Optimal dynamic control of the forest resource with changing energy demand functions and valuation of CO2 storage

Presentation at the Conference:

The European Forest-based Sector:
Bio-Responses to Address New Climate and Energy Challenges?
Nancy, France, November 6-8, 2008

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Structure of the presentation:

#1. Introduction to rational use of the forest when we consider CO2 and energy production

#2. Optimal dynamic control of the forest resource with changing energy demand functions and valuation of CO2 storage

#3. Optimal CCS, Carbon Capture and Storage, Under Risk

#4. Conclusions

#1. Introduction to rational use of the forest when we consider CO2 and energy production

The role of the forest?

- The best way to reduce the CO2 in the atmosphere may be to ***increase harvesting of the presently existing forests (!)***, to produce energy with CCS and to increase forest production in the new forest generations.

- ***We capture and store more CO2!***

The role of the forest?

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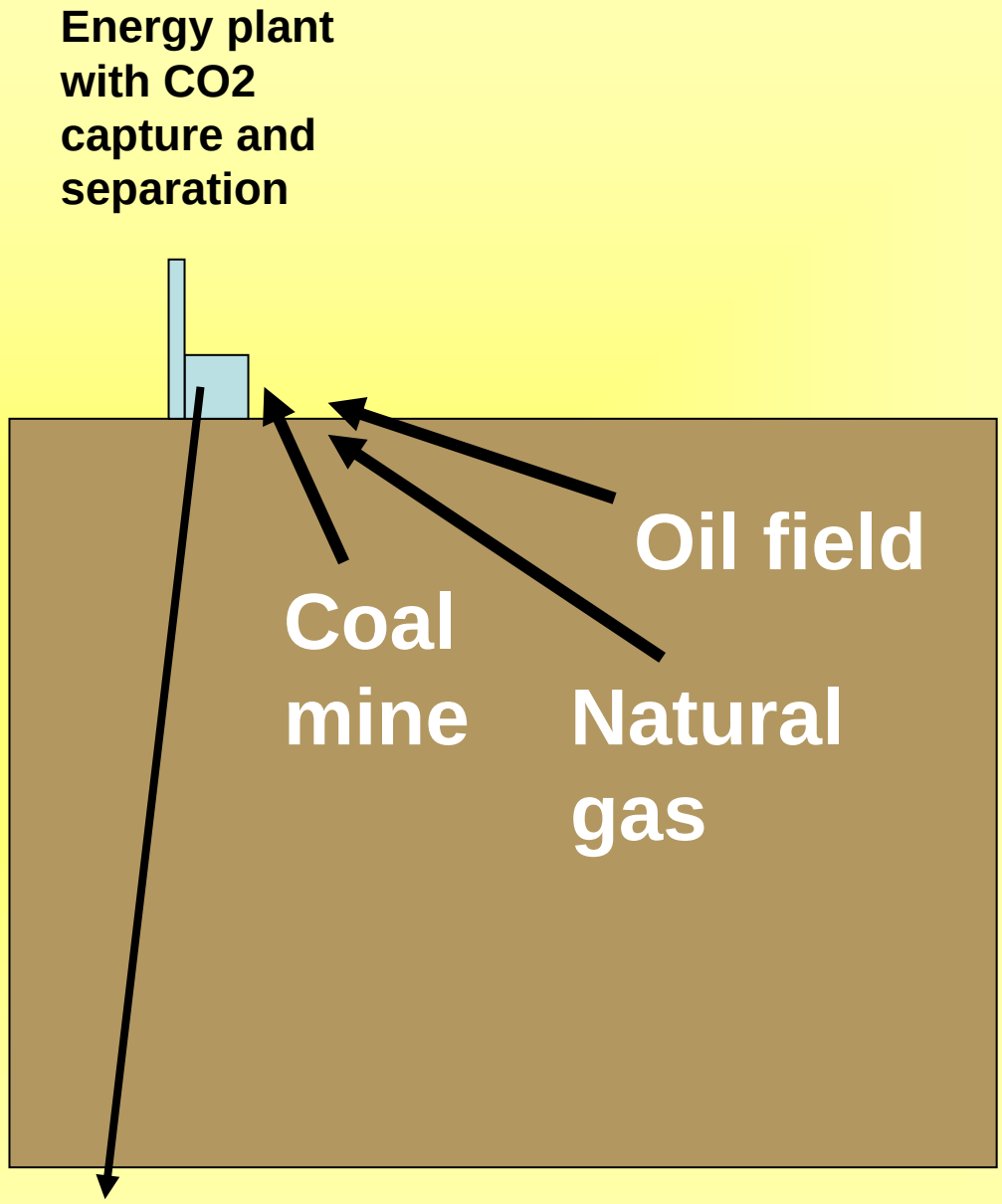
CCS, Carbon Capture and Storage, has already become the main future emission reduction method of the fossile fuel energy industry



