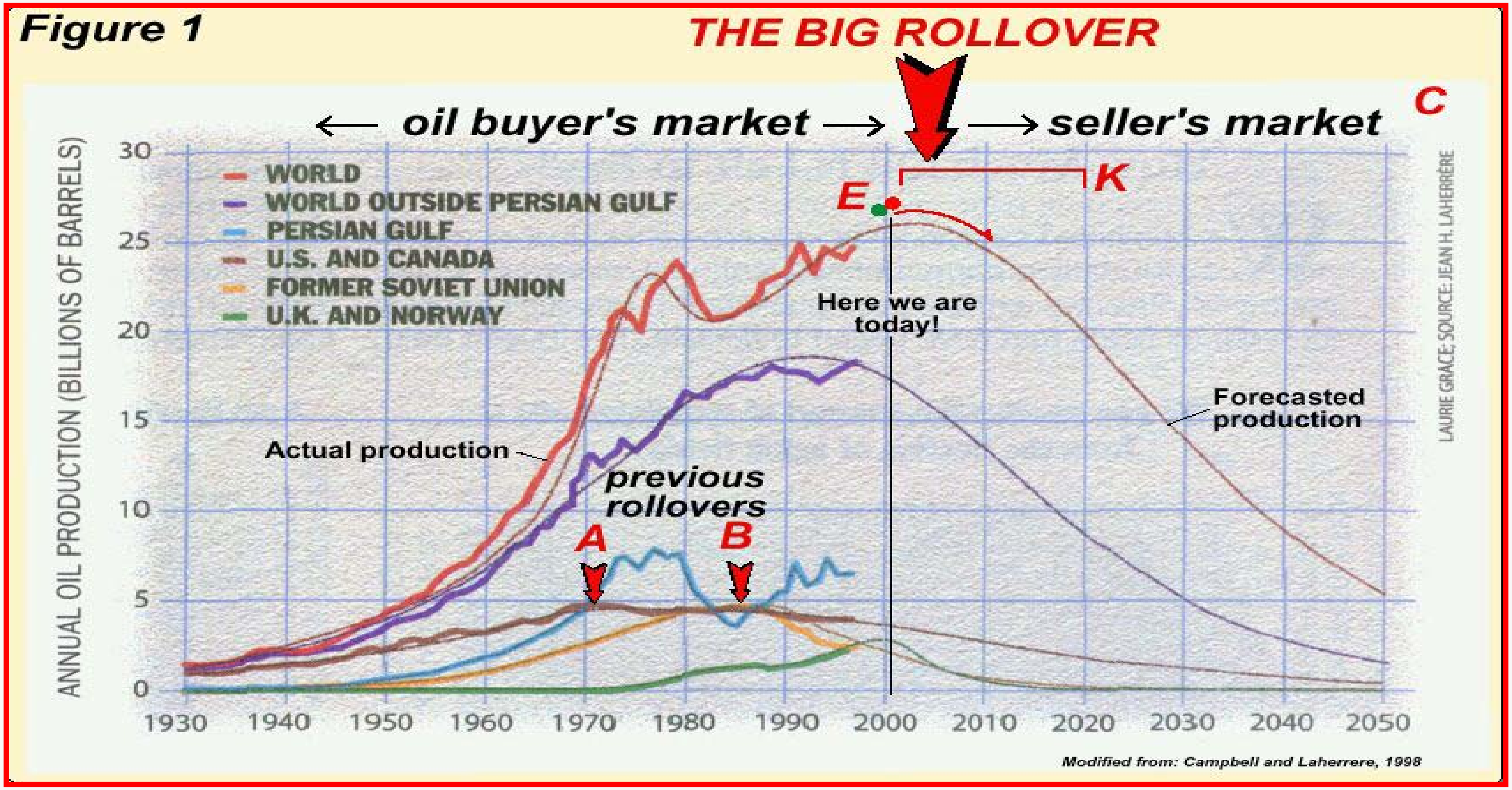


- The blue and red curves represent higher levels of remaining non-recoverable natural resources. They allow keeping exponential growth going for a little while longer.
- They offer better rewards in the short run, yet lead to massive die-off later on in the simulation.
- Many decision variables in Forrester's ***World2*** and Meadows' ***World3*** models exhibit similar behavior. ***Short-term optimization leads to subsequent collapse.***

Lessons Learnt

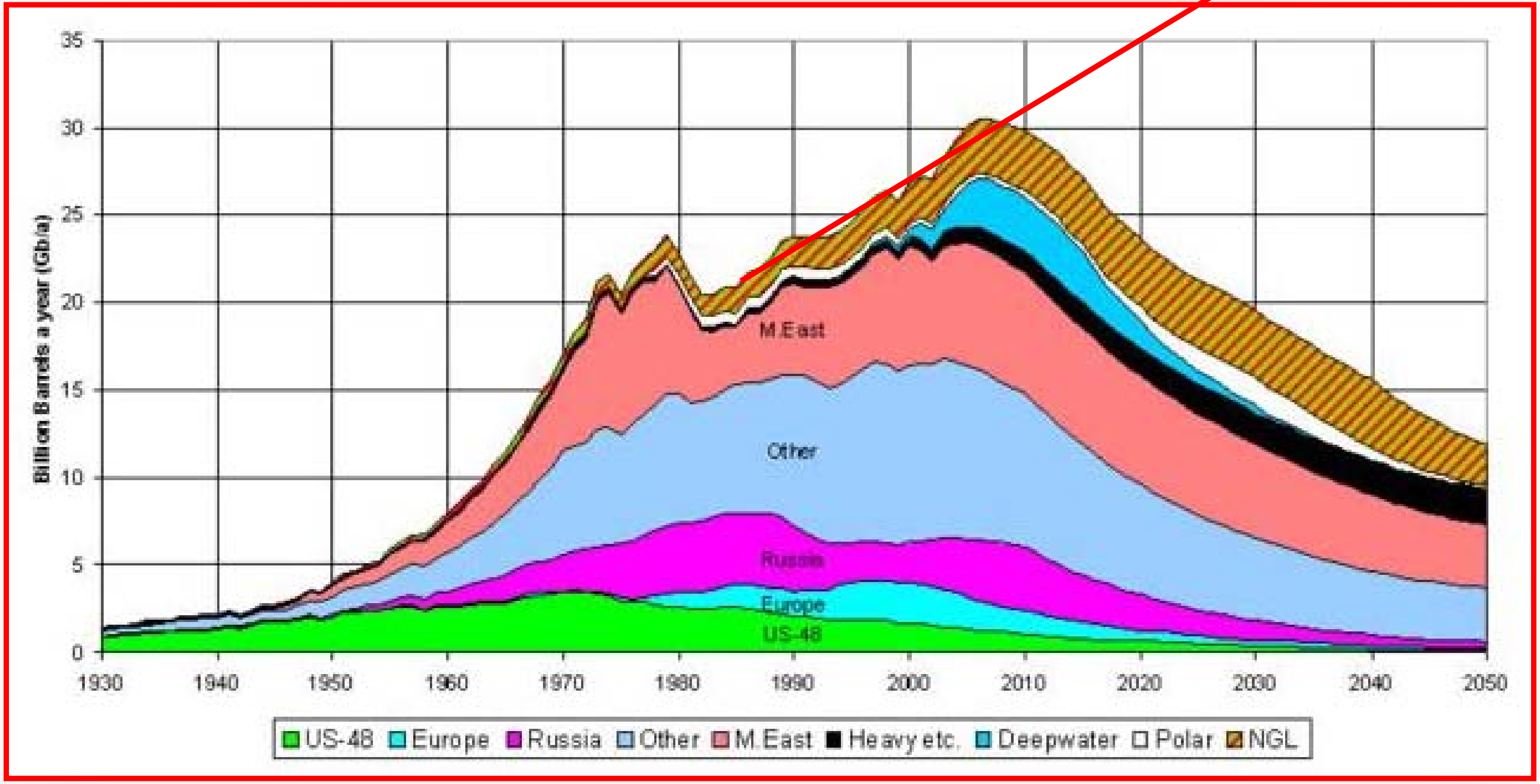
- The most important question that the world models ought to answer is: ***When is the world coming out of exponential growth?***
- The world models are fairly consistent in their answer to this question: ***It happens right about now***.
- Different quantities, such as different forms of fuels, minerals, drinking water, and food peak at different times, but they all peak essentially within one or two generations.
- This is the direct consequence of exponential growth running up against the limitations of a finite resource, namely our planet.

Peak Oil [USGS]

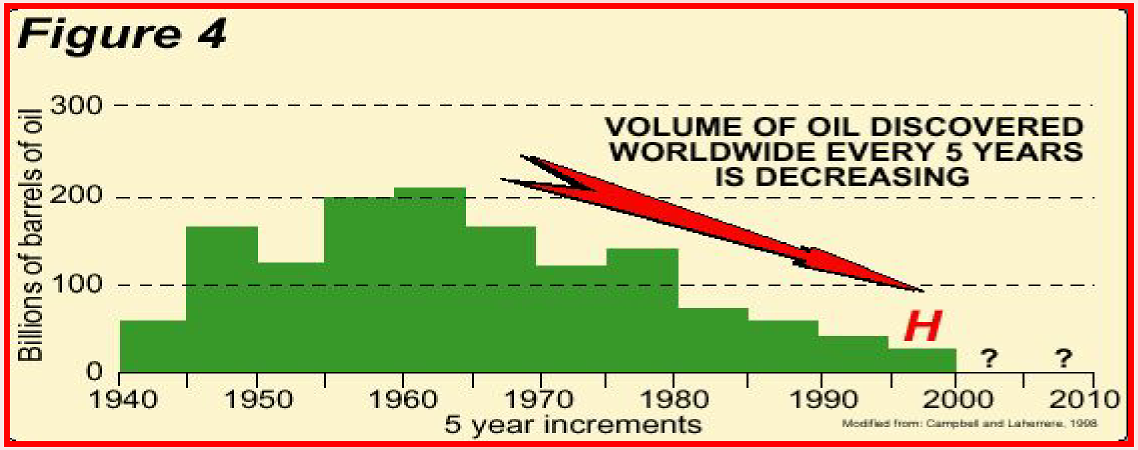


Peak Oil [ASPS]

?



