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A Brief Look at the Far Horizon

An Exploration of What's to Come for Trucking

Developed by The Technology & Maintenance Council's (TMC)
Future Truck Committee Far Horizons Subcommittee

Chairmen: Duke Drinkard, Southeastern Freight Lines
Vic Suski, ATA Engineering Dept.

"There are many things which cannot be imagined, but there is nothing which may not happen"— Old Chinese aphorism.

"What we anticipate seldom occurs; what we least expected generally happens."—Benjamin Disraeli

Introduction and Summary

There are two parts to this exploration: a detailed timeline focused on items pertaining to transportation in general and trucking in particular, with explanatory notes for some entries at the end; and a survey of various pictures or scenarios of the future- the environment within which we, and those who come after us, will have to operate.

Looking over the contents of the paper there seem to be a number of implications for truck users:

- Equipment regulations by the NHTSA seem to be decreasing, but environmental regulations will increase.
- Internal industry pressures to be "green" will increase.
- Roadside inspections of commercial vehicles will be modified as diverse new technologies appear on vehicles.
- More and more driver functions will be taken over by the truck itself.
- There will no longer be a single fuel for heavy trucks-various alternative fuels will be in use.

Technology & Maintenance Council (TMC)
2200 Mill Road • Alexandria, VA 22314 • Ph: (703) 838-1776 • FAX: (703) 684-4328
tmc@trucking.org • http://tmc.truckline.com

COUNCIL OF AMERICAN TRUCKING ASSOCIATIONS

- There will be more than one propulsion system available.
- Alternative ways of moving goods will gradually erode trucking's share of the transportation market.
- Demand for class 7 & 8 trucks will decrease and demand for smaller classes will increase.
- Liquid fuels will continue to be the primary type of fuel well into mid-century, but they will not necessarily be derived from petroleum.
- Petroleum based diesel fuel may be available over the next 40 years, but it will be very, very expensive.

Bottom Line: Developments in all spheres will come even faster than heretofore, many competing ways to respond, confusion will increase, making decision making even more difficult.

What follows is a timeline of future events that may affect the trucking industry. It is based on a review of published literature, and references for predictions are given where applicable.

PART I
PREDICTED TIMELINE OF EVENTS DIRECTLY IMPACTING TRUCKING

APPROXIMATE AVAILABILITY OF VEHICLES AND EQUIPMENT, SOME REGULATORY MILESTONES (IN BOLD), AND OTHER EVENTS

YEAR

2000
Night vision enhancement (thermal imaging, IR)
Intelligent/adaptive cruise control
On board, real time, continuous emissions measurement
Front axle disc brakes

2002
"Active" aerodynamic devices for drag reduction and braking. See note 1.
Microwave regeneration of particulate traps.
Advanced diesel engine (thermal efficiency = 55%). (See Note 2.)
Driver sleep history monitoring.
50 cetane fuel.
Active/smart suspensions.
Thermoelectric generator.
Automatic (radar) braking and lane keeping/roadway edge detection. (See Note 3.)
Intersection hazard warning.
Vehicle and driver performance monitoring and automatic shutdown systems.

2004
Electronic braking systems for trucks. (See Note 4.)
Reefer remote climate control.
GM and Mercedes will have production ready fuel cell vehicles.

2005 Turbocompounding on heavy duty diesel engines.
Camless valve activation on heavy duty diesel engines. (See Note 5.)
Dow Jones industrial Average reaches 15,000. (Ref. 1)
Fully automatic ships able to navigate and dock automatically (Ref. 2)
Assisted lane keeping systems in trucks and buses (Ref. 2).
See Note 4 and entry under 2002.
Underride regulations for straight trucks (estimated).
Trucking industry freight volume hits 8.2 billion tons; $446.2 billion gross revenues for the industry (Ref. 3).
Last coal mine closes (Ref. 4).
Hybrid vehicles in use, $87 million market demand (Ref. 5). (See Note 6.)

2006 Frontal aggressivity regulations (tractors) (estimated).
Side underride regulations for trailers (estimated).
Alternative fuel mandate for private fleets (vehicles <8500lbs), (estimated).
U.S. industry will need 155,000 mechanics (up from 137,000 in 2001), (Ref. 6).

2007 EPA requires heavy duty diesel engines emit no more than 0.01 grams/bhp/hr of particulate matter; 0.20 gm/bhp/hr of NOx, and no more than 0.14 gm/bhp/hr of non methane hydrocarbons.
EPA requires diesel fuel sulfur content be reduced to 15ppm.
Regenerative braking systems in trucks capture >50% of wheel braking energy (Ref. 7).
"Electric" truck - accessories driven by electricity rather than belts off the engine, available. (See Note 7.)
Most new major road projects will be supported by tolls or remote fees (Ref. 8)

2008 Passenger cars with automatic steering (Ref. 2).
Tare weight of tractor trailer combinations reduced 20% (Ref. 7).
Rollover avoidance technology available (Ref. 7). (See Note 8.)

2010 (The following items are predicted for the period 2006- 2010):
Automatic fire protection systems in commercial vehicles.
Resonant Macrosonic Synthesis (RMS) refrigeration compressors (acoustic device). (See Note 9.)
Advanced materials (fireproof liquid crystal polymers, carbon/aramid fibers) in use for commercial vehicle construction
Hydrogen fueled vehicles cost competitive with petroleum fueled vehicles (Ref. 9.)
MAGLEV (Magnetically Levitated Vehicle) in limited operation. (See Note 15.)
Steer by wire, brake by wire for passenger cars (Ref.10)
Mach 3 supersonic transport in operation
Tilt rotor aircraft in shuttle runs
First segments of intelligent vehicle/highway system open (2010-Ref. 9) See Note and entry for 2016.
Electrification of truck stops underway on a large scale. (See Note 10.)

2011 Electric vehicles in use (70% probability) (Ref. 5).
Software will be able to repair itself (Ref. 8). (See 2012 below**).**

2012 Machine "learning" – computer programs learn by trial and error to adjust their behavior-becomes common (67% probability) (Ref.5).
Aerospace (trans-atmospheric) planes enter commercial service (Ref. 4).
Worldwide air cargo business triples over 1998 (Ref. 11).

2013 Recyclable plastic components used in making 50% of passenger cars (58% probability) (Ref.5).

2014 Ceramic engines for commercial vehicles (no cooling systems). (See Note 11.)

2015 Autonomous (driverless) cars on smart highways (Ref. 2) (See Note 12.)
World population reaches 7.2 billion (Ref. 12). Ref. 2 predicts 7 billion by 2011.
Computers evolve to where they have almost human- like intelligence.
See 2017 entry.

2016 Fuel cell electric vehicles in use (58% probability) (Ref.5)
ITS systems deployed (58% probability) (Ref. 5). (See Note 12.)

2017 Human knowledge exceeded by machine knowledge (Ref.2). (See Note 13.)

2018 Autonomous (driverless) truck convoys using electronic towbar (Ref. 2). (See Note 12.)

2020 Automated highway systems and autonomous vehicles in use (Ref. 9). Ref. 2 predicts this by 2015.
Artificial Intelligence reaches human levels and evolves far more rapidly than biology would permit. (Ref. 4) (See Note 13.)
Computers overtake humans in overall intelligence. (Ref. 2). (See Note 13.)
Half of all goods sold electronically (55% probability) (Ref. 5). (See Note 14.)
Reference 2 predicts this in the period 2010-2014.
Alternate forms of freight transportation e.g. air freight, (perhaps lighter-than-air), high-speed marine vessels, pneumatic tunnels erode trucking market share. (See Note 15.)
Fuel Cell trucks become commercially viable (Ref. 13).
Earliest date forecast for 50% of ultimate oil resources expended, decline in production thereafter (Ref. 13).
Truck traffic expected to have doubled by 2020 over 2000. (Ref. 14).
See Note 15.

NOTES

1. A concept, which involves blowing air around the perimeter of the trailer rear face, has demonstrated a minimum 40% reduction in aerodynamic drag in wind tunnel tests of a model tractor-trailer combination. This concept also can increase the downward force on the trailer by blowing from the top slot thus enhancing braking and possibly eliminating

the need for engine brake retarders. A full report on the results of the research is in SAE paper 2001-01-2072. Tests using an actual combination vehicle were scheduled for late 2001.

2. This is the LE-55 research project funded by the DOE and conducted by several engine manufacturers. It involves advanced fuel injection systems (30,000-40,000psi), turbocompounding, greater turbocharger efficiency, advanced materials, ceramic intake and exhaust ports. Such an engine will use alternative fuels, one fluid for both lubrication and cooling and is projected to have a durability of 750,000 miles and a brake specific fuel consumption (bsfc, in pounds of fuel per horsepower per hour) of 0.25, compared to 0.31 for current (2000) engines, and a thermal efficiency of 55% compared to 44% for current engines. The project is currently underway.
3. Freightliner and Praxair cooperated in a DOT funded Intelligent Vehicle Initiative (IVI) project and demonstrated a system in 1999-2001 to aid the driver in lane keeping. The system uses a miniature camera, which views the road ahead and transmits the video to an image processor which reads the lane markings and determines the truck's position in the lane.
4. Electronically controlled braking systems are currently (2000-2001) being tested by a large truck fleet as part of the U.S. DOT's Intelligent Vehicle Initiative (IVI).
5. International has demonstrated such an engine. An electrohydraulic system is used for fuel and air management. The engine should have higher torque and an integrated compressor brake. Other estimates for availability are between 2004 and 2007.
6. There are three notable demonstration projects underway. The U.S. Army, Volvo NA, Lockheed Martin Control Systems and Radian, Inc. have combined to produce a class 8 tractor powered by 2-250hp AC induction motors and a 460 hp Cummins N14 diesel engine. It has a lead acid battery pack. It features regenerative braking. Fuel economy is expected to be significantly better and emissions 50% lower than a comparable straight diesel powered tractor. (The same Lockheed HybriDrive system has been tested in a UPS van, an Army 5 ton tactical truck and an Orion bus). It is being tested at a number of Army installations. ISE Research has developed a prototype using natural gas in a spark ignited GM 4.3L engine and a 2200 rpm AC generator in a Kenworth T800B tractor. It has a 300hp battery pack. In 1997 Navistar International announced a concept truck using the Lockheed HybriDrive and a Navistar T444E diesel engine in a 27,000lb GVW medium truck. It has regenerative braking. The truck weighs 1,000lb more than a comparable conventionally powered truck. In 2001 International's Rodica Baranescu announced that they had determined their future medium duty trucks would be hybrids.
7. The DOE has a current project with an engine manufacturer to achieve this. It features an electrically driven turbocharger (rather than being driven by exhaust gases), a combined motor/generator, and electric turbocompounding.
8. The project described in note 4 also includes a "Roll Advisor and Control" system developed by Freightliner with MeritorWabco. Freightliner reportedly plans to make it standard on the Century Class S/T trucks. It uses Freightliner's proprietary roll stability advisor and integrates a rollover control function that cuts power and activates the engine brake at rollover threshold.
9. RMS uses acoustic principles to compress gasses in refrigerators. Sound waves are generated by a specially shaped cavity. Gas pressures can reach hundreds of psi. An acoustic compressor would have no moving parts, and could use any refrigerant. An appliance manufacturer was reported (in 1997) to be working with the technology to develop reliable, durable and energy efficient refrigerators and air conditioners.