BBC World News 2008-10-17:

- ***The British government declares that the CO2 emissions will be reduced by 80% by 2050!***
- ***CCS is the method to be used in combination with fossile fuels such as coal.***

Reference to CCS in the energy industry and EU policy

2nd Annual EMISSIONS REDUCTION FORUM: - Establishing Effective CO2, NOx, SOx Mitigation Strategies for the Power Industry, CD, Marcus Evans Ltd, Madrid, Spain, 29th & 30th September 2008

The CD (above) includes presentations where several dominating European energy companies show how they develop and use CCS and where the European Commission gives the general European emission and energy policy perspective.

Conference programme:

http://www.lohmander.com/Madrid08/MadridProg08.pdf

Lohmander, P., Guidelines for Economically Rational and Coordinated Dynamic Development of the Forest and Bio Energy Sectors with CO2 constraints, Proceedings from the 16th European Biomass Conference and Exhibition, Valencia, Spain, 02-06 June, 2008 (In the version in the link, below, an earlier misprint has been corrected.)
http://www.Lohmander.com/Valencia2008.pdf

Lohmander, P., Economically Optimal Joint Strategy for Sustainable Bioenergy and Forest Sectors with CO2 Constraints, European Biomass Forum, Exploring Future Markets, Financing and Technology for Power Generation, CD, Marcus Evans Ltd, Amsterdam, 16th-17th June, 2008
http://www.Lohmander.com/Amsterdam2008.ppt

Lohmander, P., Tools for optimal coordination of CCS, power industry capacity expansion and bio energy raw material production and harvesting, 2nd Annual EMISSIONS REDUCTION FORUM: - Establishing Effective CO2, NOx, SOx Mitigation Strategies for the Power Industry, CD, Marcus Evans Ltd, Madrid, Spain, 29th & 30th September 2008

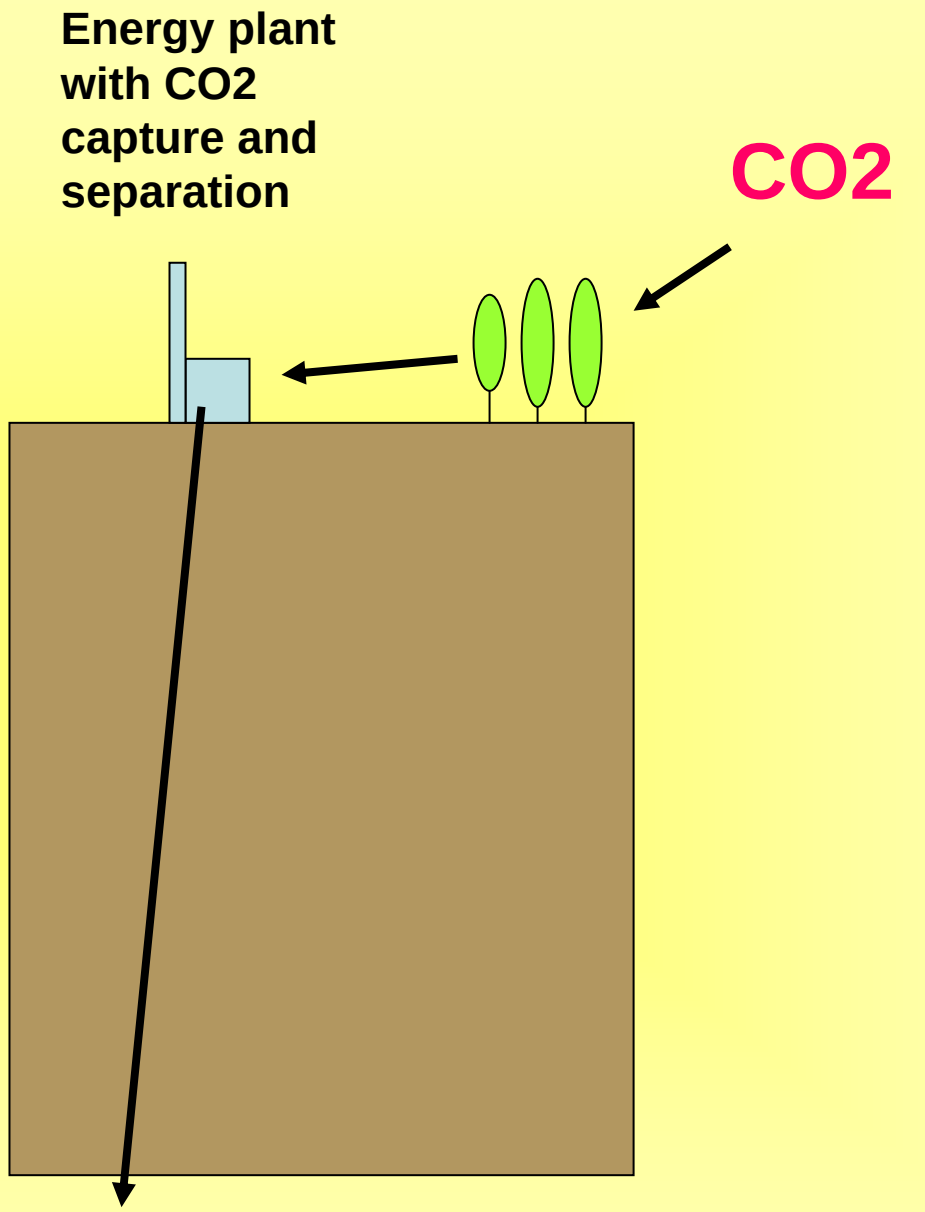
http://www.lohmander.com/Madrid08/Madrid_2008_Lohmander.ppt