New Oil Discovery [USGS]



- The new discoveries can be predicted quite well. They follow an exponential decay curve.
- Integrating this curve over time generates the curve of total previous discoveries, which is an s-shaped curve similar to the infections of the chain letter. This allows to estimate the total amount of oil in the ground.

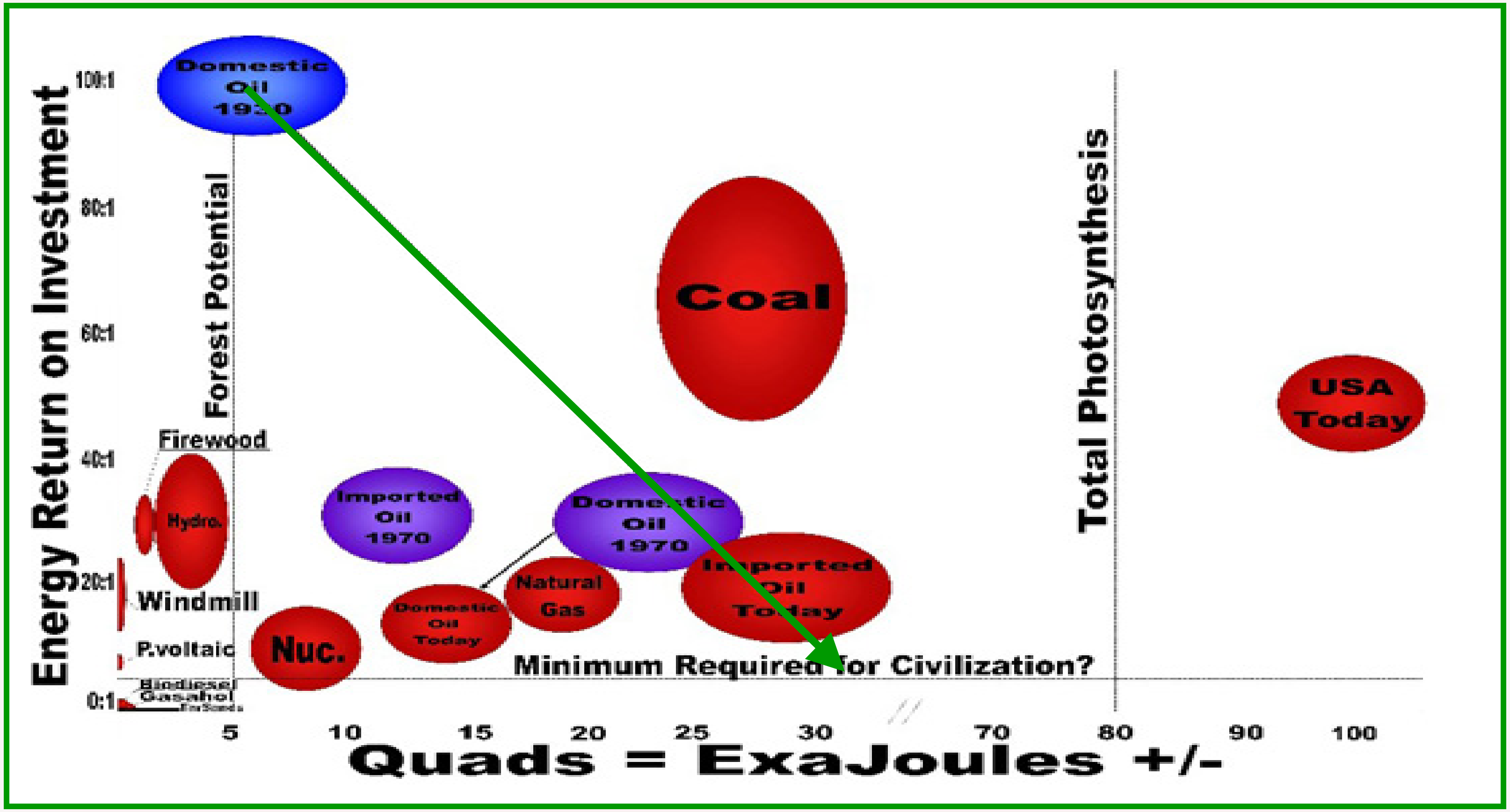
Hubbert's Curve

- Different oil fields are being produced at different times.
- The production of each oil field grows initially, then reaches a peak, and finally decays.
- Irrespective of the shape of the individual production curves, the sum of these individual production curves follows invariably a bell-shaped Gaussian distribution.
- M. King Hubbert predicted on this basis correctly the peak of oil production in the US without Alaska to occur in 1971. He predicted world oil to peak around 2000.

The Curse of Shrinking EROEI

- As oil becomes more scarce, its price will rise.
- Consequently, deposits that were previously not economical to produce, suddenly become profitable.
- Doesn't this solve the ***Peak Oil*** problem?
- Unfortunately, it doesn't. These deposits were previously not economical to produce … because they cost more money –and energy– to produce.
- The ***EROEI (Energy Returned On Energy Invested)*** measures, how much oil needs to be burned in order to produce one new barrel of oil.
- Unfortunately, the EROEI of oil is rapidly shrinking.

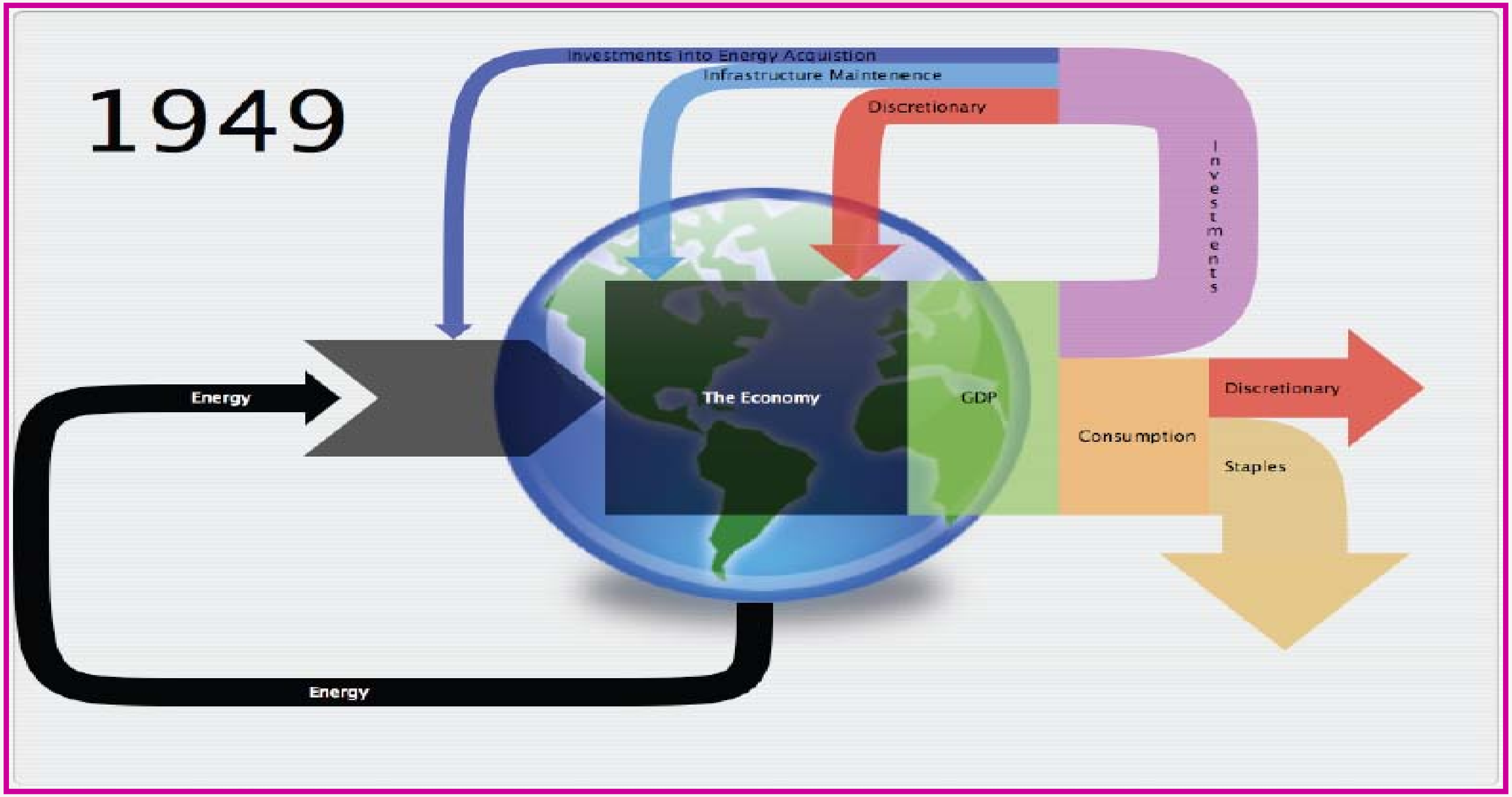
The EROEI of Oil [C. Hall]



The EROEI of Oil is Shrinking Fast

- Tar sands and oil shale were hitherto not profitable to produce, because their EROEI is low (around 5).
- Once the EROEI of an energy source falls below 1.0, it makes little sense to produce it.
- If the EROEI of all energy sources falls below a value of about 5, our industrial civilization is doomed [C. Hall].
- The EROEI of oil is shrinking fast. It has already shrunk by approximately a factor of 10. It is currently somewhere around 10. These are estimates as exact numbers are unavailable.