There are other developments in the area of refrigeration, reported in 1997. One is magnetic refrigeration which uses a metal, which heats up when magnetized, and cools down when demagnetized. Another is thermoelectric refrigeration, which uses materials that change temperature when an electric current passes through them. This would replace the mechanical compressor and be quieter, more reliable and efficient. These materials could also be used to convert waste heat from gasoline or diesel engines into electrical power.

10. The New York State Energy Research and Development Agency (NYSERDA) let a contract, in 2000, for electrification of a truck stop on the New York Thruway as a demonstration project. A private company is reportedly "electrifying" three truck stops in Tennessee. This is basically a shore power concept which allows the truck to shut down and plug into the truck stop's power.
11. Research has been going on since the early 1980s on engines with ceramic components. In the mid 1980s An Army truck with a "ceramic" (then termed adiabatic) engine drove from Michigan to Orlando, FL. Technical barriers ultimately restricted development to component parts of the engine. These ceramic components are part of the DOE's LE-55 program described in Note 2.
12. There are a number of predictions ranging from 2010 to 2020. Driverless autos have been demonstrated and automated/smart highways also, but not yet the two together. Trucks using an "electronic towbar" were demonstrated by Daimler Chrysler in 2000, as part of the European "Promote-Chauffer" Program, 1996-1998. In this test two heavy duty tractor-trailer combinations (530hp Mercedes Benz ACTROS 1853LS) were run 18-48feet apart (30 feet appeared to be the optimum spacing). The lead vehicle was driven by a driver and the following vehicle was completely automated and followed every movement of the lead vehicle. Tests were run on a test track at speeds of approximately 36 and 48 mph. Fuel consumption of the following vehicle was reduced from 10-17% (in gallons used per mile) at 36mph and 15-21% at 48 mph. The lead vehicle experienced a 7% reduction in fuel consumption. The lead vehicle had an empty trailer and the following vehicle was loaded to a total of 56,000lb. Plans were to experiment next on public highways. There may in fact be truck convoys using the electronic towbar concept in use in 2018. However, Thomas B. Deen (Ref. 15), Executive Director of the Transportation Research Board (TRB) from 1980 to 1994 believes Intelligent Transportation Systems (ITS) will be deployed less rapidly than expected by advocates of these technologies because of a host of institutional problems. He goes on to say "Many truckers are suspicious that ITS will be the avenue for adding another layer of taxes. Many other potential applications of ITS require a level of cooperation by a number of entities larger than we are accustomed to; therefore progress will be slow".
13. There are various estimates/predictions regarding this, ranging from 2010 to 2025. What is interesting is the large number of people predicting this.
14. Kurt Salmon Associates (KSA) estimated that in 1992 85% of all retail sales were through stores and 15% through phone orders, computer based shopping, etc. For 2010 only 45% of all retail sales are expected to be in store. KSA also believes an ever increasing portion of all types of retailing will require next day delivery, driving freight away from long haul carriers and toward air carriers coupled with LTL and smaller trucks. Reported in Ref. 17.
15. In 2001 the Texas Transportation Institute, part of Texas A&M University concluded that it was technically feasible to build a below ground route for unmanned rail vehicles. Their ongoing 5 year study also found that on a Dallas to Laredo route freight could be moved

for 1/3rd as much as by tractor-trailer combinations. (Wall Street Journal, Wednesday, August 8th 2001). Transport Topics, July 23rd, 2001 reported that the state of Connecticut funded a study which showed that barges could move freight from New York Harbor to points in eastern Connecticut, Massachusetts and Rhode Island cheaper than could trucks. The Federal Highway Administration and Volpe National Transportation Research Center have concluded that moving freight by cargo carrying capsules below ground is technically feasible, although questions remain regarding the economics of such a concept (linear induction propulsion). The Army Corps of Engineers is studying the advantages of barge traffic vis a vis trucking. A possible concept could be a barge analog to trucking's LTL carriage. In June, 1998 a Minnesota DOT workshop suggested a high speed train/truck (put the whole truck on the train) be used in heavy use corridors such as Chicago to Minneapolis. MAGLEV continues to entice technologists. The U.S. National Energy Strategy of 1991 estimated MAGLEV for commercial transportation would be introduced in 2015. An aircraft manufacturer, American Utilicraft Corp, designed an airfreighter using turboprop engines which, (on paper), could carry 15,000 pounds over 400 nautical miles at an operating cost of 8.5 cents/pound, which the company says is close to trucking costs. Consultants are saying that as many as 62 million more vehicles will be on the highways in 2020 and "the idea that we are going to solve the traffic congestion problem is an illusion". (Anthony Downs, Brooking Institution).

PART II
VARIOUS PICTURES OF THE FUTURE

The studies described below developed scenarios for the future. These scenarios are not meant to be predictions, but plausible alternatives given various assumptions and trends. They may or may not come about and if they do it will be in modified form. The most general and global one is described first and more specific, freight transportation ones last.

1. *Beyond the Limits,* Reference 16
In April 1968, The Club of Rome, a group of thirty individuals from ten countries- scientists, educators, economists, humanists, industrialists and national and international civil servants- met to discuss the then present and future predicament of man. These discussions led to the Volkswagen Foundation financing a computer model of the world's growth, developed at Massachusetts Institute of Technology. The model examined population, agricultural production, natural resources, industrial production and pollution. A layman's version of the final report, "The Limits to Growth," was published in 1972. In 1992 the same team that did the 1972 work published a re-look at the earlier work, "Beyond the Limits." Computer simulations of thirteen scenarios were run. The results caused the authors to conclude that:

a. Human use of many essential resources and generation of many kinds of pollutants have already surpassed rates that are physically sustainable. Without significant reductions in material and energy flows, there will be in the coming decades an uncontrolled decline in per capita food output, energy use, and industrial production.
b. This decline is not inevitable. To avoid it a comprehensive revision of policies and practices that perpetuate growth in ma-

terial consumption and in population must occur; and a rapid, drastic increase in the efficiency with which materials and energy are used must come about.

c. But even with much more efficient institutions and technologies, the limits of the earth's ability to support population and capital are close at hand, probably not more than a doubling or two away.

The results of the scenario simulations are in Appendix I. In general they show a rise in industrial output, food, pollution, life expectancy, and population after 2000, peaking roughly between 2020 and 2050, then collapsing by 2100. In most scenarios the world of 2100 approximates that of the 1900s. This book is a pitch for sustainability and being environmentally and ecologically sensitive, these being the only ways to avoid collapse. It is strongly recommended that this book be read, not only for the results of the scenario investigations, but the ways in which they were investigated, the systems approach that was taken, and because it gives one a way to relate the various global forces at work to possible business futures.

2. *The Future Highway Transportation System and Society,* Reference 17

This 1997 study was focused on passenger travel but had a few paragraphs on freight transportation. Trends noted were that the U.S. manufacturing base was becoming more decentralized and smaller production facilities were moving closer to population centers to reduce transportation costs. This trend was expected to reduce demand for Class 7 and 8 truck carriers and increase demand for smaller class truck shipments in and around population centers. Another trend noted was continued growth in truck volumes and weights. Long haul carriers would be moving fewer but larger loads. However, Deen Ref. 15, expects 57'-63' trailers, double 48' trailers and triple 40' trailers in use on selected parts of the national Highway System by 2020.