Lohmander, P., Optimal CCS, Carbon Capture and Storage, Under Risk, International Seminars in Life Sciences, UPV, Universidad Politécnica de Valencia, Thursday 2008-10-16

http://www.Lohmander.com/OptCCS/OptCCS.ppt

How to *reduce the CO2 level* in the atmosphere,

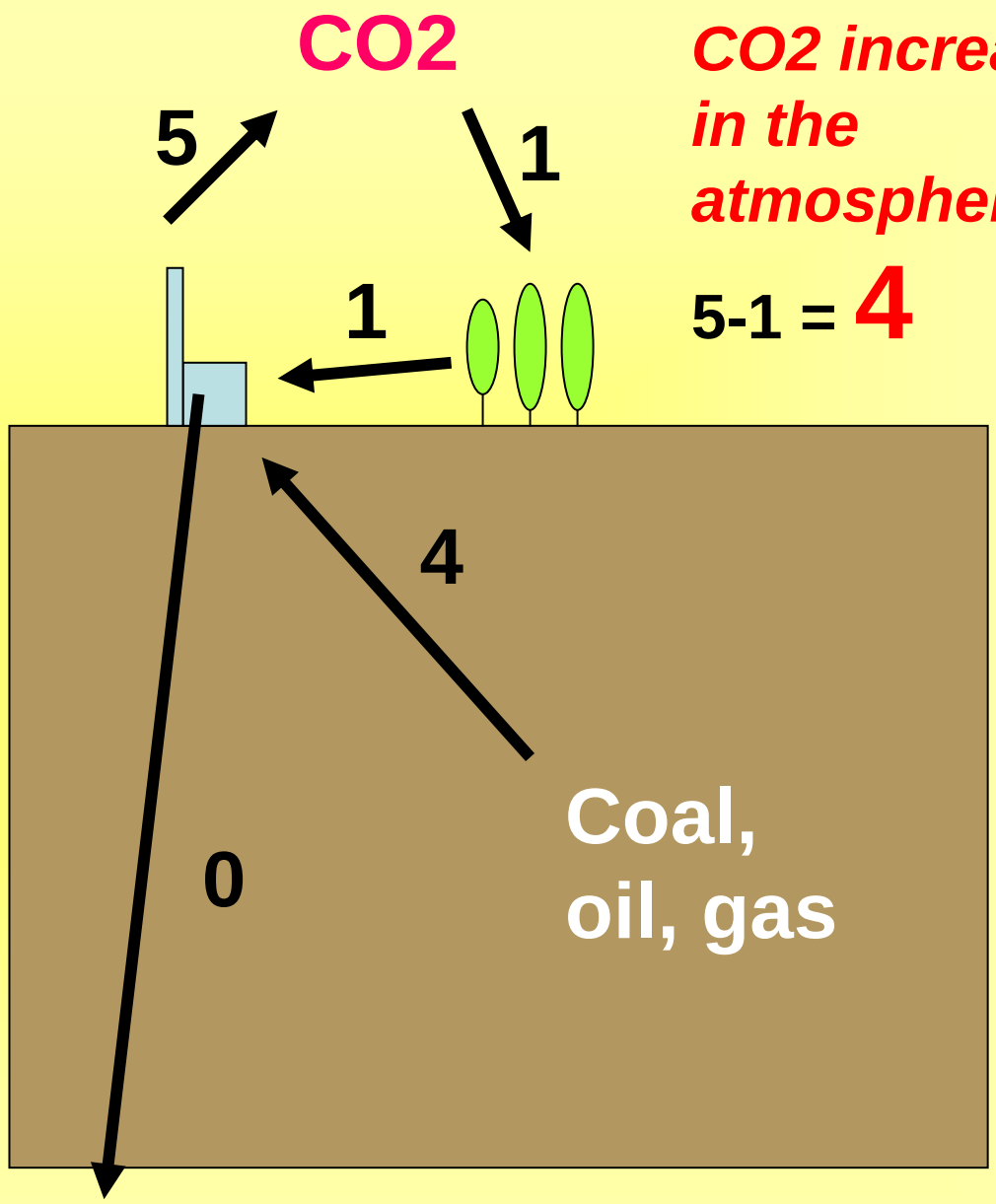
not only to decrease the emission of CO2