Energy and Economy Diagram [C. Hall]



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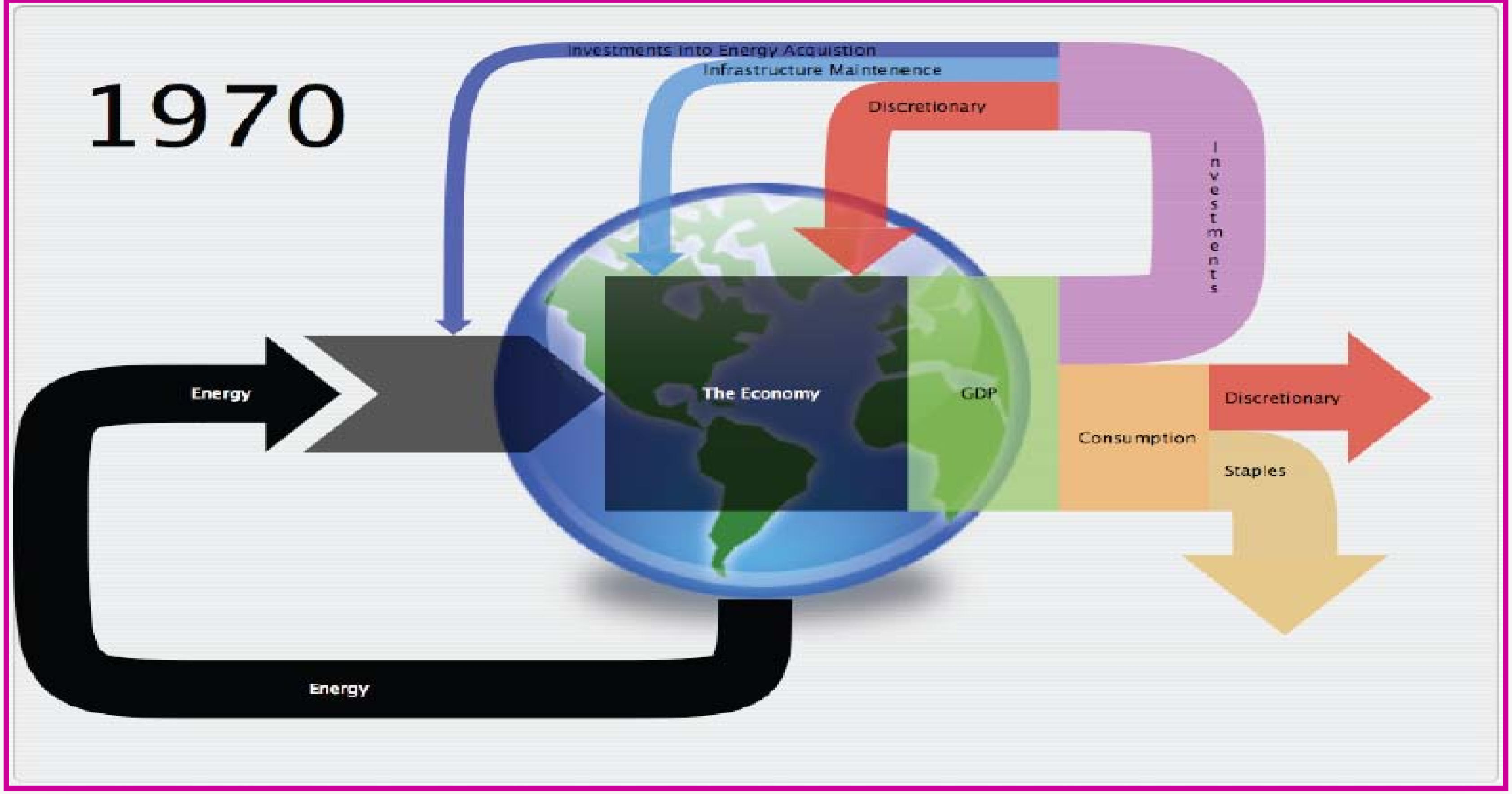

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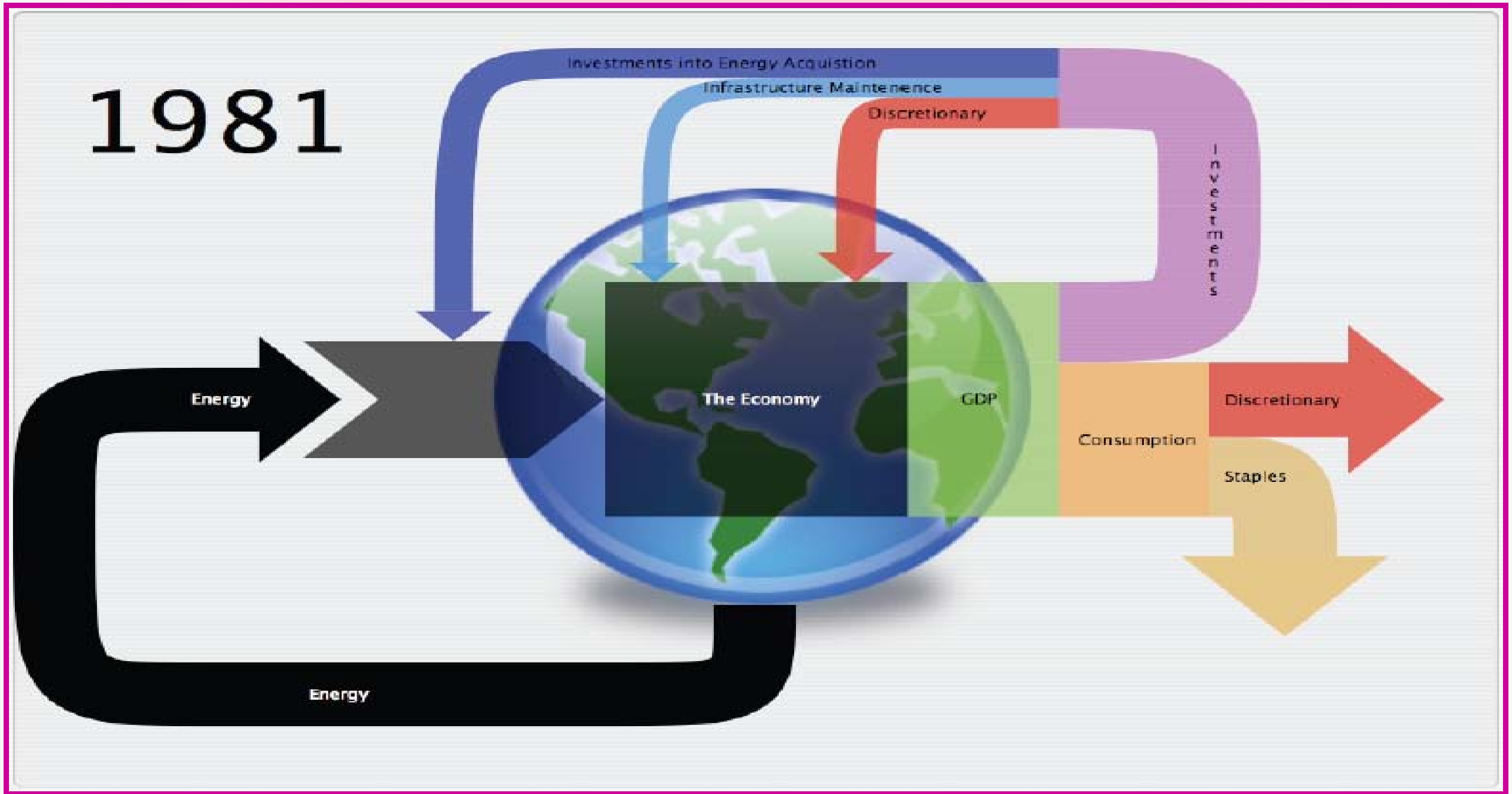

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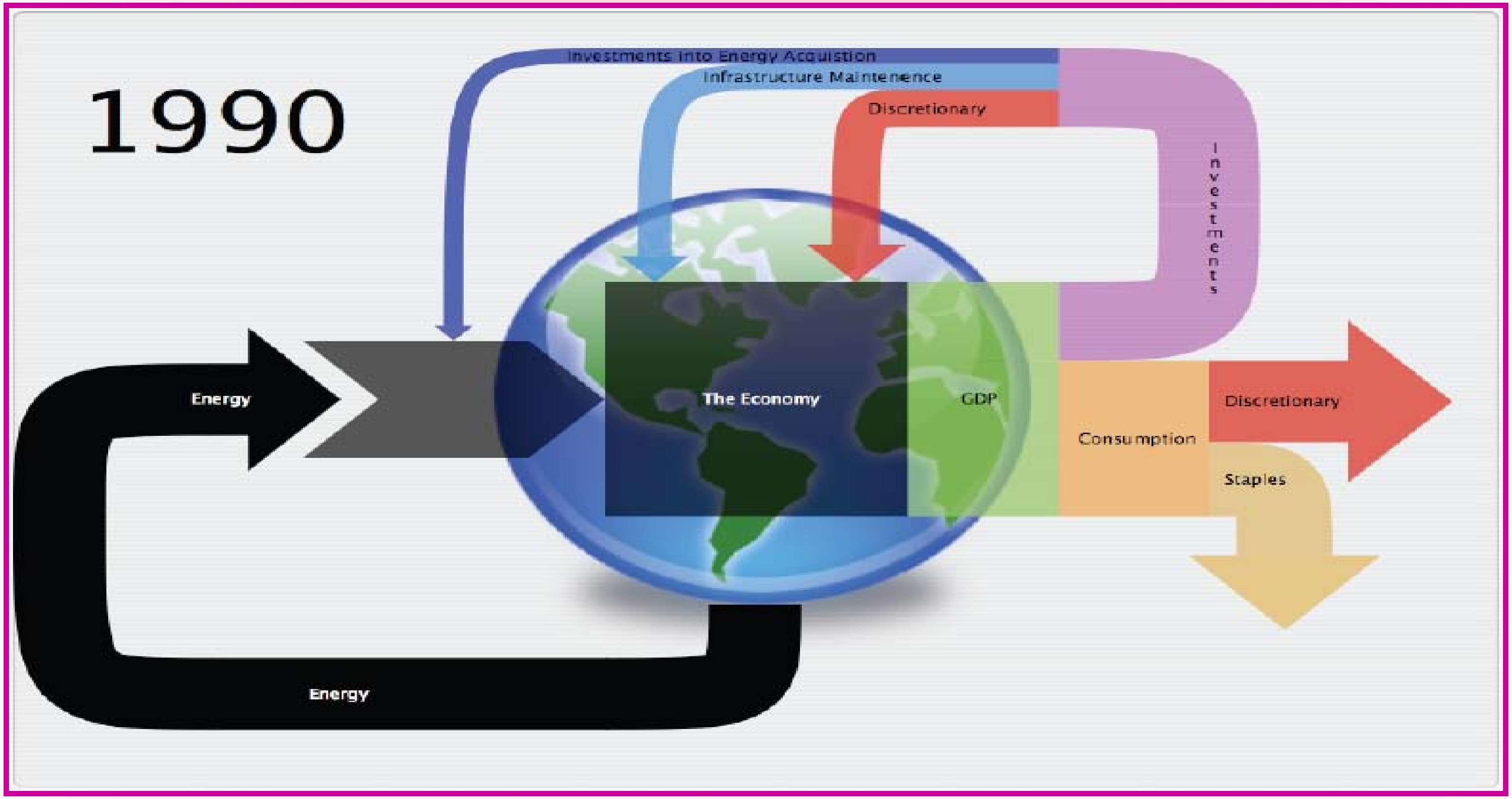