3. *Future Highway Energy Use: a Fifty year Perspective,* Reference 13

This study was conducted by the DOE. A draft was released in January 2001. It looked at various futures for passenger cars, light trucks and heavy trucks. It contains pretty specific scenarios for heavy vehicles and their fuels. The study emphasizes that it is not a prescription but rather an exploration of possible futures. The scenarios involving heavy trucks are as follows:

a. Base Case: 50 year projection assumes no improvement in vehicle fuel economy, continued population and economic growth, a declining rate of growth in VMT.

b. Scenario 1: Enhanced conventional diesel trucks with advanced engines, drivetrains and tires. In 2050 fleet mpg for Class 7 & 8 trucks assumed to be 7.3 mpg; class 3-6 mpg assumed to be 15 mpg. **Energy and oil consumption and carbon production reduced 20% from base case.**

c. Scenario 2: Advanced technology diesel (higher pressure fuel injection) plus use of lighter weight materials in Classes 7 & 8, mpg = 8.6 mpg; hybrid electric in classes 3-6, mpg = 20.8. **Energy, oil, carbon reduced 33%.**

d. Scenario 3: Freight modal shift and efficiency. Considers advanced trucks of scenario 1, advanced locomotive technologies to improve fuel efficiency by 18%, and freight shift from trucks to rail starting in 2001 and reaching 10% by 2050. **Energy, oil and carbon reduced 26%.**

e. Scenario 4: Advanced technology diesel per scenario 2, assumes 1/3 of the diesel fuel market is biodiesel, also used by locomotives. **Energy reduced 33%, oil consumption 55%, and carbon 42%.**

f. Scenario 5: Advanced technology diesel, Solid-oxide fuel cell, hybrid medium trucks and Fischer-Tropsch (FT) diesel fuel. Assumes FT diesel from domestic natural gas introduced in 2020 replaces 50% of the diesel fuel by 2050. Diesel – fueled solid oxide fuel-cell trucks (become commercial in 2020) penetrate 20% of the market in 2050. **Energy requirements & carbon production reduced 40%, oil consumption 70%.**

g. Scenario 6: Three fuel future- Hydrogen, biodiesel, petroleum diesel: Hydrogen fuel –cells added to the mix of scenario 5. For fuels assume 5% hydrogen, 33% biodiesel, 50% FT diesel and 12% petroleum diesel. For trucks assume 5% hydrogen fuel cell, 20% SOFC, 75% advanced technology diesel, and hybrid medium duty trucks. **Energy reduced 43%, oil 87% and carbon 59%.**

The report estimates that remaining conventional oil resources combined with economic growth cases for world oil demand implies that 50% of the world's endowment of conventional oil will be used up before 2040 at the latest, or by 2010 at the earliest. (In the U.S. highway energy use is expected to grow 21/2 times by 2050). Long before the 50% exhaustion point is reached a transition to alternative energy sources must begin. Without advanced vehicle and fuel technologies and strong public policies, the most likely transition would be from conventional oil to synthetic fuels (liquid fuels similar to gasoline and diesel derived from natural gas, coal, tar sands, oil shale).

With more intensive refining and at greater cost, conventional petroleum products can be made from unconventional sources. The time to fully implement a new vehicle technology in all vehicles on the road is 30 years or more, and the time to fully implement a new fuel is even longer. Therefore, the U.S. should start transportation's energy transition immediately.

See *www.ott.doe.gov/presentations2.html* for the full report.

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APPENDIX I

Scenarios from *Beyond the Limits*

Each scenario determined the effect of resource consumption, population, pollution, food production, and industrial output (termed the "State of the World") on life expectancy, consumer goods per person, food and services per person (termed the "Material Standard of Living").

The scenarios are shown in sets of two graphs for each, the upper graph showing the state of the world, and the lower one the effect on the material standard of living.

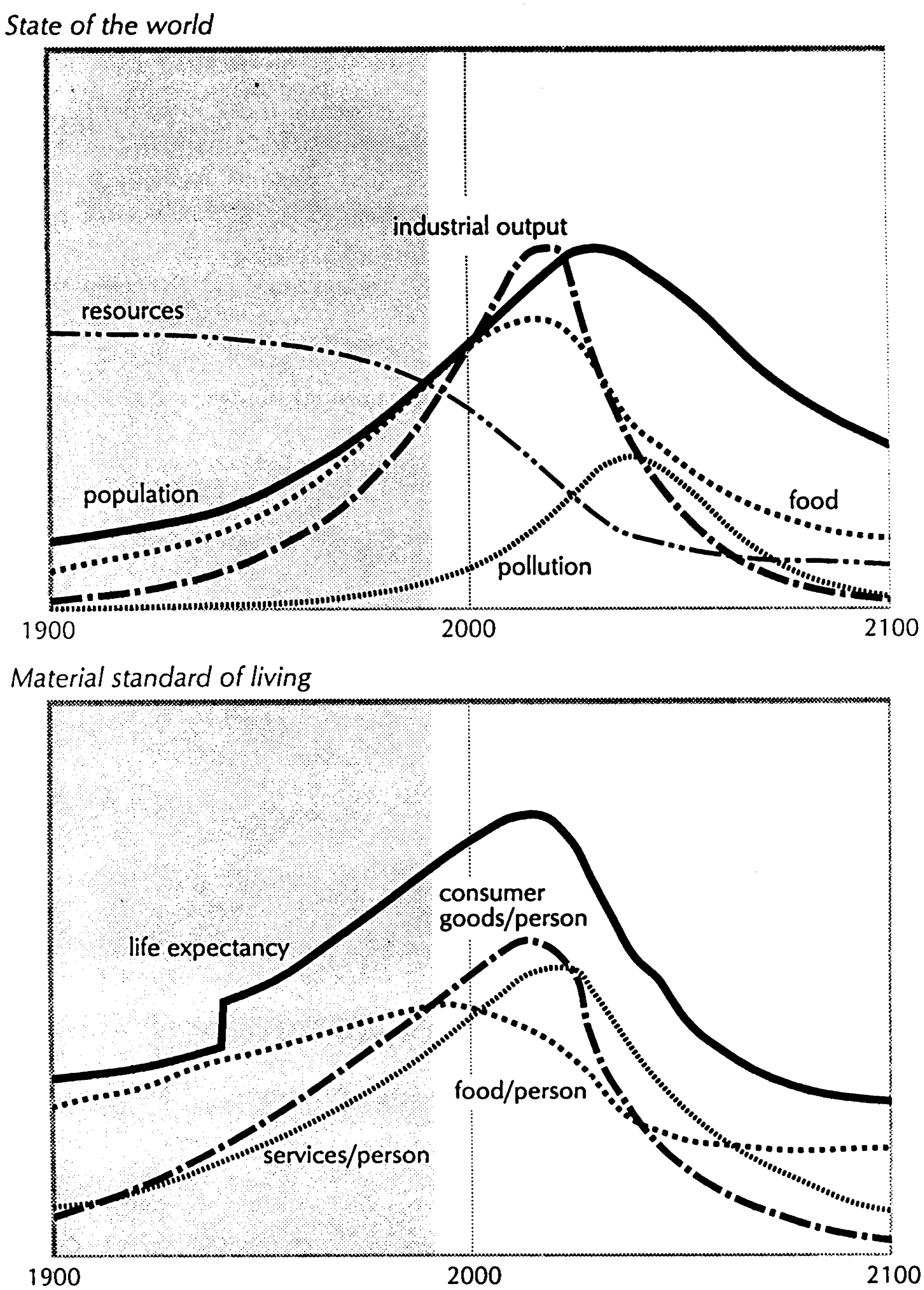
The first scenario is from the 1972 *Limits to Growth*, and is taken as the baseline. It shows peaks sometime after 2000 and then a gradual decline to 2100 when the material standard of living approximates that of the 1900s. This is the general outcome for most of the scenarios. Each of the scenarios has a short description of the measures assumed to be taken to create the outcomes shown. Note that for scenarios 7,8,9,10and 11 the time for corrective action to have been taken has passed.

(Graphs reproduced with permission of Chelsea Green publishing Co.)

Scenario 1: The “Standard Run” from *The Limits to Growth*

The world society proceeds along its historical path as long as possible without major policy change. Population and industry output grow until a combination of environmental and natural resource constraints eliminate the capacity of the capital sector to sustain investment. Industrial capital begins to depreciate faster than the new investment can rebuild it. As it falls, food and health services also fall, decreasing life expectancy and raising the death rate.