The role of the forest in the CO2 and energy system

- ***The following six pictures show that it is necessary to intensify the use of the forest for energy production in combination with CCS in order to reduce the CO2 in atmosphere!***
- **All figures and graphs have been simplified as much as possible, keeping the big picture correct, in order to make the main point obvious.**
- **In all cases, we keep the total energy production constant.**

The present situation.

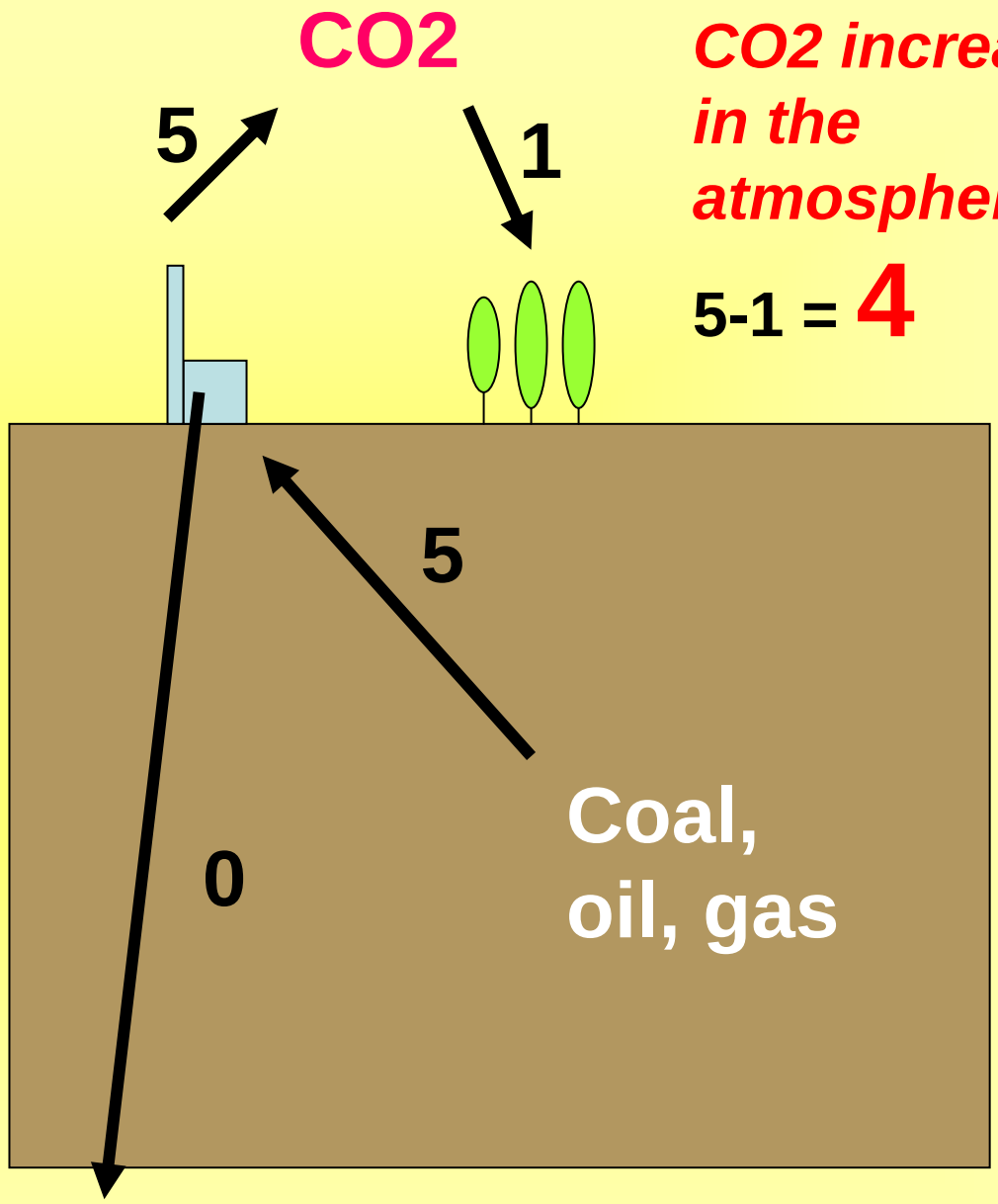


CO2 increase in the atmosphere:

5-1 = 4

Permanent storage of CO2

If we do not use the forest for energy production but use it as a carbon sink. *Before the forest has reached equilibrium*, this happens:



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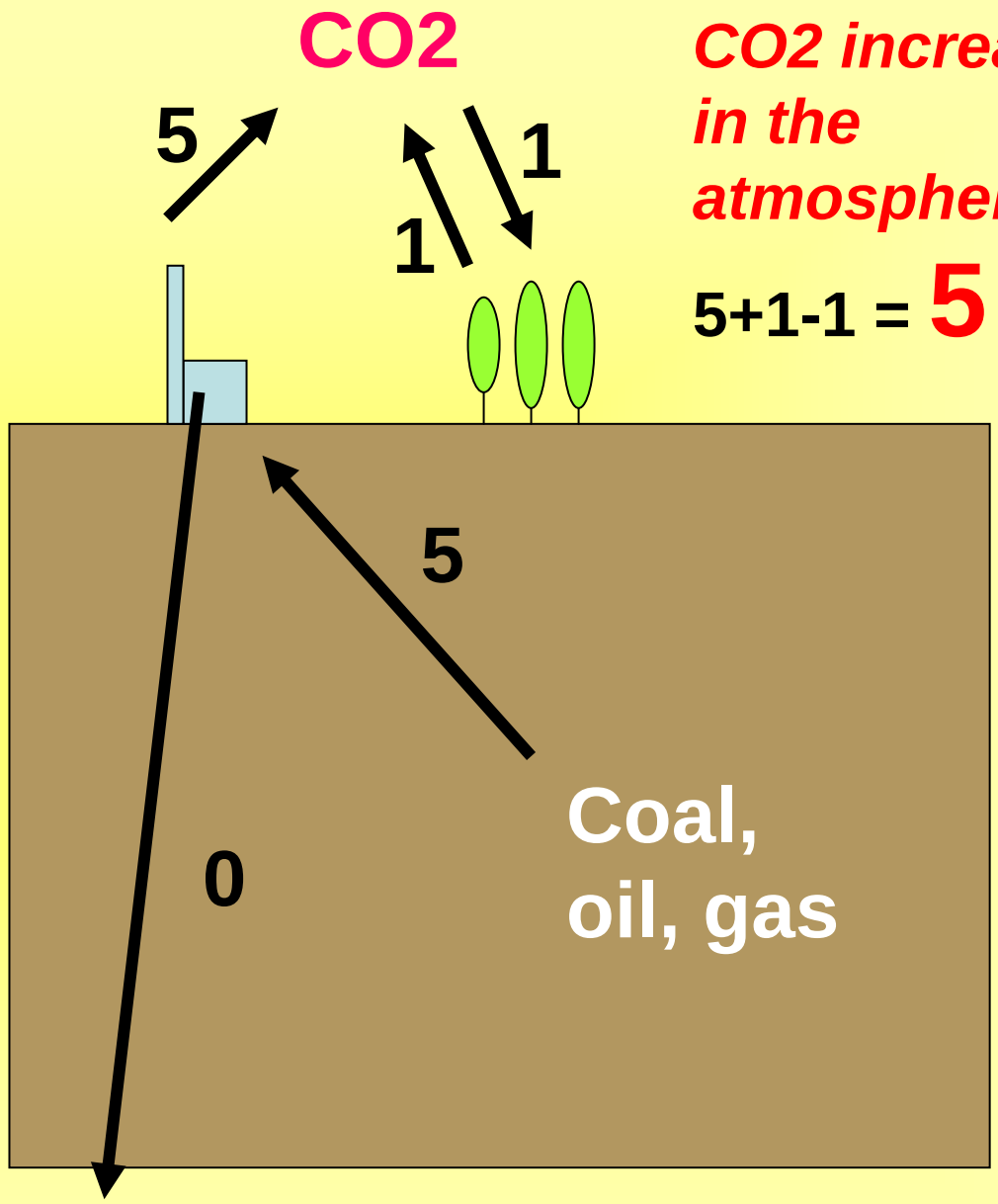
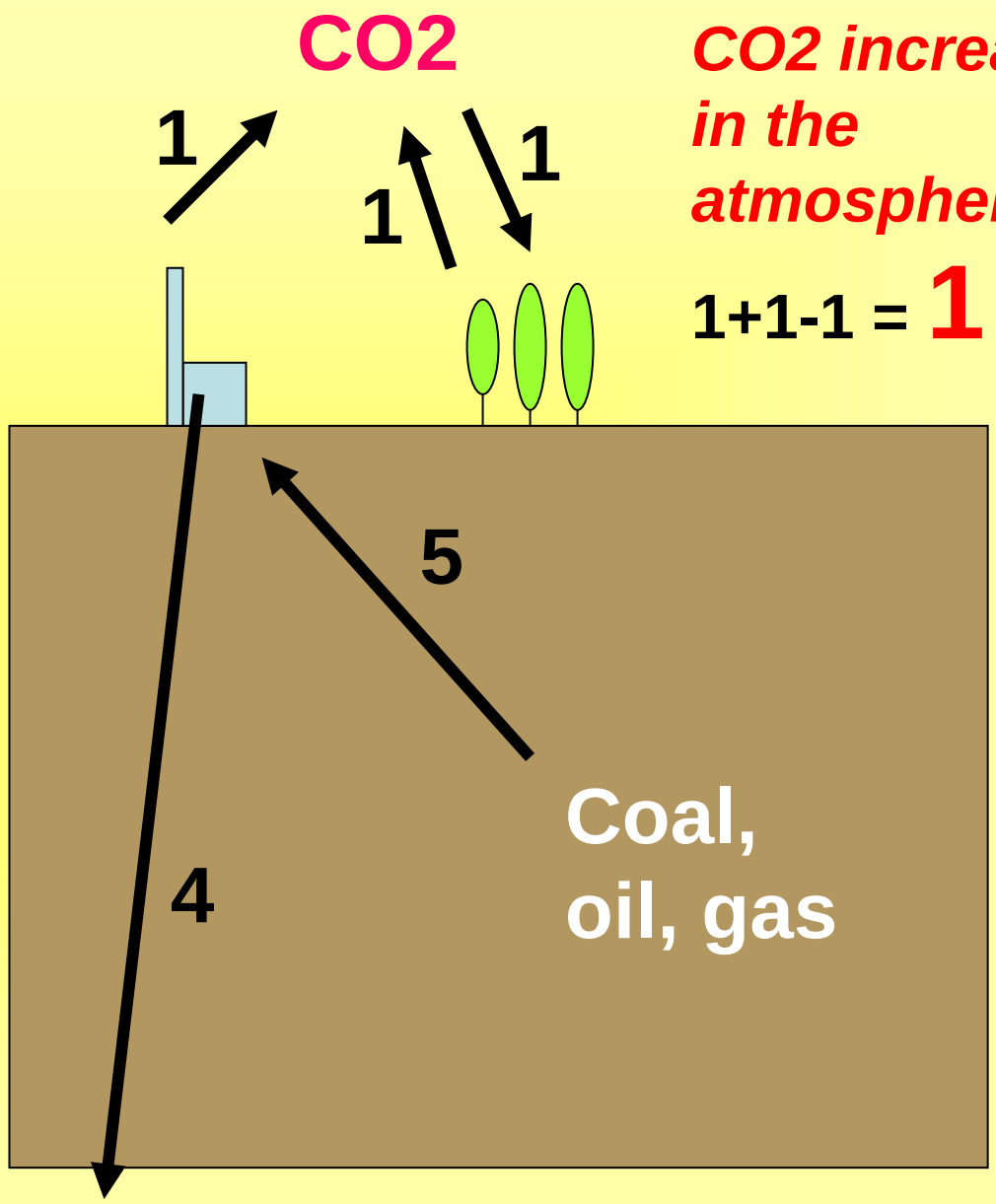