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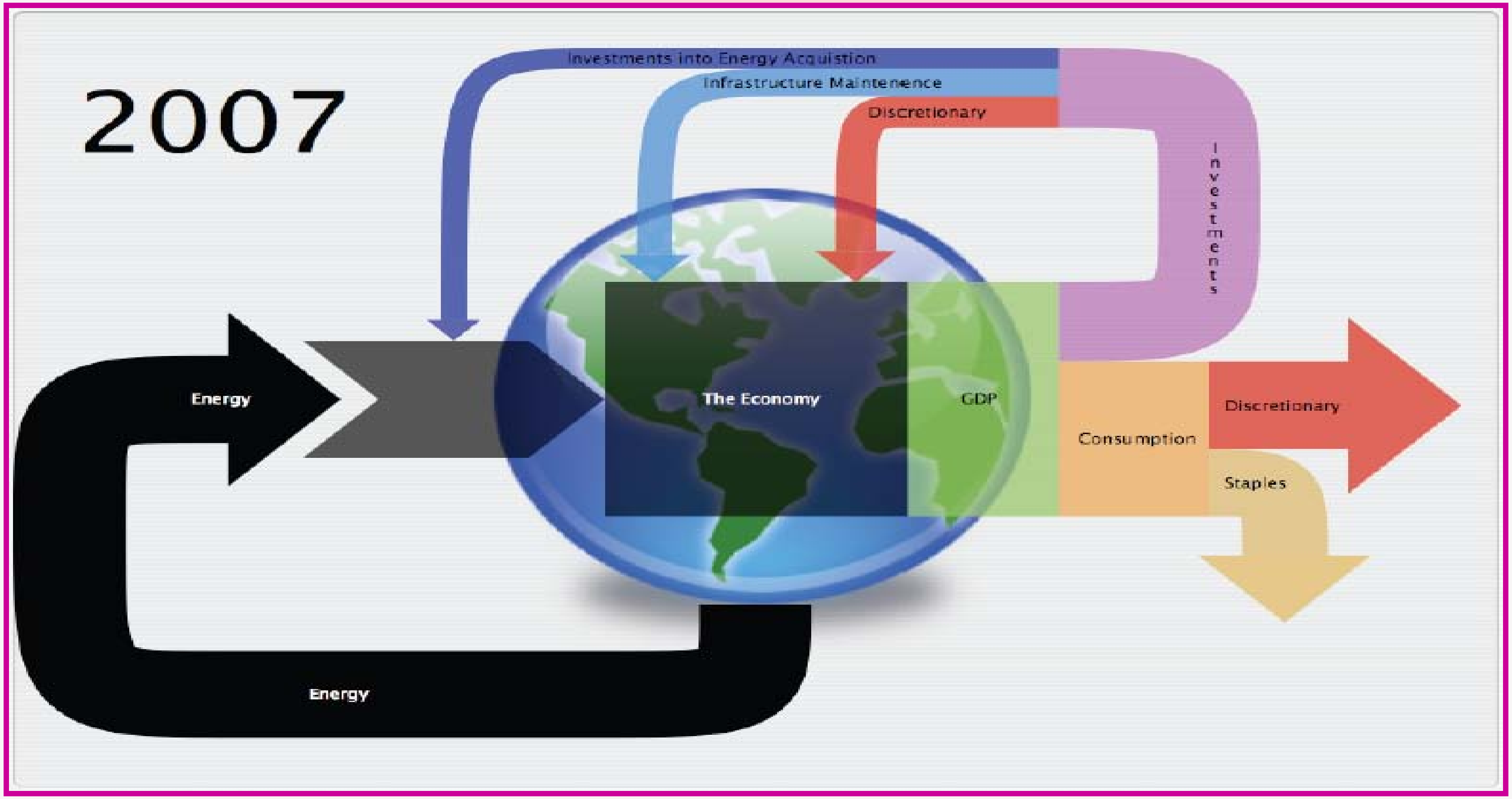

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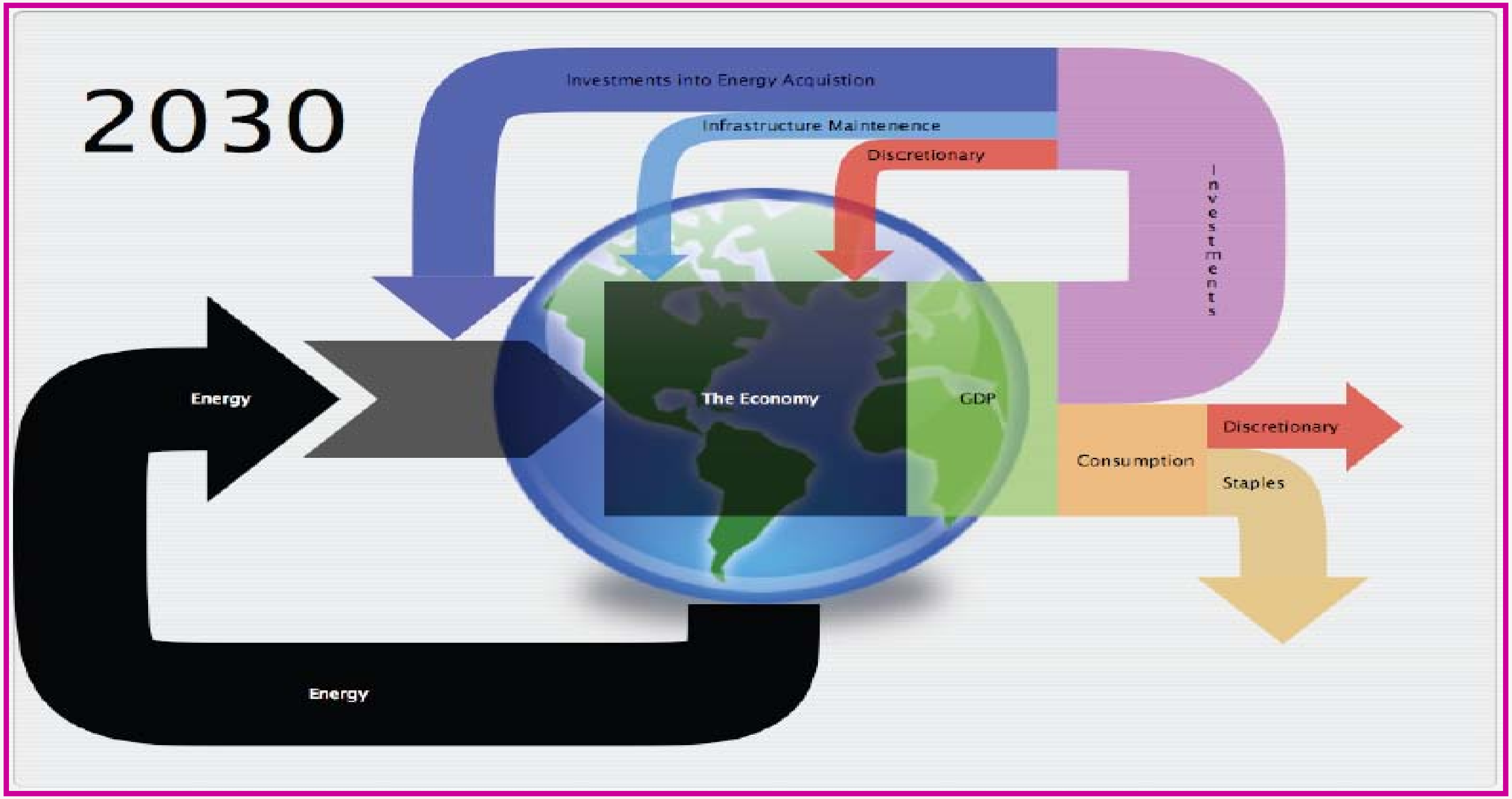