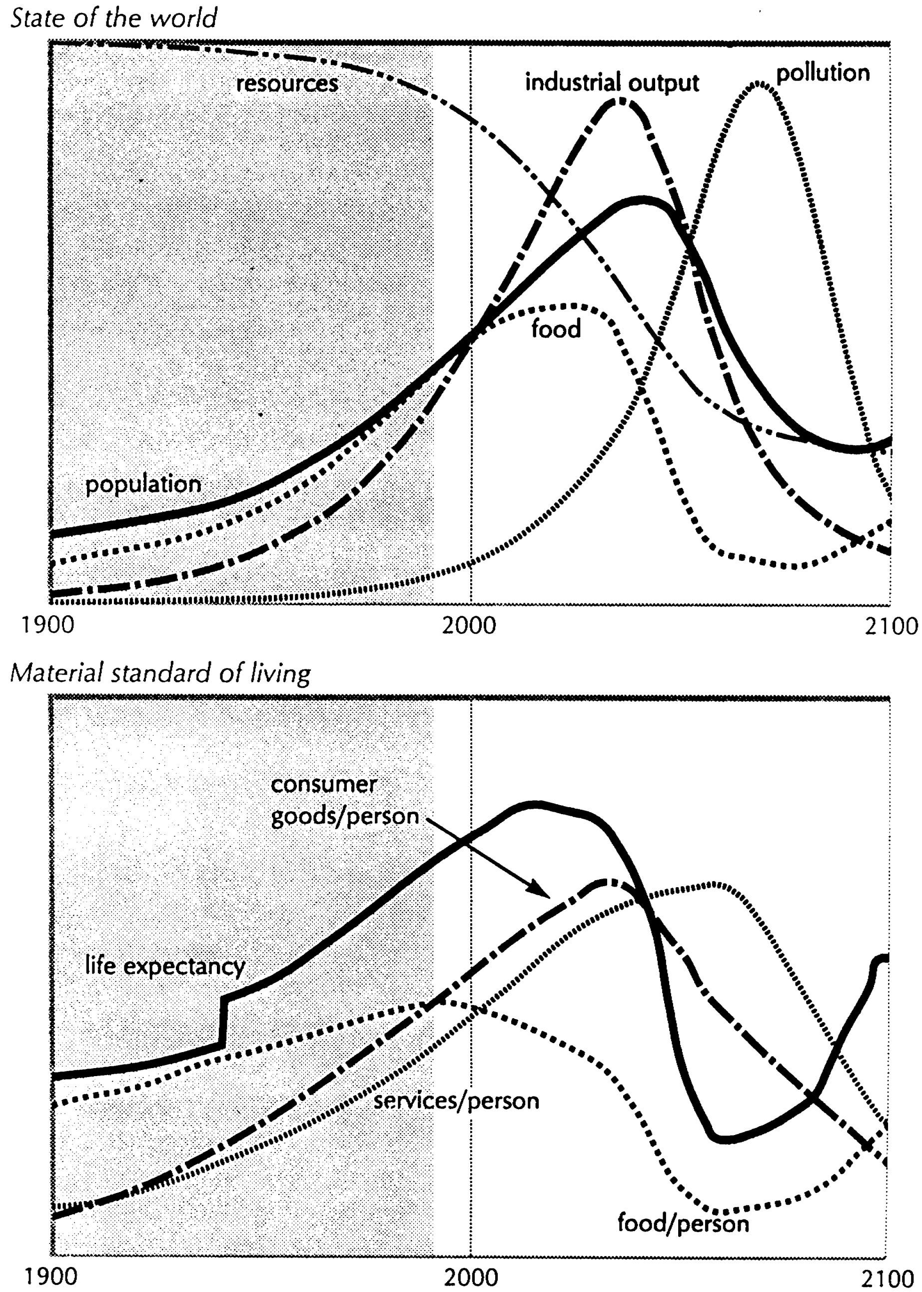
SCENARIO 1



Scenario 2: Doubled Resources Are Added to Scenario 1

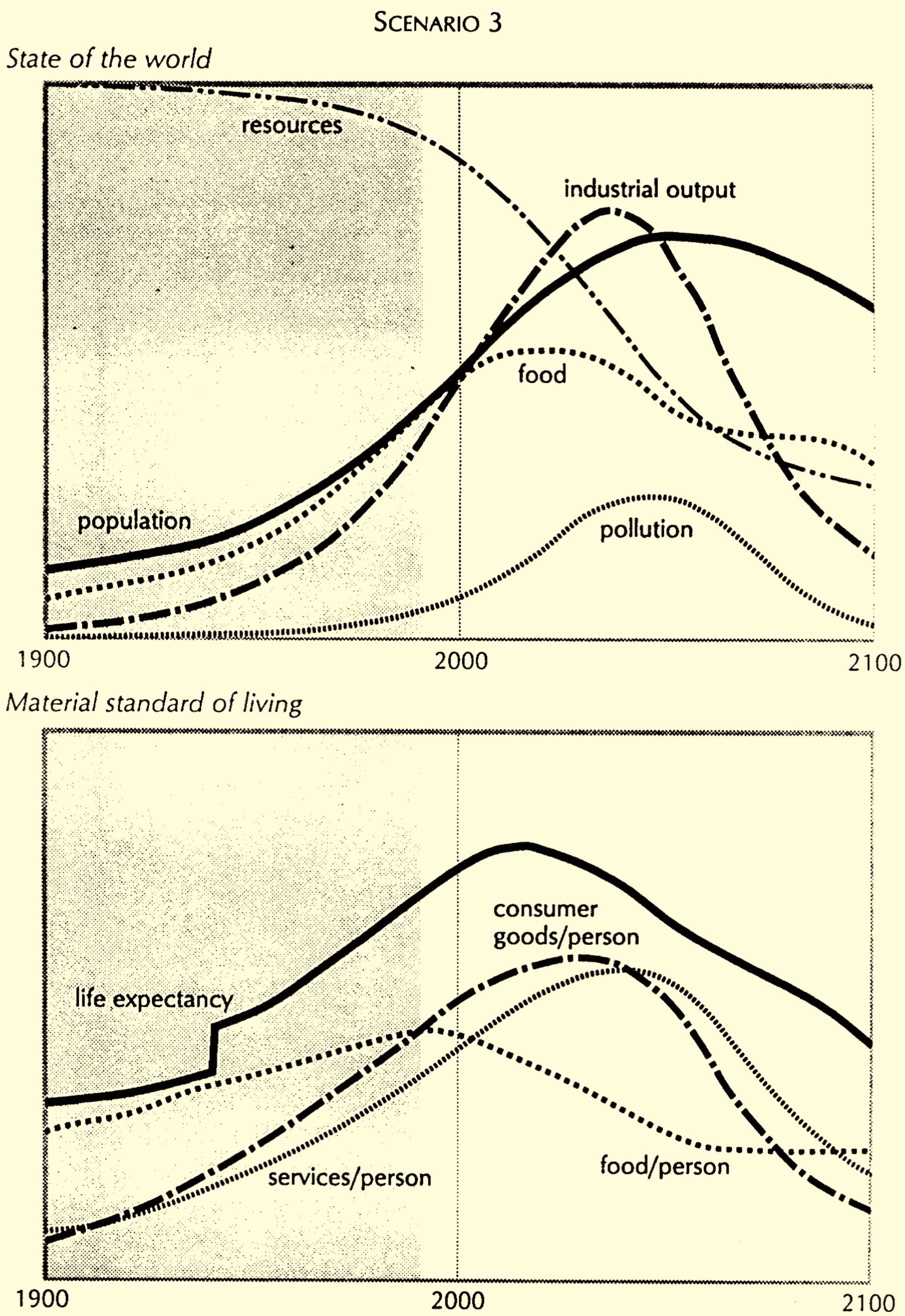
If we double the natural resource endowment we assumed in Scenario 1, industry can grow 20 years longer. Population rises to 9 billion by 2040. These increased levels generate much more pollution, which reduces land yield and forces much greater investment in agriculture. Eventually, declining food raises the population death rate.

SCENARIO 2



Scenario 3 DOUBLE RESOURCES AND POLLUTION CONTROL TECHNOLOGY

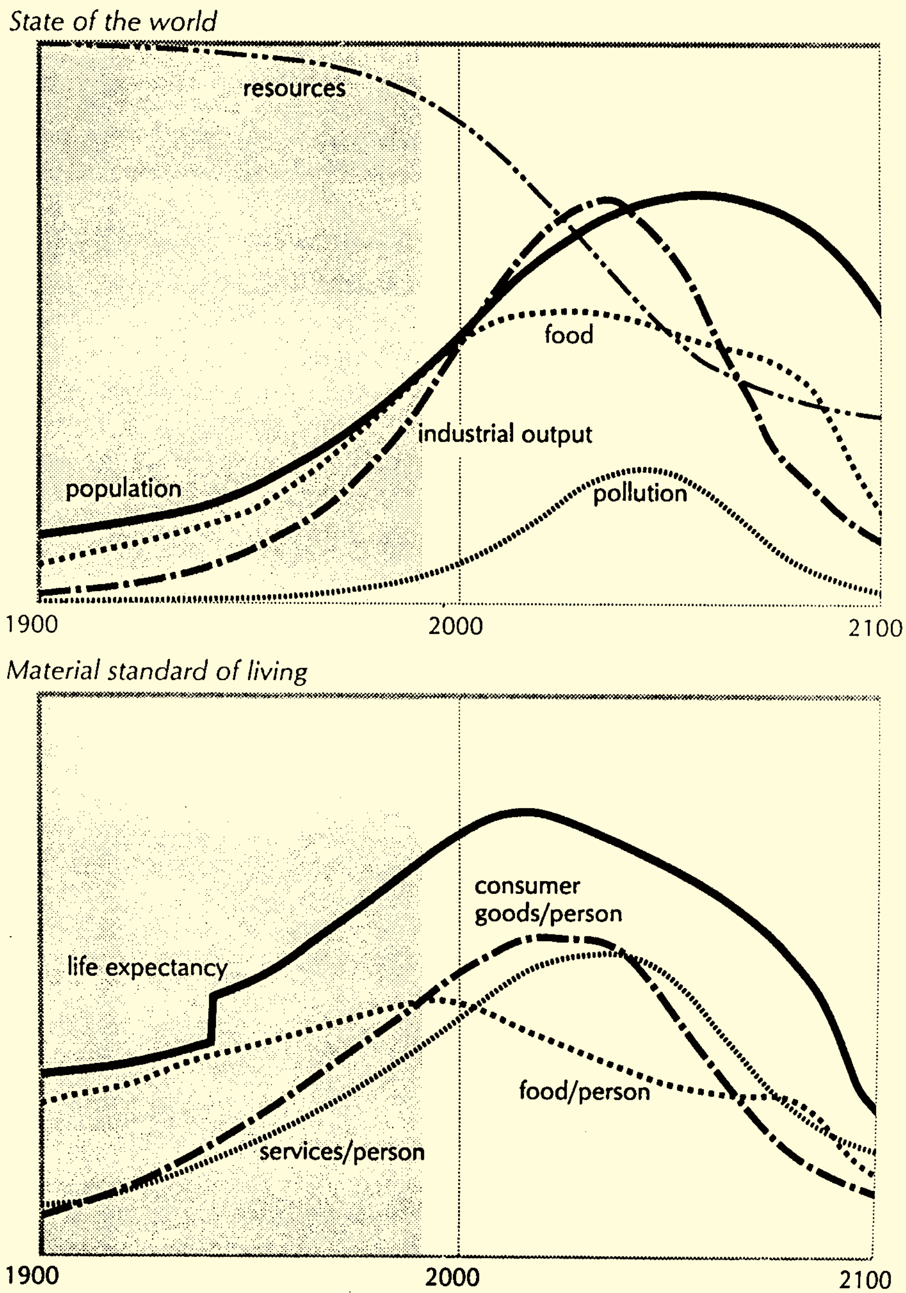
In this scenario we assume doubled resources, as in Scenario 2, and also increasingly effective pollution control technology, which can reduce the amount of pollution generated per unit of industrial output by 3% per year. Pollution nevertheless rises high enough to produce a crisis in agriculture that draws capital from the economy into the agriculture sector and eventually stops industrial growth.