CO2 increase in the atmosphere:

5+1-1 = 5

If we use CCS with 80% efficiency and let the forest grow until it reaches equilibrium.

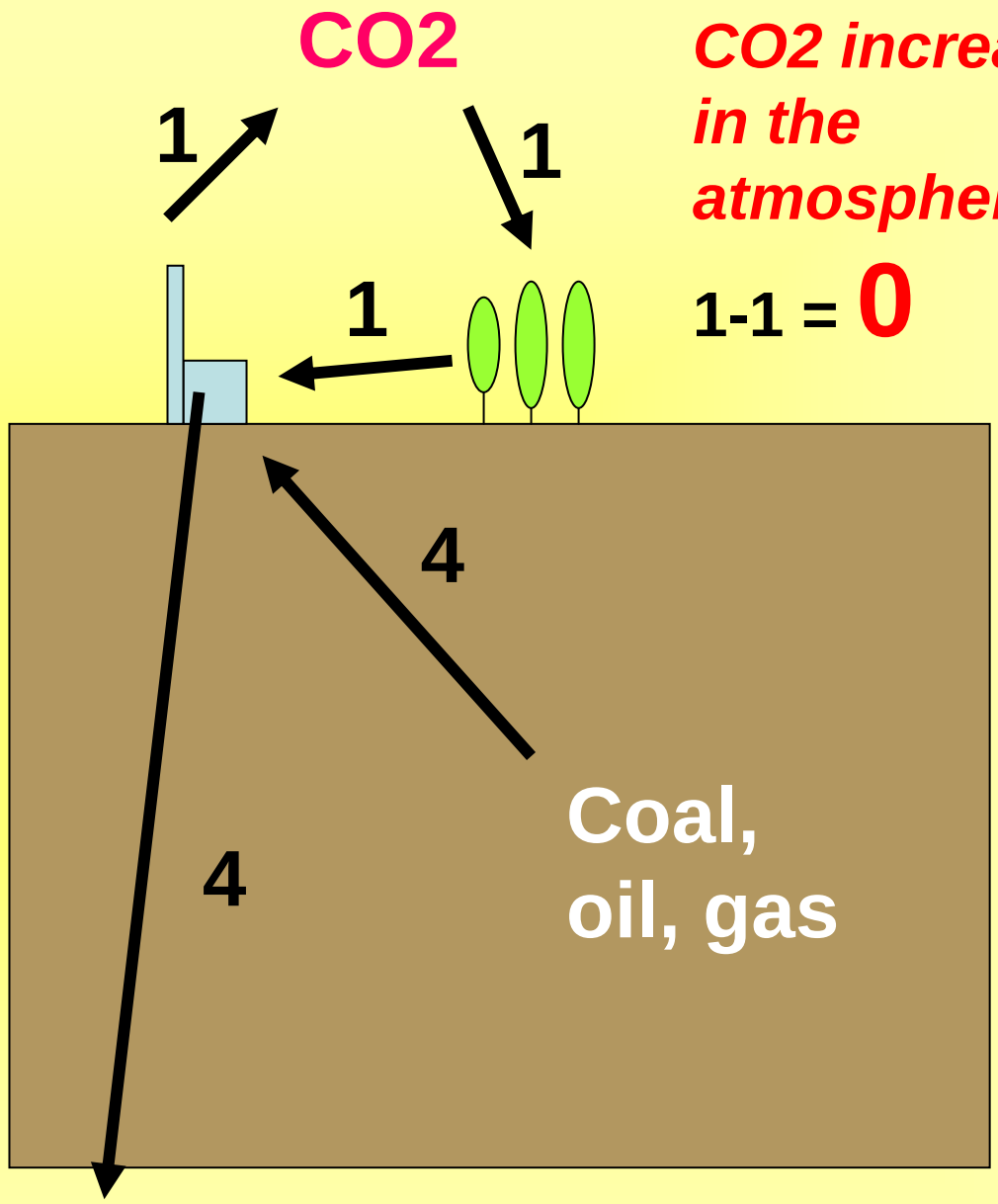


CO2 increase in the atmosphere:

1+1-1 = 1

Permanent storage of CO2

If we use CCS with 80% efficiency and use the forest with ”traditional” low intensity harvesting and silviculture.