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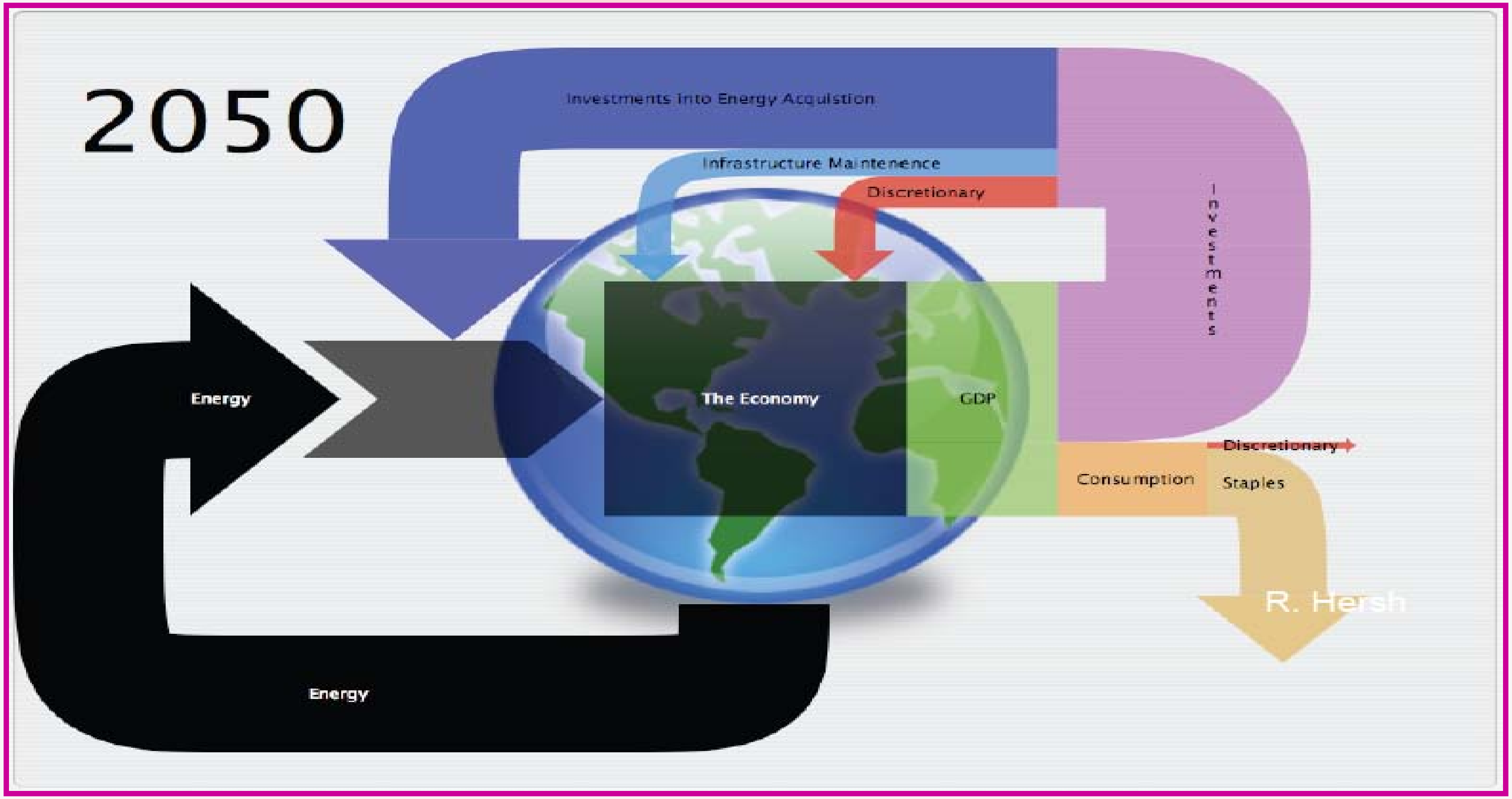


What Does This Mean I?

- Due to shrinking EROEI, we need more and more energy to drive our economy.
- As we move down the back slope of Hubbert's curve, energy becomes more expensive, and we need to invest a larger percentage of our generated wealth into the production of energy.
- Since we need to feed ourselves, less and less money is available for discretionary spending.
- According to Hall's model, discretionary spending will reach 0 around the year 2050. After that time, we need all of our wealth, just to feed ourselves.

What Does This Mean II?

- By 2050, we are living in a subsistence economy.
- The industrial society is essentially over.
- However, the resulting subsistence economy is highly inefficient, because there are far too many people living on the planet.
- We need huge energy resources just to keep everyone fed.
- If the amount available for discretionary spending turns negative, this means that we can no longer feed everyone in spite of our best efforts.
- This is when the die-off begins.

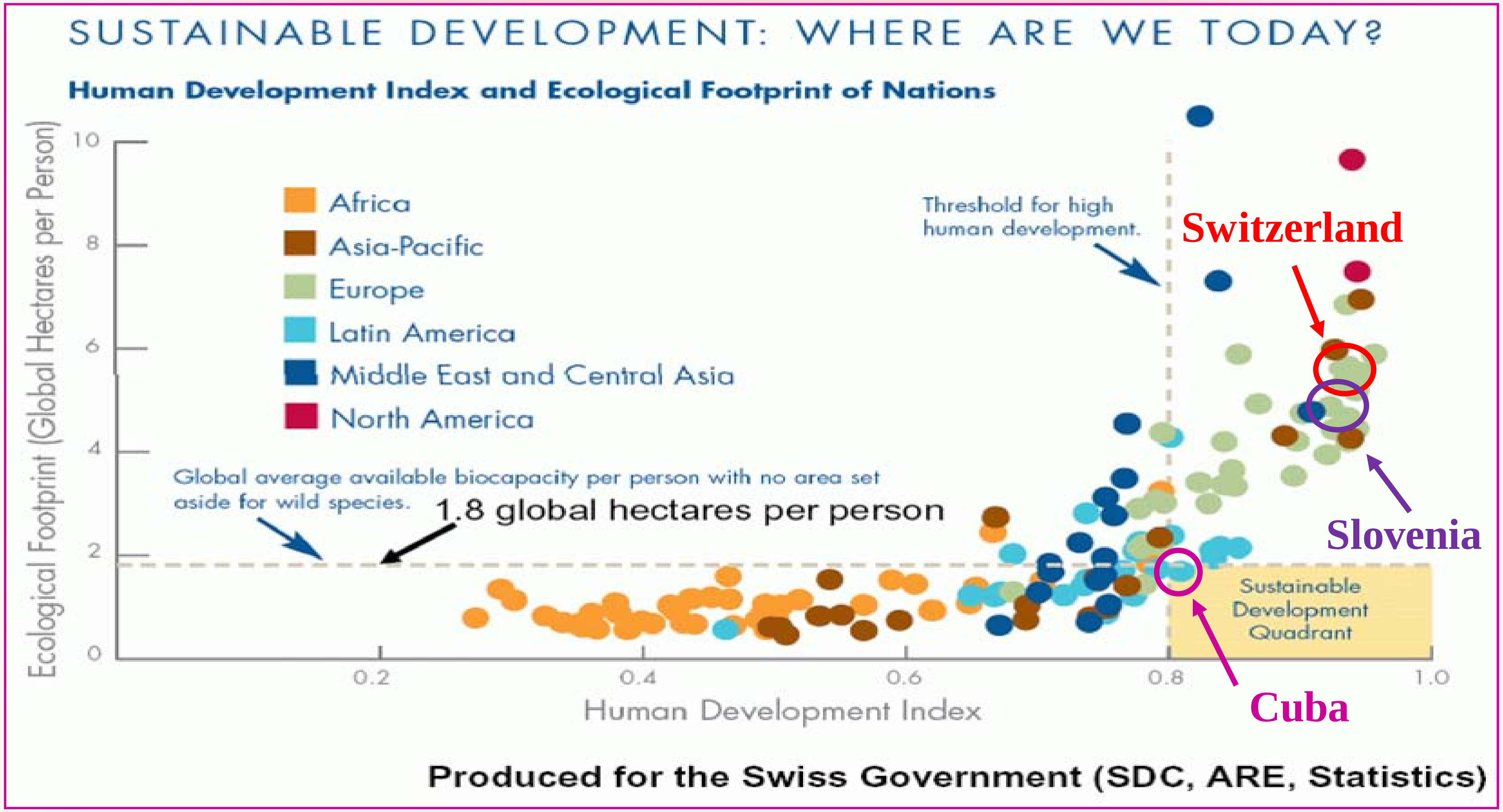
How Much Oil/Gas Do We Still Have I?

- Oil reached worldwide its plateau around 2004.
- According to our best estimates, oil will stay on the plateau roughly until 2012.
- Thereafter, we'll be on the downward slope of Hubbert's curve.
- The reduction in oil production will be progressive.
- It will take very few years, in spite of demand destruction, until demand for the commodity can no longer be met by supply.
- At that time, oil will become expensive, and not everyone will be able to get it.

How Much Oil/Gas Do We Still Have II?

- The producer nations will satisfy their own demand first.
- Therefore, oil export will shrink faster than oil production.
- Nations that rely heavily on oil imports will be in big trouble.
- Gas is predicted to peak about 14 years after oil.
- Thus, gas will be available for a little while longer.
- However, gas is not as easily transportable as oil, and therefore, gas may not be available everywhere.