Scenario 4 DOUBLE RESOURCES, POLLUTION CONTROL TECHNOLOGY, AND LAND YIELD ENHANCEMENT

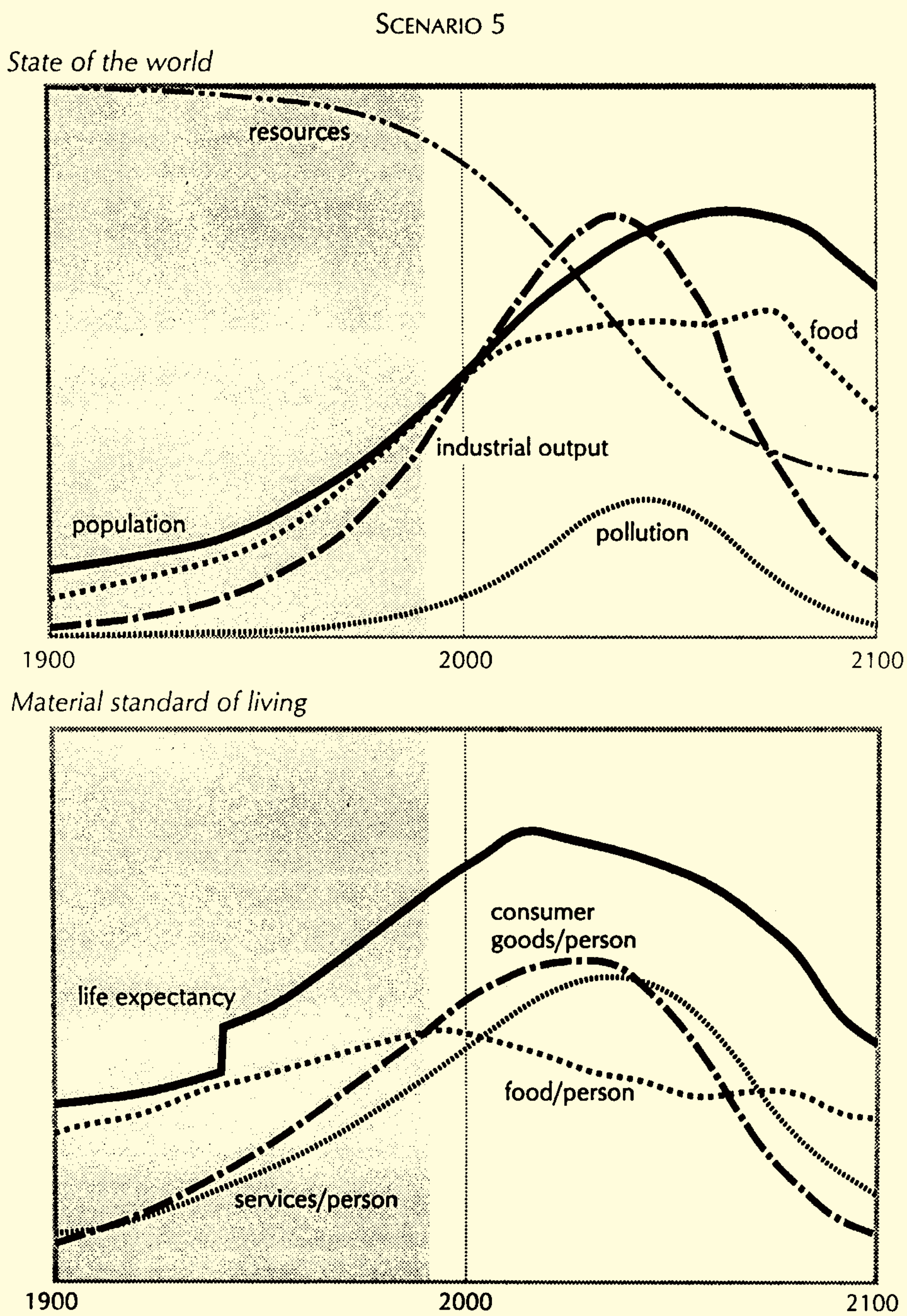
If the model world adds to its pollution control technology a set of technologies to increase greatly the yield per unit of land, the high agricultural intensity speeds up land loss. The world's farmers are getting higher and higher yields on less and less land, and at an ever-higher cost to the capital sector.

SCENARIO 4



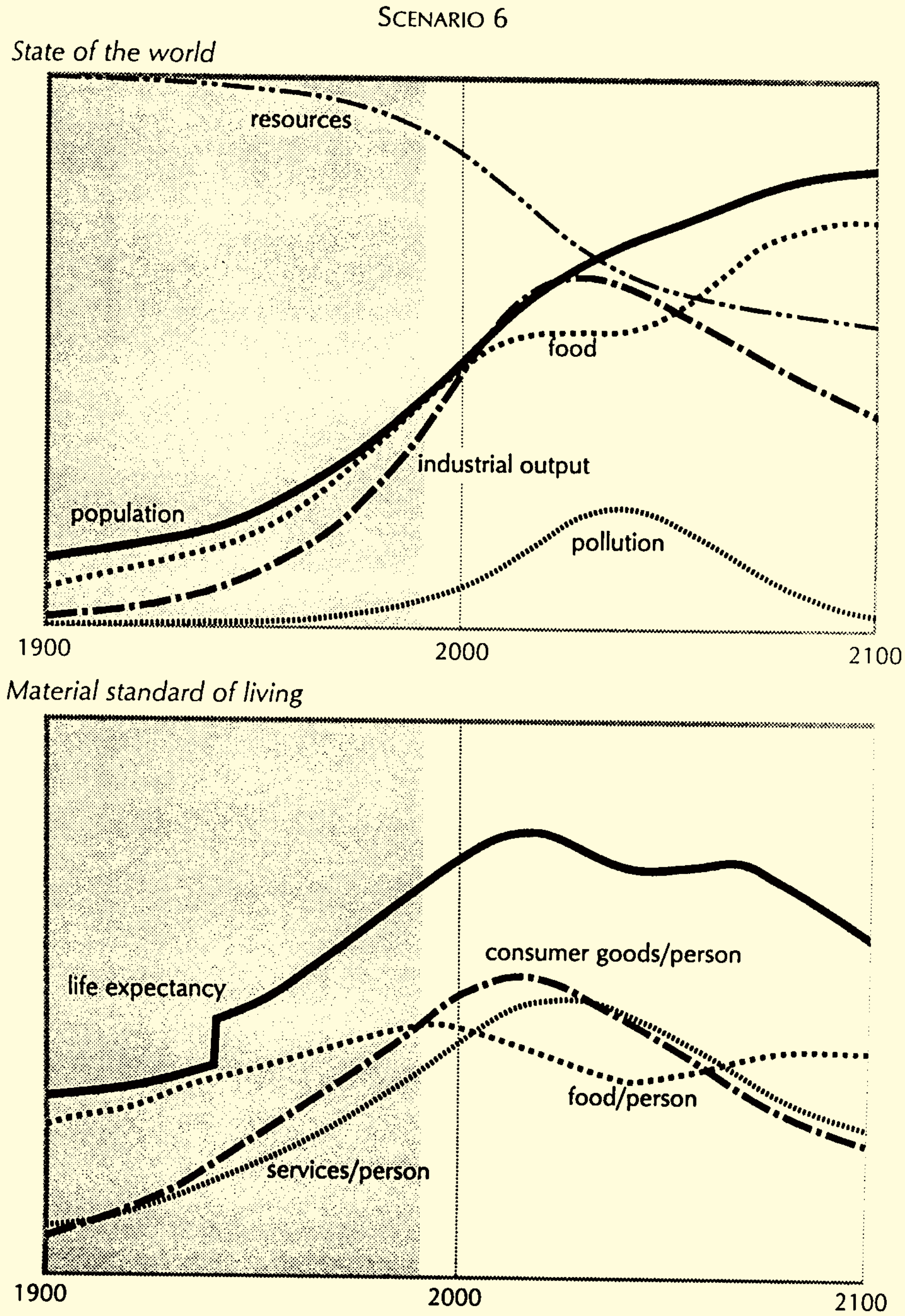
Scenario 5: Doubled Resources, Pollution Control Technology, Land Yield Enhancement, and Land Erosion Protection

Now a technology of land preservation is added to the agricultural yield-enhancing and pollution-reducing measures already tested. The result is further population and capital growth, which leads to a crisis not in resources, pollution, or land, but in all three at once.



Scenario 6 Double Resources, Pollution Control Technology, Land Yield Enhancement, Land Erosion Protection, and Resource Efficiency Technology