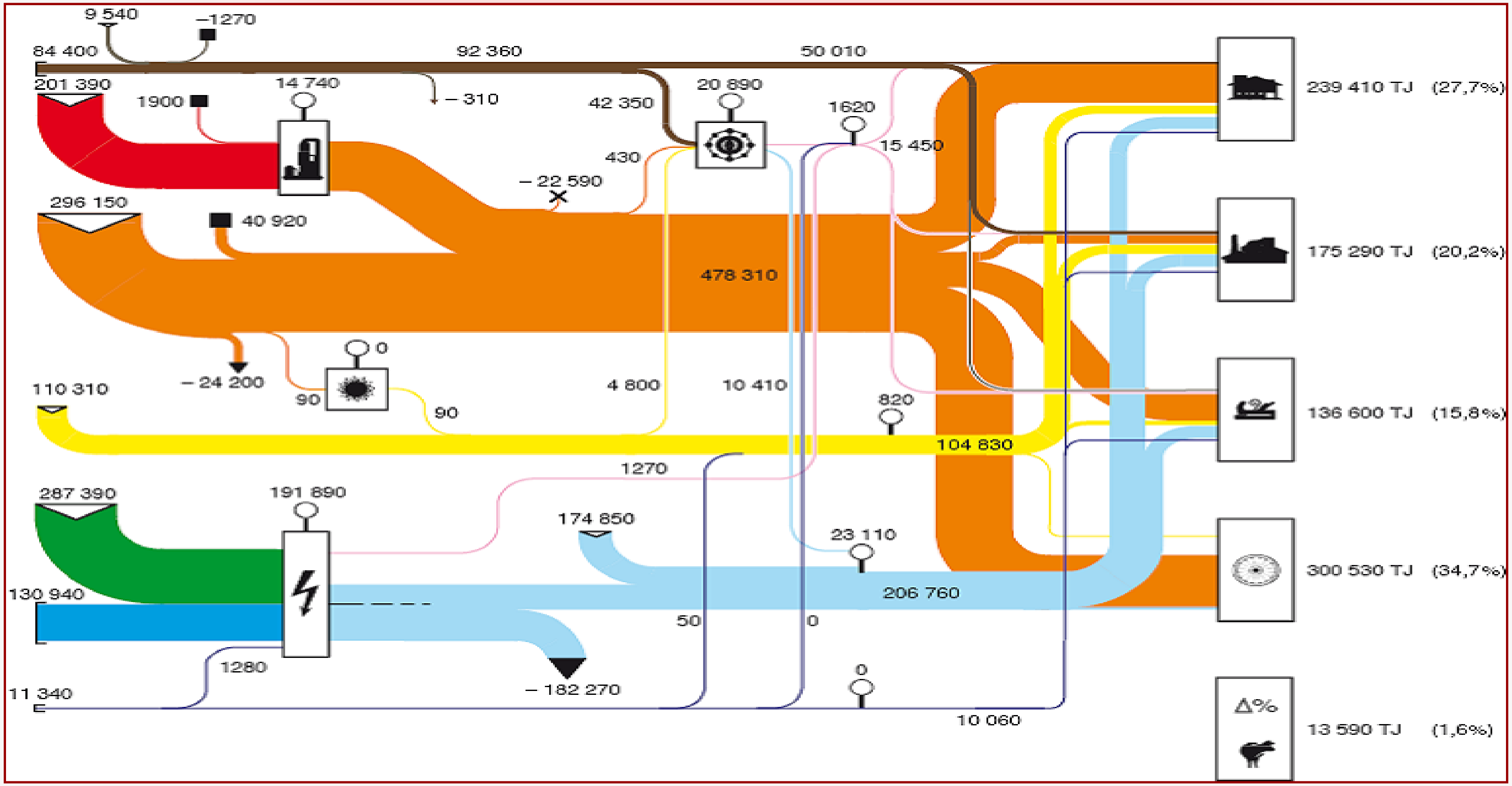
Global Ecological Footprint



The 2000-Watt-Society

- When we divide the total power that is currently generated and consumed on planet Earth by the total world population, we obtain a value of roughly 2 kW/capita.
- Consequently, our "fair share" in per capita power is roughly 2000 W.
- 2 kW/capita of power correspond to 1.8 hectares/capita of land use, the available amount of per capita land use drawn on the global footprint graph. To "work" one hectare on land, we need roughly 1 kW of power.
- This is the basis for the goal of reaching a sustainable ***2000-Watt-Society*** in Switzerland.
- Slovenia should develop a similar goal.

Energy Distribution in Switzerland



Energy Generation for Switzerland

Primary Energy	TJ	%	Source
Wood	84400	7.52	local
Crude Oil	201390	17.95	imported
Refined Oil	296150	26.4	imported
Gas	110310	9.83	imported
Nuclear Fuel	287390	25.62	imported
Hydropower	130940	11.67	local
Other Renewables	11340	1.01	local
Total:	1121920	100	
local:		20.2	
imported:		79.8	

1’121’920 TJ/yr : 365 : 24 : 60 : 60 = 35.576 GW

=> 35.576 GW : 7’851’520 = <u>4.5311 kW/cap</u>

Energy Generation for Switzerland (2)

Primary Energy	TJ	%	Source
Wood	84400	6.1	local
Crude Oil	201390	14.55	imported
Refined Oil	296150	21.4	imported
Gas	110310	7.97	imported
Nuclear Fuel	287390	25.62	imported
Hydropower (x3)	392820	20.77	local
Other Renewables	11340	0.82	local
Total:	1383800	100	
local:		27.69	
imported:		72.31	

1’383’800 TJ/yr : 365 : 24 : 60 : 60 = 43.88 GW

=> 43.88 GW : 7’851’520 = 5.5887 kW/cap

"Grey" Energy

- If I buy a car produced in Japan, Japan spends energy in the construction of my car. This is energy consumed indirectly by me in Switzerland, energy that isn't included in the Sankey diagram at all.
- This additional energy is called ***grey energy***.
- It is estimated that Switzerland consumes at least an additional 30% in grey energy indirectly. No precise numbers are available.
- Hence the true per capita consumption of energy by the Swiss populace is probably somewhere of the order of 8 kW.

Swiss Energy Mix

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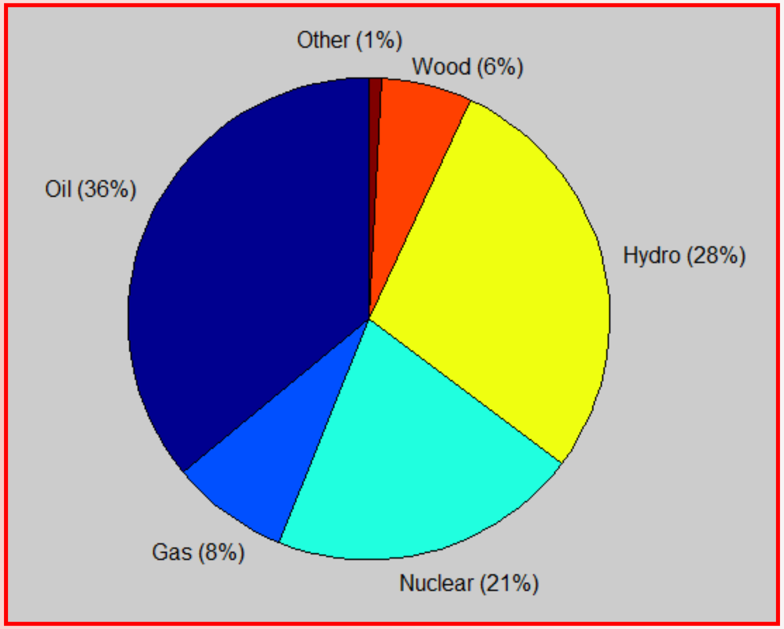
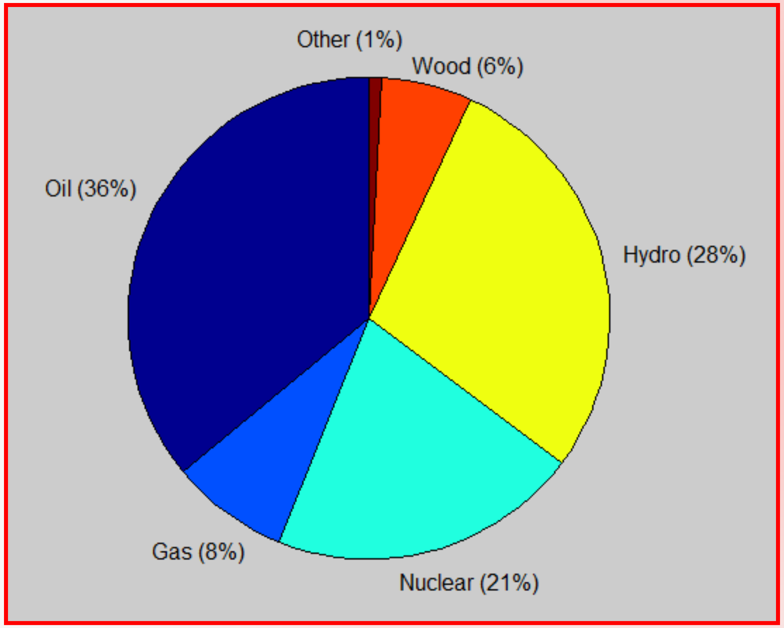
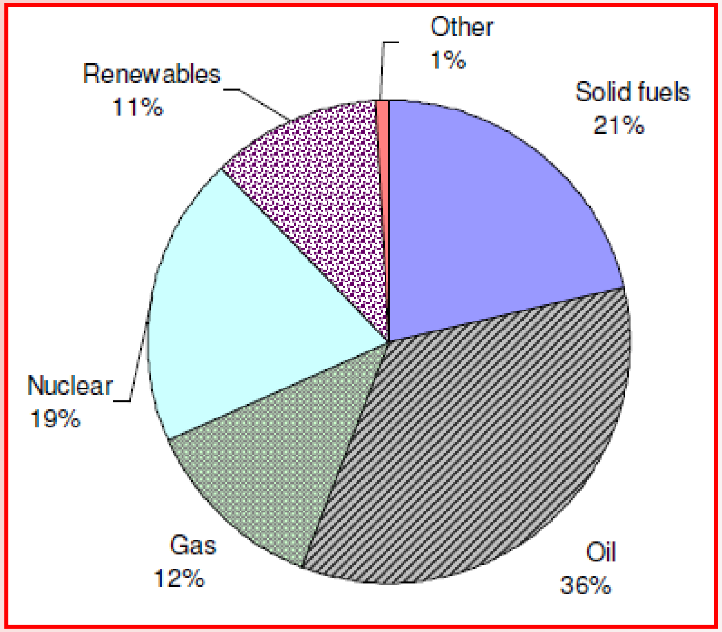
Total:	1383800	100	
local:		27.69	
imported:		72.31	



Comparison: Switzerland / Slovenia

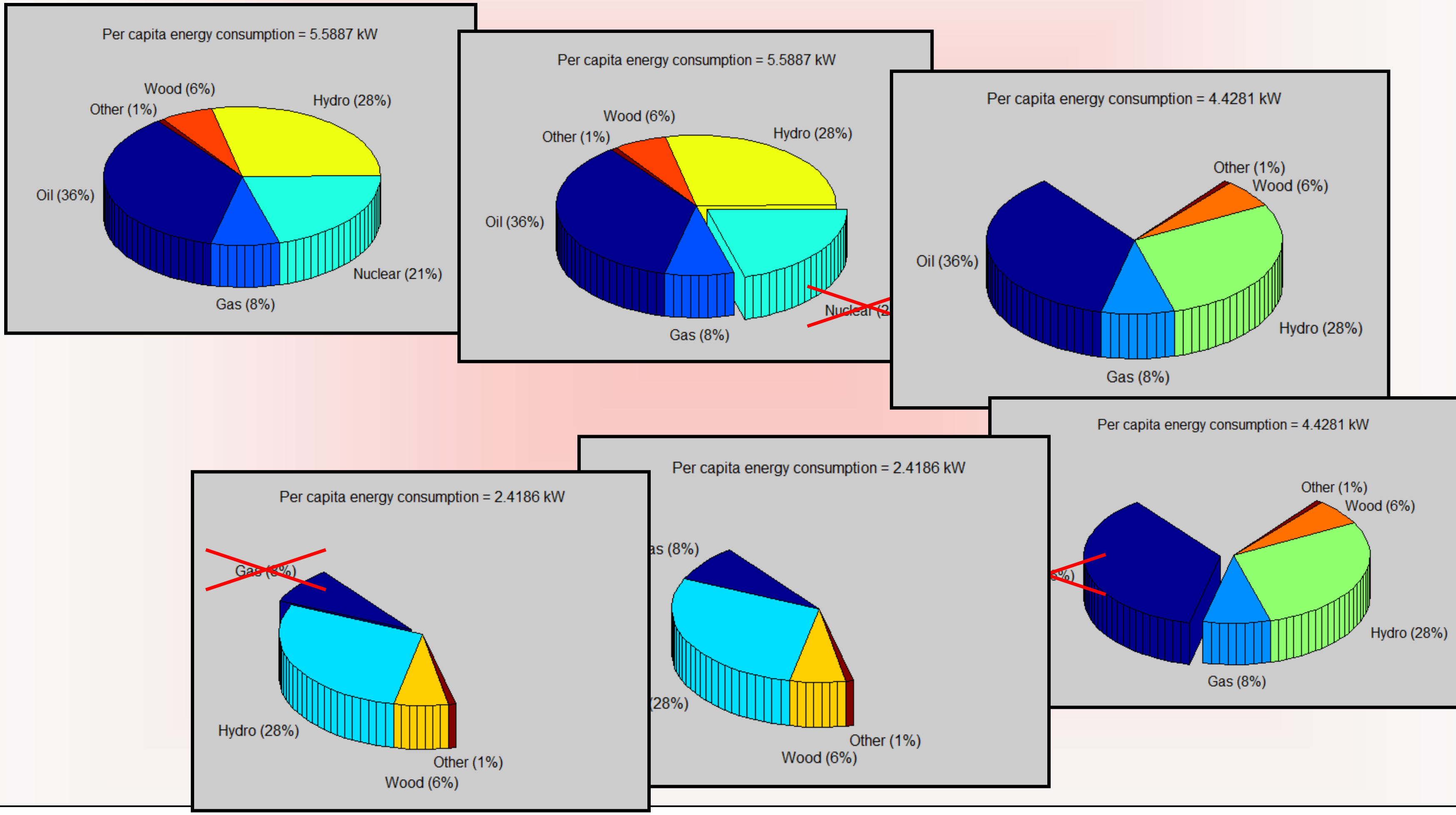


Switzerland

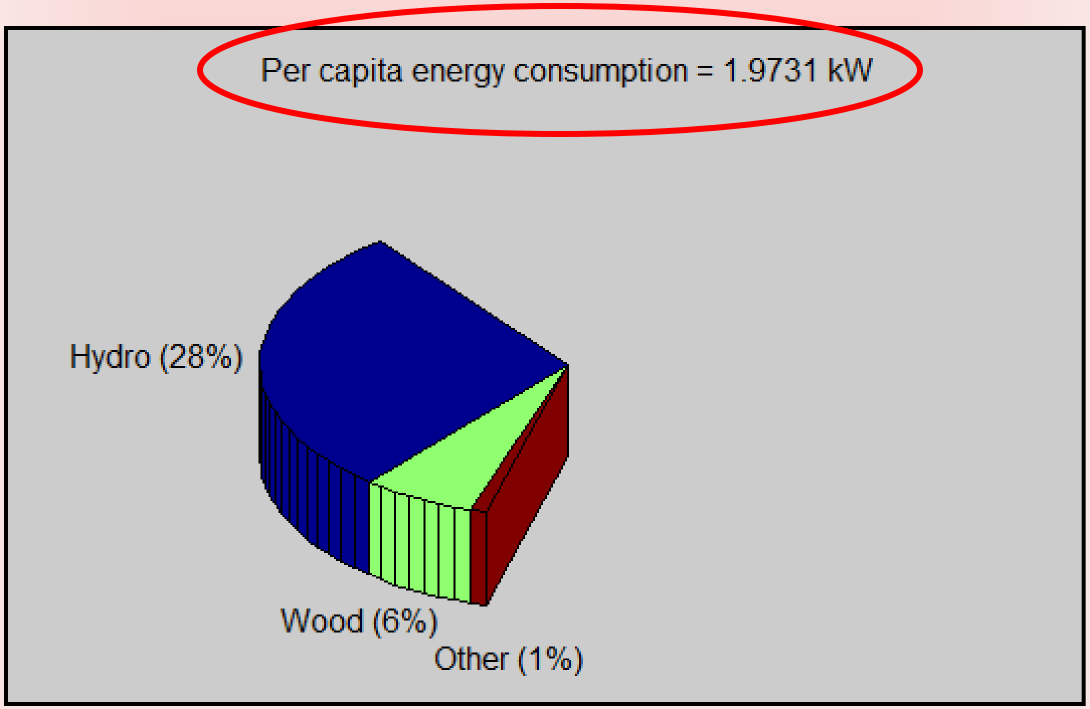


Slovenia

Sustainable Energy Consumption



Sustainable Energy Consumption (2)



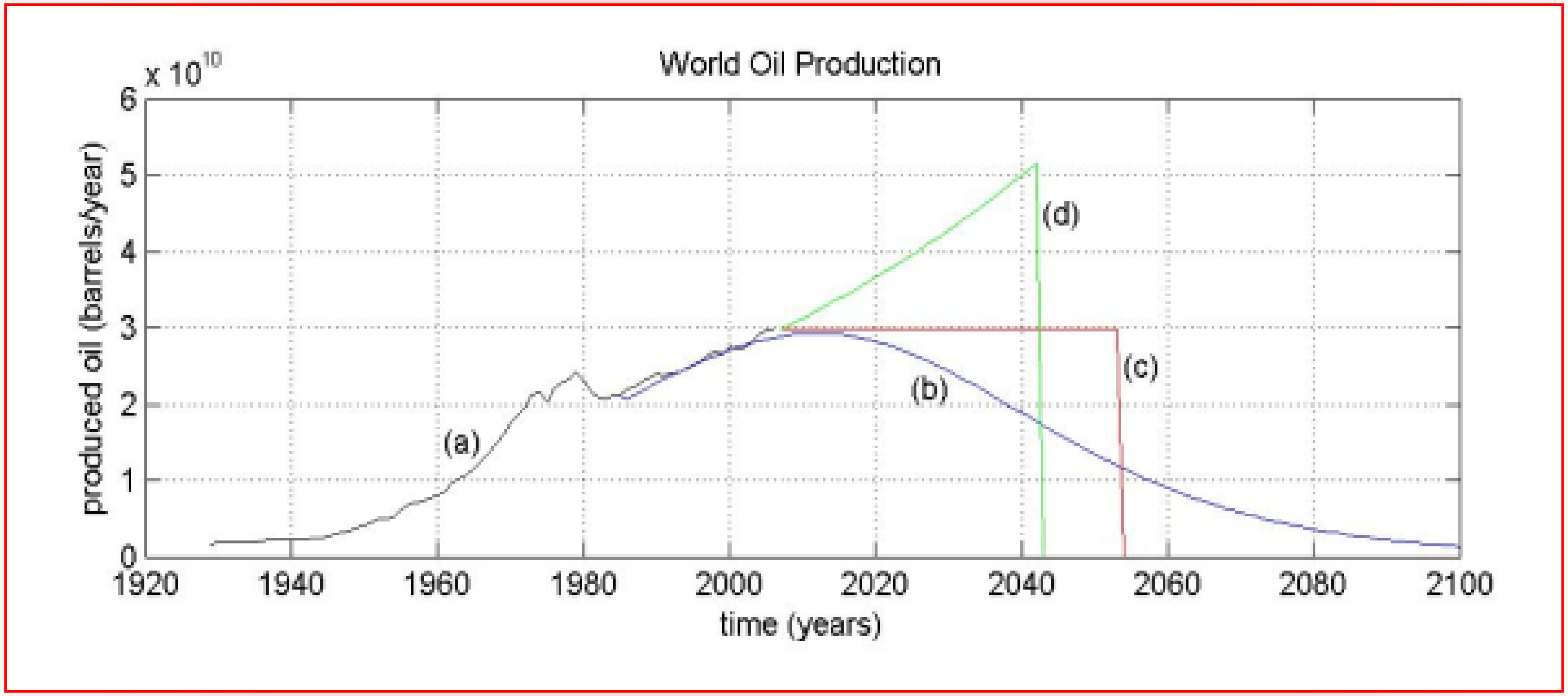
Living in an Energy-deprived World

- After the end of the fossil fuels and without nuclear power, we shall live in an energy-deprived world.
- Under the assumption of a stagnating population, we shall barely be able to maintain a 2000-Watt-Society.
- For this reason, the 2000-Watt-Society is not a goal that we wish to attain in order to reduce our energy consumption to our fair share. It is the consequence of a realistic prediction of how much energy we shall have available.