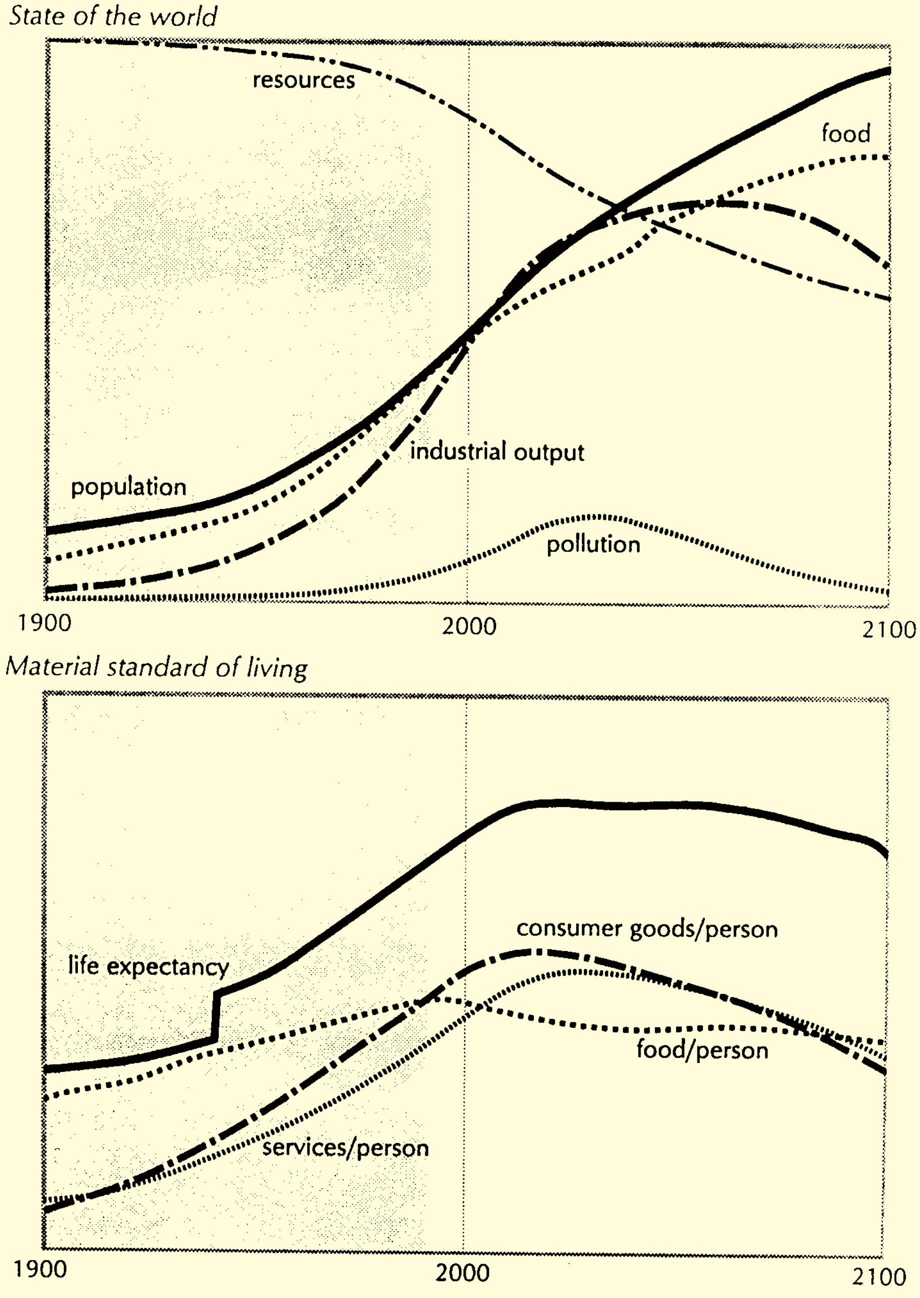
Now the simulated world is developing powerful technologies for pollution abatement, land yield enhancement, land protection, and conservation of nonrenewable resources all at once. All these technologies are assumed to cost capital and to take 20 years to be fully implemented. In combination they permit the simulated world to go on growing until 2050. What finally stops growth is the accumulated cost of the technologies.



Scenario 7 ALL TECHNOLOGIES APPLIED WITH SHORTER DELAYS

This model run is identical to the previous one, except that technology development is assumed to take only 5 years instead of 20 to have worldwide effect. Industrial output grows 20 years longer than it did in Scenario 6 and population becomes higher by 2 billion. But the material standard of living is falling slowly. The increasing cost of holding off the limits finally stops industrial growth.

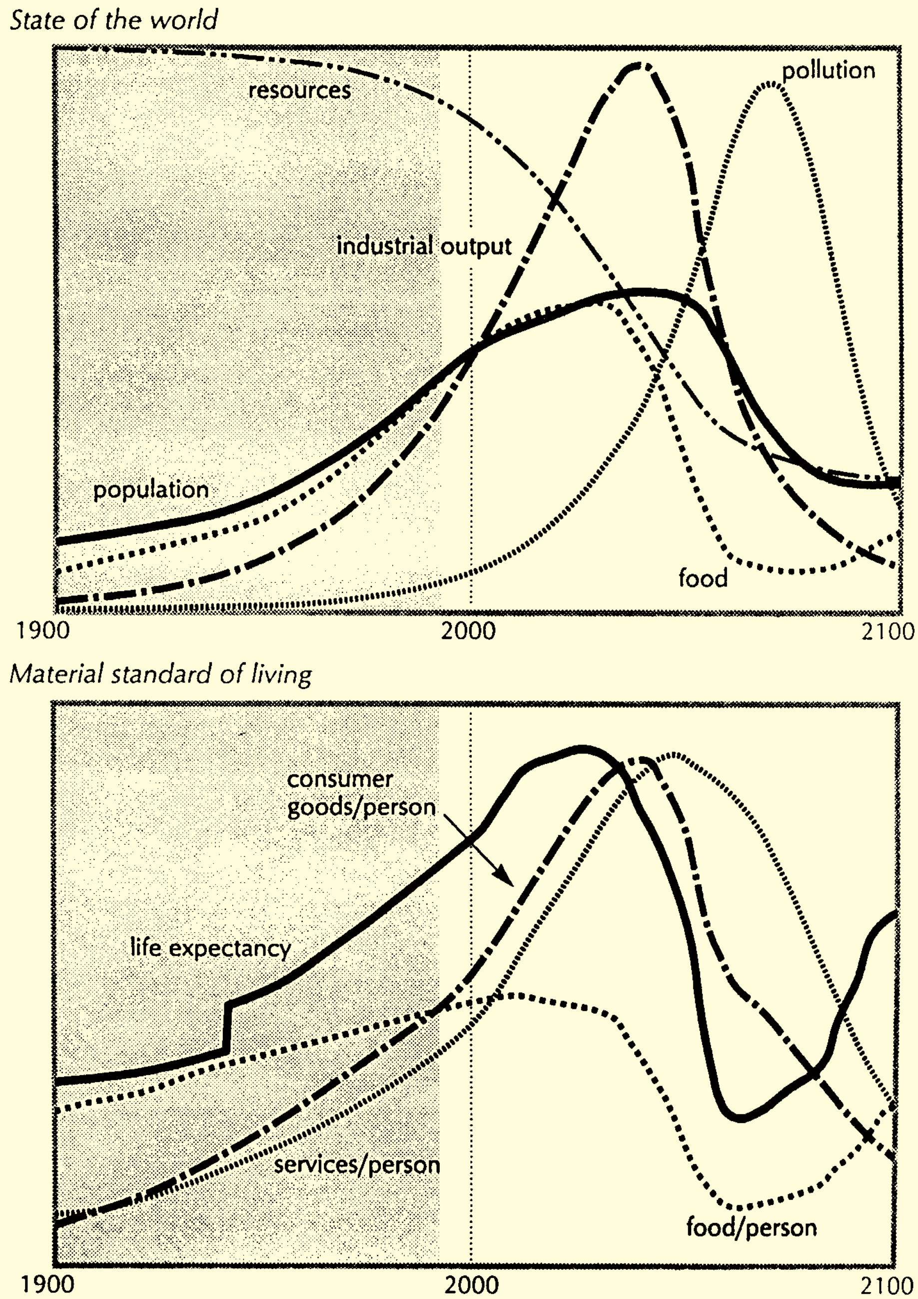
SCENARIO 7



Scenario 8 World Adopts Stable Population Goals in 1995

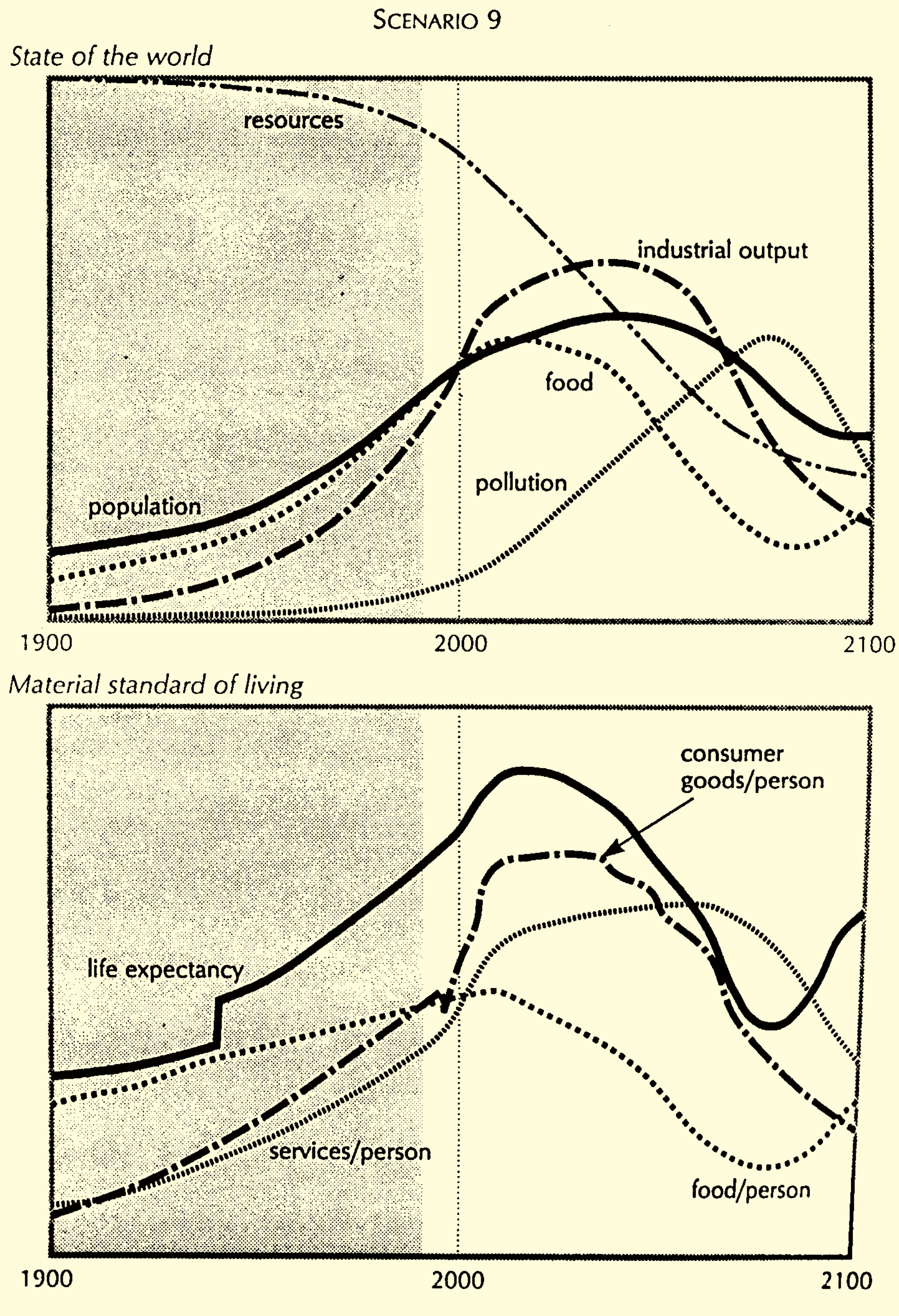
This scenario supposes that after 1995 all couples decide to limit their family size to two children and have access to effective birth control technologies. Because of age structure momentum, the population continues growing well into the 21st century. The slower population growth permits industrial output to rise faster, until it is stopped by depleting resources and rising pollution.

Scenario 8



Scenario 9 WORLD ADOPTS STABLE POPULATION AND INDUSTRIAL OUTPUT GOALS IN 1995

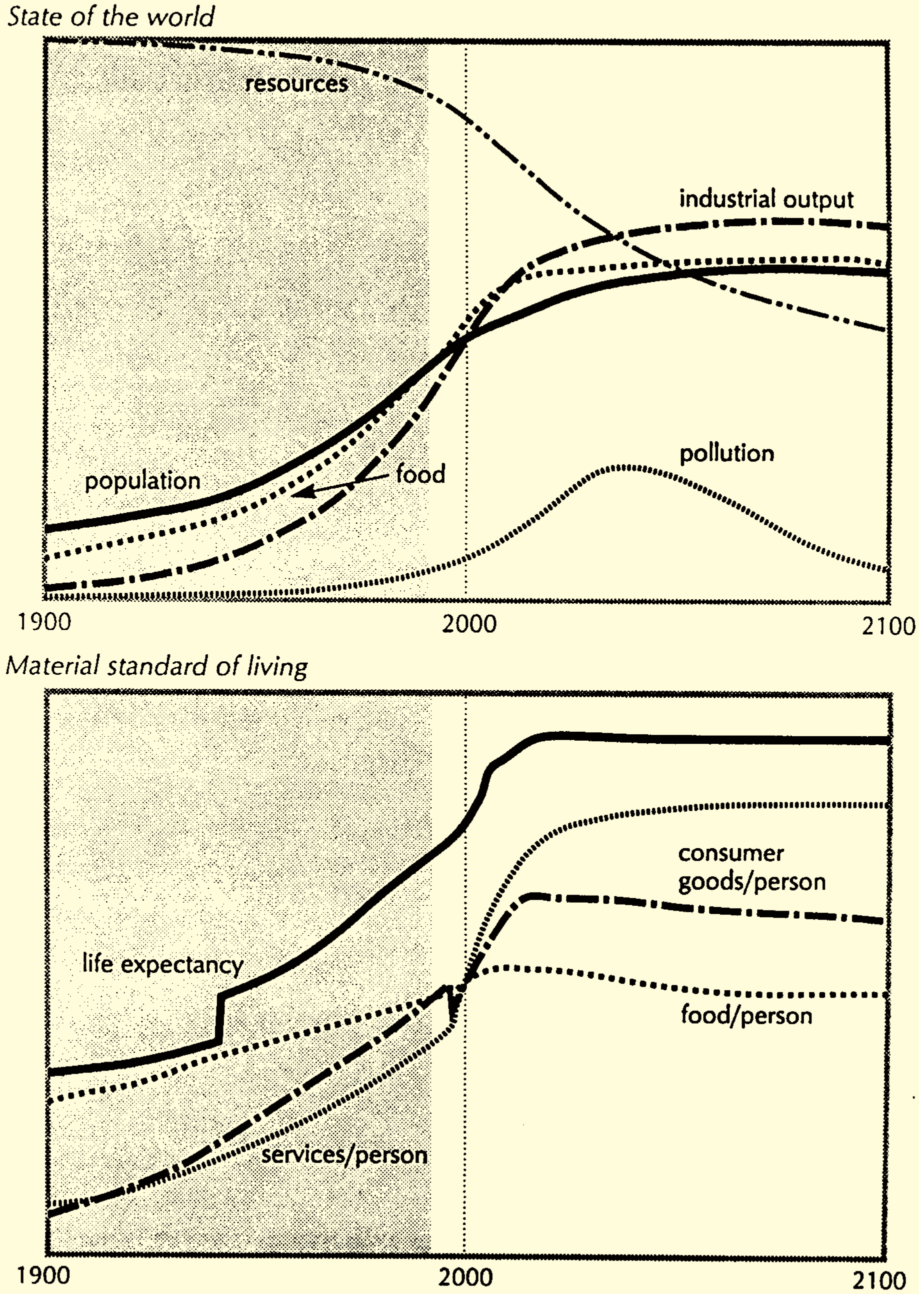
If the population adopts both a desired family size of two children and a deliberately moderated goal for industrial output per capita, it can maintain itself at a material standard of living 50% higher than the 1990 world average for almost 50 years. Pollution continues to rise, however, stressing agricultural land. Per capita food production declines, eventually carrying down life expectancy and population.



Scenario 10 STABILIZED POPULATION AND INDUSTRY WITH TECHNOLOGIES TO REDUCE EMISSIONS, EROSION, AND RESOURCE USE ADOPTED IN 1995

In this scenario population and industrial output per person are moderated as in the previous model run, and in addition technologies are developed to conserve resources, protect agricultural land, increase land yield, and abate pollution. The resulting society sustains 7.7 billion people at a comfortable standard of living with high life expectancy and declining pollution until at least the year 2100.

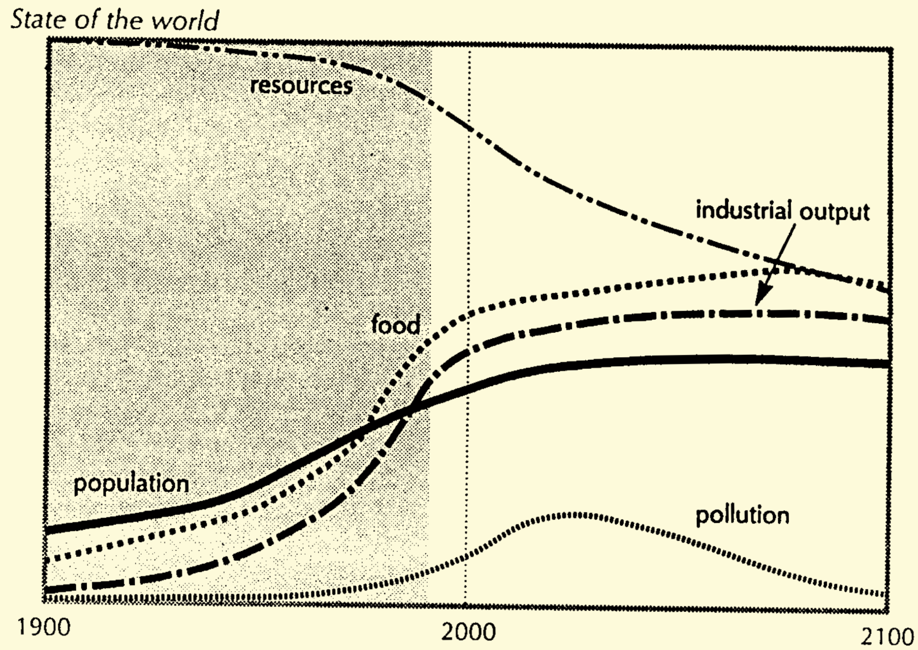
SCENARIO 10

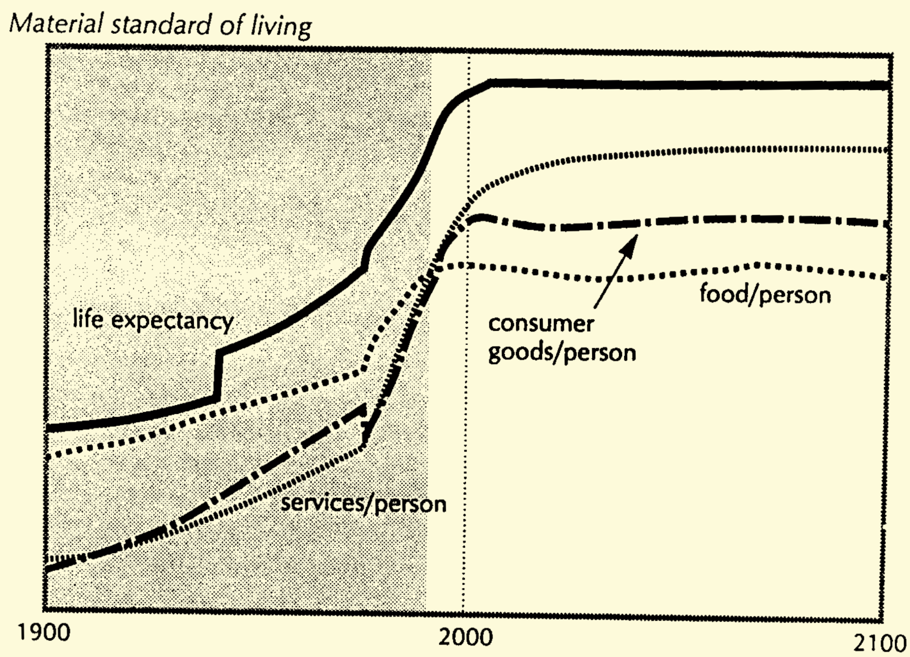


Scenario 11 — STABILIZED POPULATION AND INDUSTRY WITH TECHNOLOGIES TO REDUCE EMISSIONS, EROSION, AND RESOURCE USE ADOPTED IN 1975

This simulation includes all the changes that were incorporated into the previous one, but the sustainability policies are implemented in the year 1975 instead of 1995. Moving toward sustainability 20 years sooner would have meant a considerably lower final population, less pollution, more nonrenewable resources, and a slightly higher material standard of living.