Living in an Energy-deprived World (2)

- The situation for Slovenia is quite similar.
- Slovenia imports roughly **70%** of its energy, mostly in the form of oil, gas, and nuclear fuel rods. These resources will disappear.
- Coal is dirty and although there are still two coal mines in operation in Slovenia, one is in the process of being shut down.
- Nuclear power isn't sustainable either in the long run. We'll be running out of nuclear fuel also quite soon. Right now, the world demand for nuclear fuel can only be met by decommissioning nuclear missiles and downgrading their fuel.
- Both in Switzerland and in Slovenia solar and wind power currently provide less than **1%** of the total energy need. More can and should be done, but it won't fill the gap.

Different Predictions of Oil Reserves



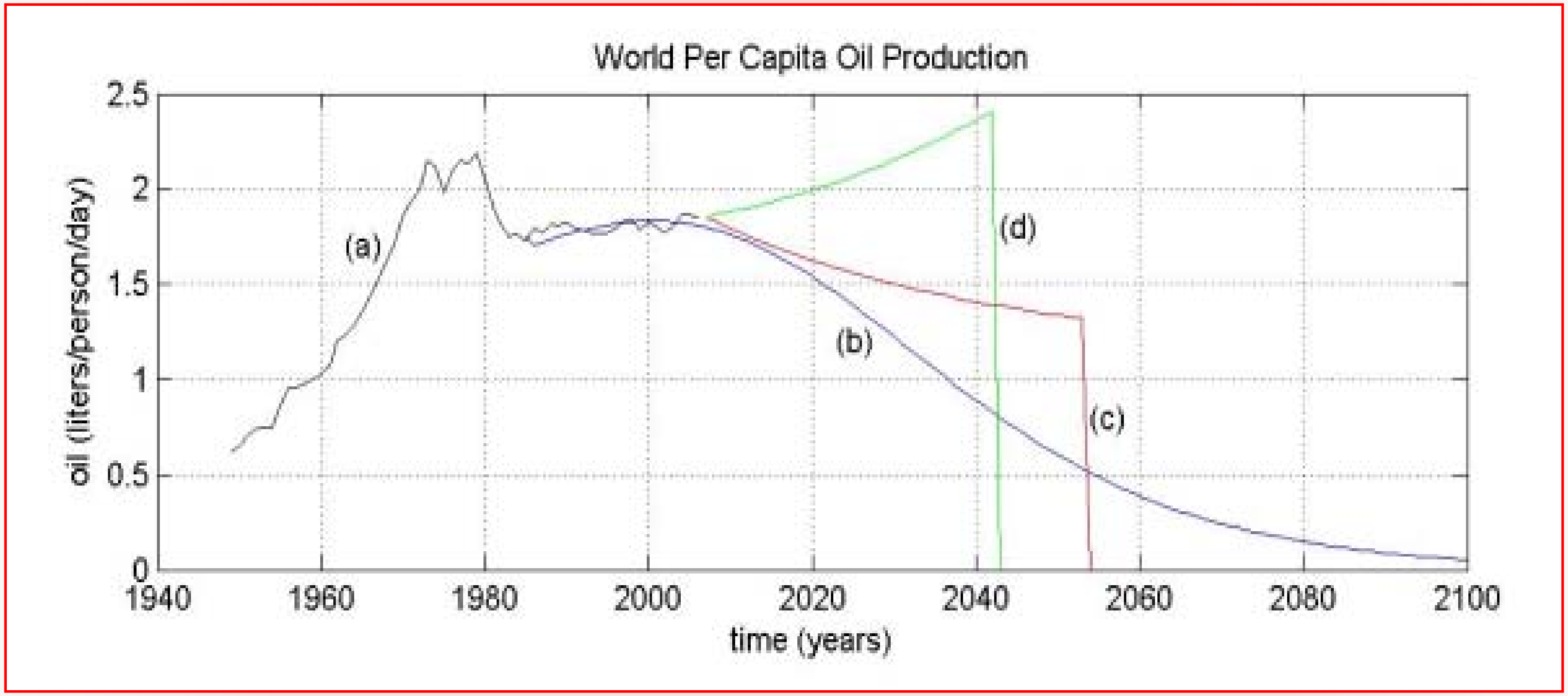
(a) **Historical Data**

(b) **Hubbert Extrapolation**

(c) **Constant Extrapolation**

(d) **Exponential Growth**

Different Predictions of Oil Reserves (2)



(a) Historical Data
(b) Hubbert Extrapolation
(c) Constant Extrapolation
(d) Exponential Growth

What Can Slovenia Do?

- The most cost-effective way of countering energy shortage is through ***energy savings***.
- Slovenia should aggressively push for minergy housing. Neighboring regions, such as Austria, for example, have done much more in this respect in recent years.
- Slovenia needs to push for more fuel-efficient lighter vehicles. The weight of the average passenger car in Slovenia has risen in recent years (!!) Although newer cars are more fuel efficient than older ones, the additional size and weight of the larger cars unfortunately hurt.

What Can Slovenia Do? (2)

- The demand for electricity will continue to rise. Slovenia should invest in infrastructure for a ***robust grid***, e.g. by increasing the percentage of hydro power, thereby reducing the risk of repeated brownouts and blackouts.
- More incentives should be given to let people use electricity during off hours.
- A refrigerator or freezer doesn't need to consume electricity 24/7. It would make sense to install smart sensors between the refrigerators and the wall outlet that sense instability in the grid and temporarily switch off the device whenever the grid becomes unstable.

What Can Slovenia Do? (3)

- Slovania should invest heavily in ***solar and wind power***.
- These energy sources are not yet economically competitive, but they make electricity delivery to individual consumers more reliable.
- Solar and wind power will not solve our energy problems, not by a long shot. Yet, every additional kW of power helps.
- We'll need ***all of what we can get***.

What Can Slovenia Do? (4)

- Slovenia should plan to replace its current nuclear power station that will need to be shut down within the next decade by a new nuclear power station.
- Since the planning and construction of such a power station takes about 10 years, planning should start now.
- Nuclear power in its current form is not sustainable either. We'll also run out of uranium.
- Yet, a new nuclear power station will take some pressure off the energy situation by buying us more time to transition to sustainability.

Global Warming I

- The climate change problem is intimately linked to the fossil fuel problem.
- Burning fuel means to oxidize the fuel.
- When we burn fossil fuel, we oxidize carbon to carbon dioxide:

$$C + O_2 \rightarrow CO_2$$

- ***The production of CO_2 is not a by-product of burning fossil fuel … it is the product!***

Global Warming II

- For this reason, by knowing how much oil, gas, and coal we can still produce, we can calculate accurately, how much CO_2 we shall emit into the atmosphere by burning it.
- By burning the producible remaining conventional oil and gas, we emit enough CO_2 into the atmosphere to raise the average temperature on this planet by about 3-5 degrees.
- ***Burning the producible remaining coal may result in the extinction of the human race.***
- The average temperature during the last ice age was only 4-8 degrees below the current temperature.

Climate Zones

- Our planet knows four climate zones: polar, moderate, sub-tropical, and tropical.
- A warmer planet means that the polar zone will shrink. The moderate and sub-tropical zones will move closer to the poles and therefore shrink in size.
- The tropical belt will increase in size.
- The four zones are created by wind patterns.
- The rotation of the planet causes friction in the air. The air closer to the poles thereby gets accelerated, producing Westerly winds, whereas the air over the tropics gets decelerated, producing Easterly winds.
- The sub-tropical zone in between has little wind.

A Warmer Planet is a Drier Planet I

- Water evaporates over the oceans, making the air more humid.
- As the wind carries the humid air to the colder land masses, the air cools down, the dew point sinks, and it starts raining.
- The sub-tropical belts are dry due to lack of wind.
- The polar zones are dry due to low temperature.
- As the planet heats up, more water evaporates, making the air over the oceans more humid and therefore heavier.
- As the total kinetic energy of the planet remains the same, air flow slows down, and there is less wind.

A Warmer Planet is a Drier Planet II

- Because of the decreased wind, the humid air is carried more slowly to the land masses.
- Rainfall increases close to the coastal lines exposed to the wind, but very little rainfall can be observed further inland.
- Hence the desert areas will grow.
- Less food can consequently be produced.
- This is not just a theory. This same pattern has been observed 150 million years ago during the Permian.

What Should We Do I?

- The burning of all remaining producible oil and gas is in all likelihood inevitable.
- Hence we'll probably have to live with a 3-5 degree raise in temperature. ***It won't be pretty!***
- We need to avoid ***at all cost*** burning the remaining coal. This requires intergovernmental regulatory efforts.
- The developed nations will need to help the developing nations catch up at least to some extent. Otherwise, they won't play ball.

What Should We Do II?

- Carbon capture and sequestration (CCS) is probably a pipe dream.
- The amount of CO_2 produced is simply too large to store it anywhere.
- As the world becomes energy starved, it won't accept the reduction in efficiency caused by CCS techniques, and consequently, the coal ***will*** be burned once we get it out of the ground.
- We need to develop alternative sources of energy fast enough so that burning coal becomes less of a necessity.

It Doesn’t Look Good

- Mankind is addicted to exponential growth.
- Addictions don’t feel bad. They feel good.
- People don’t stop their addictions until they hit bottom.
- Can we afford to wait with changing our ways until the world lies in tatters?