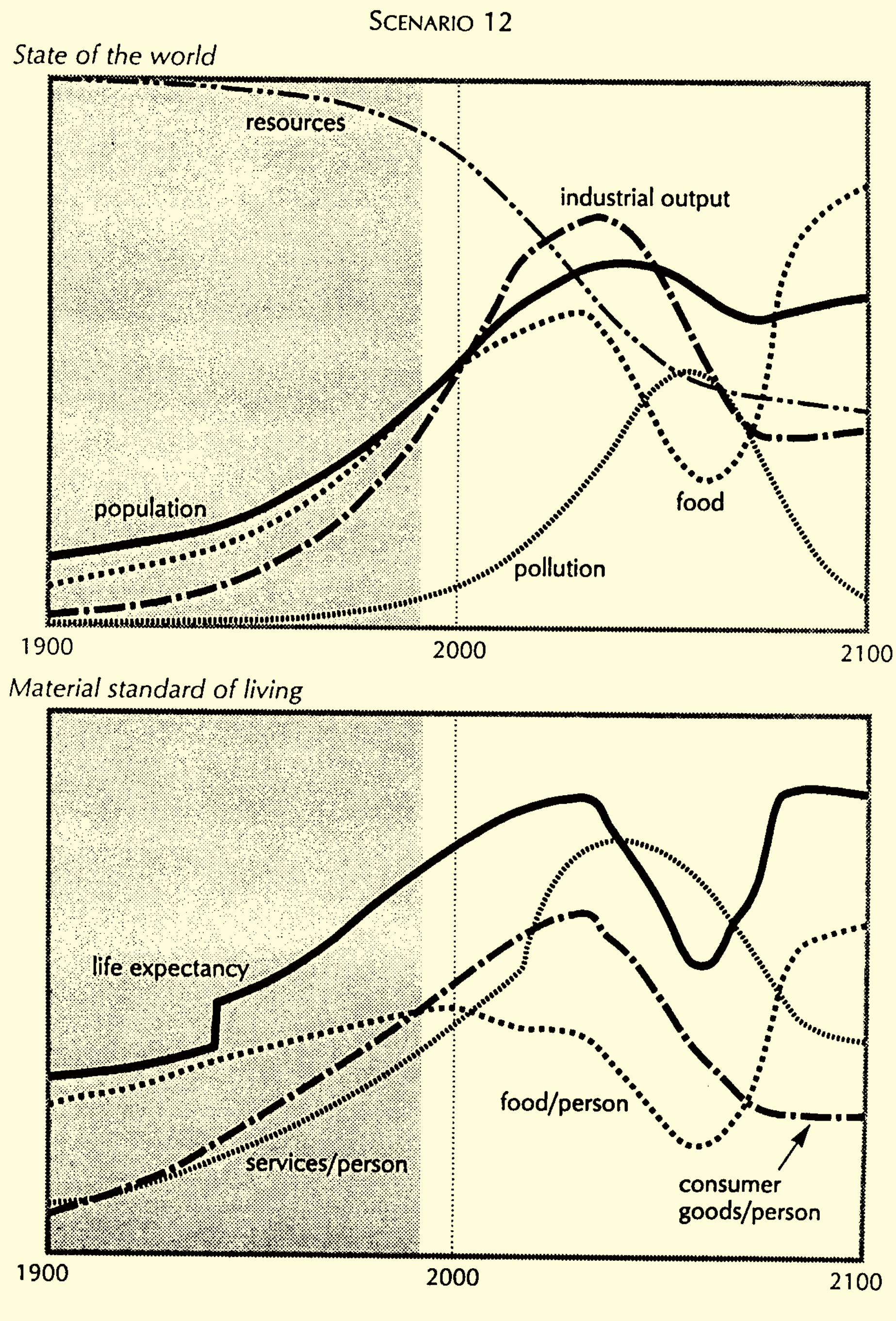
SCENARIO 11





Scenario 12 STABILIZED POPULATION AND INDUSTRY WITH TECHNOLOGIES TO REDUCE EMISSIONS, EROSION, AND RESOURCE USE ADOPTED IN 2015

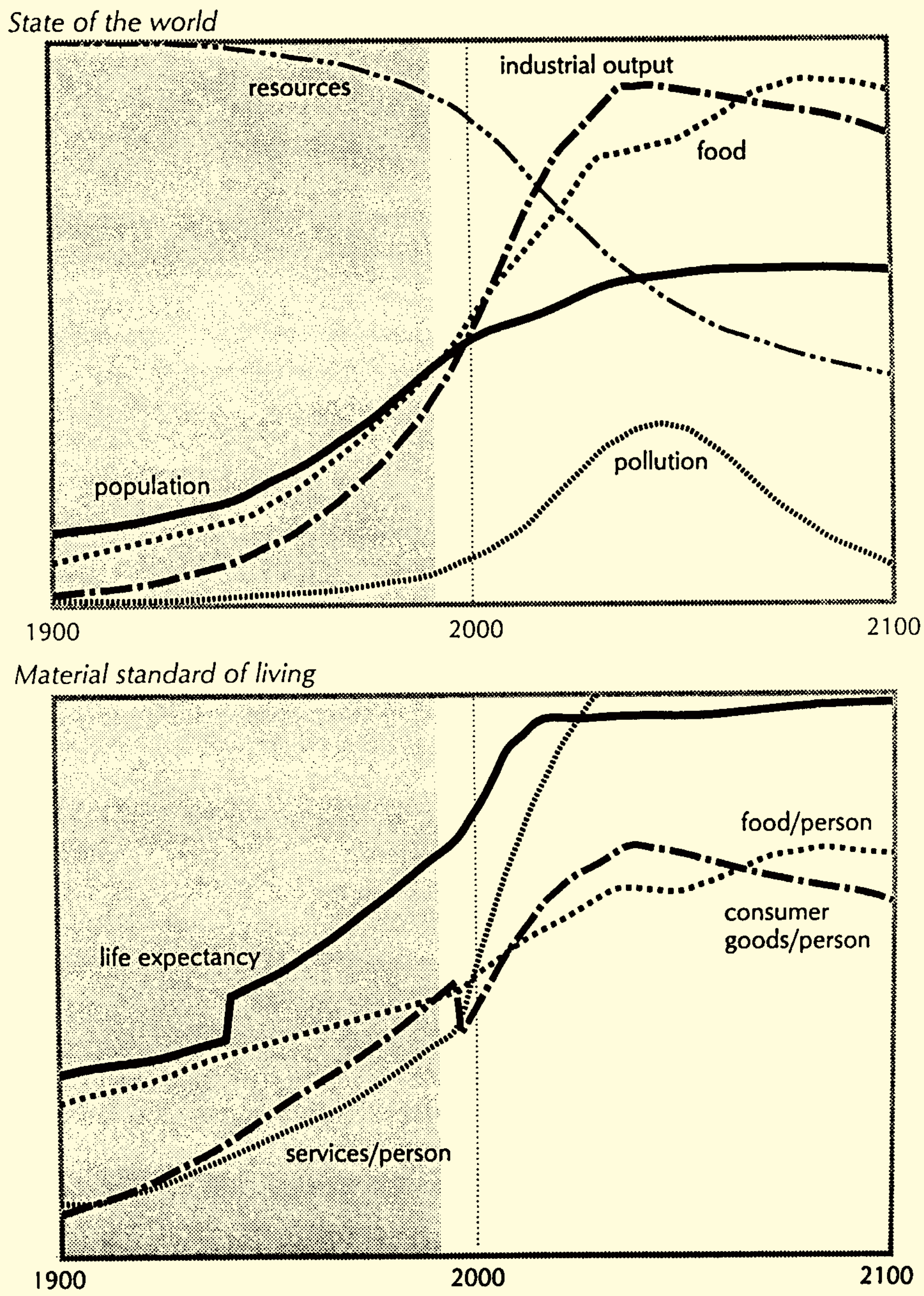
Waiting to implement the sustainability policies until the simulated year 2015 allows population, industry, and pollution to rise too high. Even the effective technologies operating in this scenario cannot forestall a decline, although they do manage to reverse the decline at the end of the 21st century.



Scenario 13 EQUILIBRIUM POLICIES BUT WITH HIGHER GOALS FOR FOOD AND INDUSTRIAL OUTPUT

Using the same general policies as were implemented in Scenario 11, but with much higher demands for food and consumption places much greater stress on the global resource base. Initially the living standard is higher, but by 2100 the simulated world shows clear signs of unsustainability.

SCENARIO 13



<u>APPENDIX II</u>
WILD CARDS

The following is a list of events that could happen in the future at anytime that would significantly impact the trucking industry.

- Another Chernobyl
- Civil war between former Soviet states goes nuclear
- Civil war in the U.S.
- Collapse of the sperm count
- Collapse of world's fisheries
- Encryption invalidated
- End of nation state
- Terrorism gets beyond ability of governments to control
- Global financial revolution
- Global food shortage
- Hackers blackmail the Federal Reserve
- Human mutation
- Ice cap breaks up
- Inner cities arm and revolt
- Life expectancy hits 100 years
- Major chaos in Africa
- Loss of intellectual property rights
- Major U.S. military unit mutinies
- Nanotechnology takes off
- Non-carbon economy
- Nuclear terrorist attack on U.S. or Europe
- Rise of an American dictator
- Social breakdown in U.S. or Europe
- Viruses become immune to all known treatments
- World-wide epidemic
- Whole generation functionally illiterate and cannot effectively read write, think, work
- Computer chip/OS maker blackmails country or world