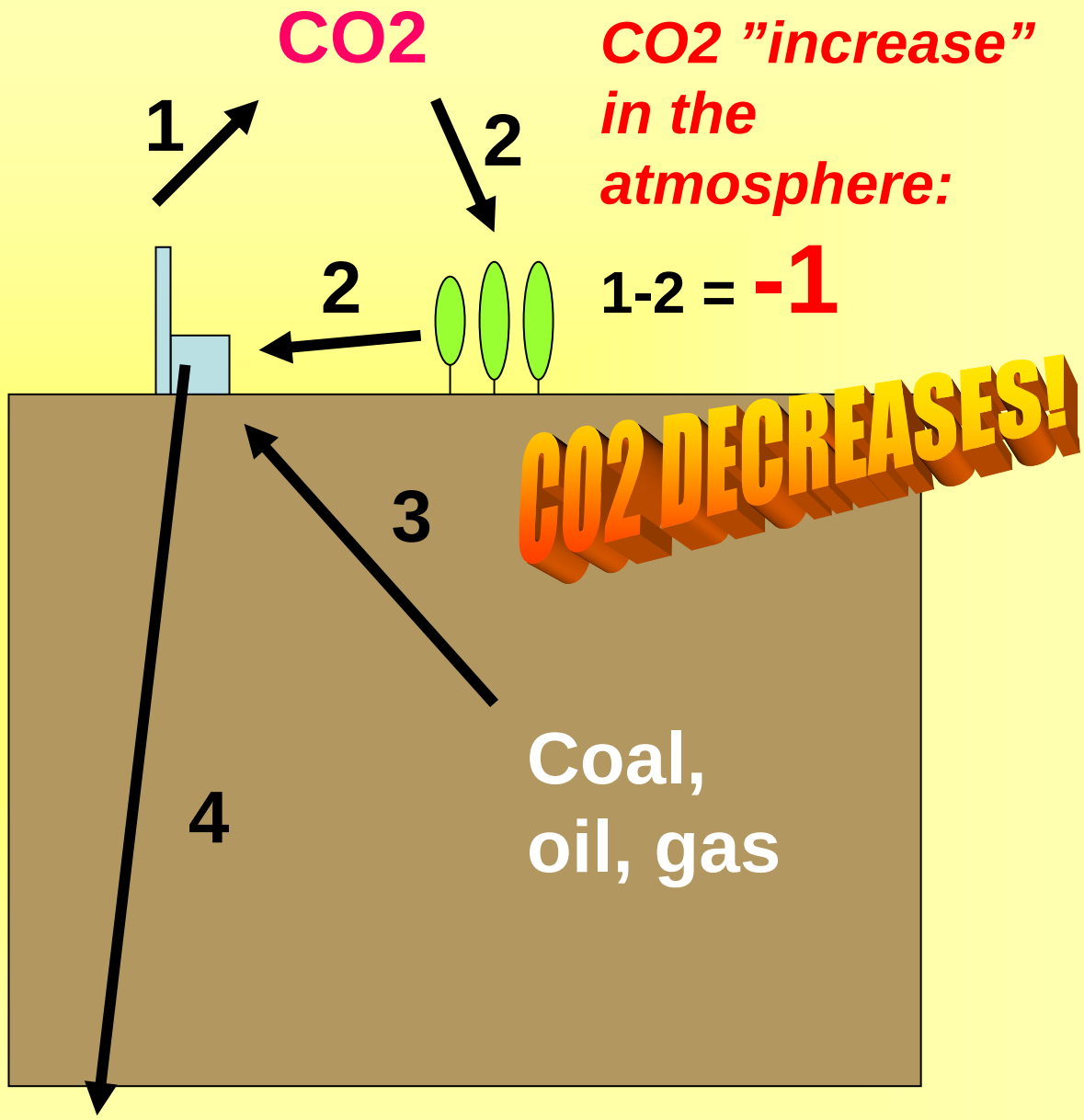


CO2 increase in the atmosphere:

1-1 = 0

Permanent storage of CO2

If we use CCS with 80% efficiency and use the forest with increased harvesting and high intensity silviculture.



CO2 "increase" in the atmosphere:

1-2 = -1

General conclusions:

- The best way to reduce the CO2 in the atmosphere may be to ***increase harvesting of the presently existing forests (!)***, to produce energy with CCS and to increase forest production in the new forest generations.

- ***We capture and store more CO2!***

#2. Optimal dynamic control of the forest resource with changing energy demand functions and valuation of CO2 storage

The optimal control derivations and the software are found here:

Lohmander, P., Optimal resource control model & General continuous time optimal control model of a forest resource, comparative dynamics and CO2 consideration effects, Seminar at SLU, Umea, Sweden, 2008-09-18

http://www.lohmander.com/CM/CMLohmander.ppt

Software:

http://www.lohmander.com/CM/CM.htm

Economic valuation of CO2 storage in the natural resource

Economic Valuation of the Production of Energy and Other Industrial Products

$$\max\left\{ J = \int_{t_1}^{t_2} e^{-rt}\left(\left(f_1 + f_2 t\right)x + \left(k_1 + k_2 t\right)u + k_3 u^2\right)dt \right\}$$

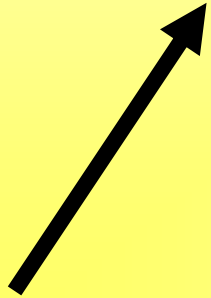
The Total Economic Result (Present Value)

The Stock Level

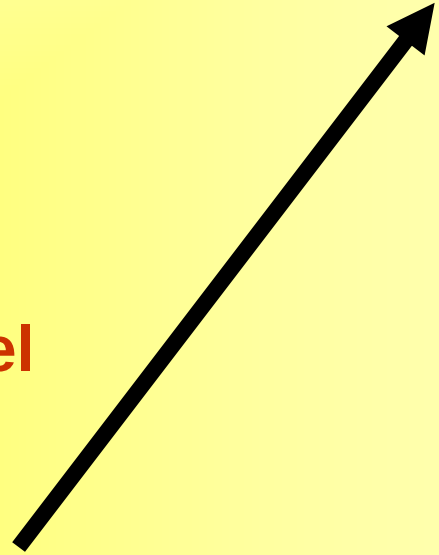
The "Control" Level

$$\dot{x} = f(x,u,t) \quad ; \quad x(t_1) = x_1, \quad x(t_2) = x_2$$

The change of the stock level during a marginal time interval

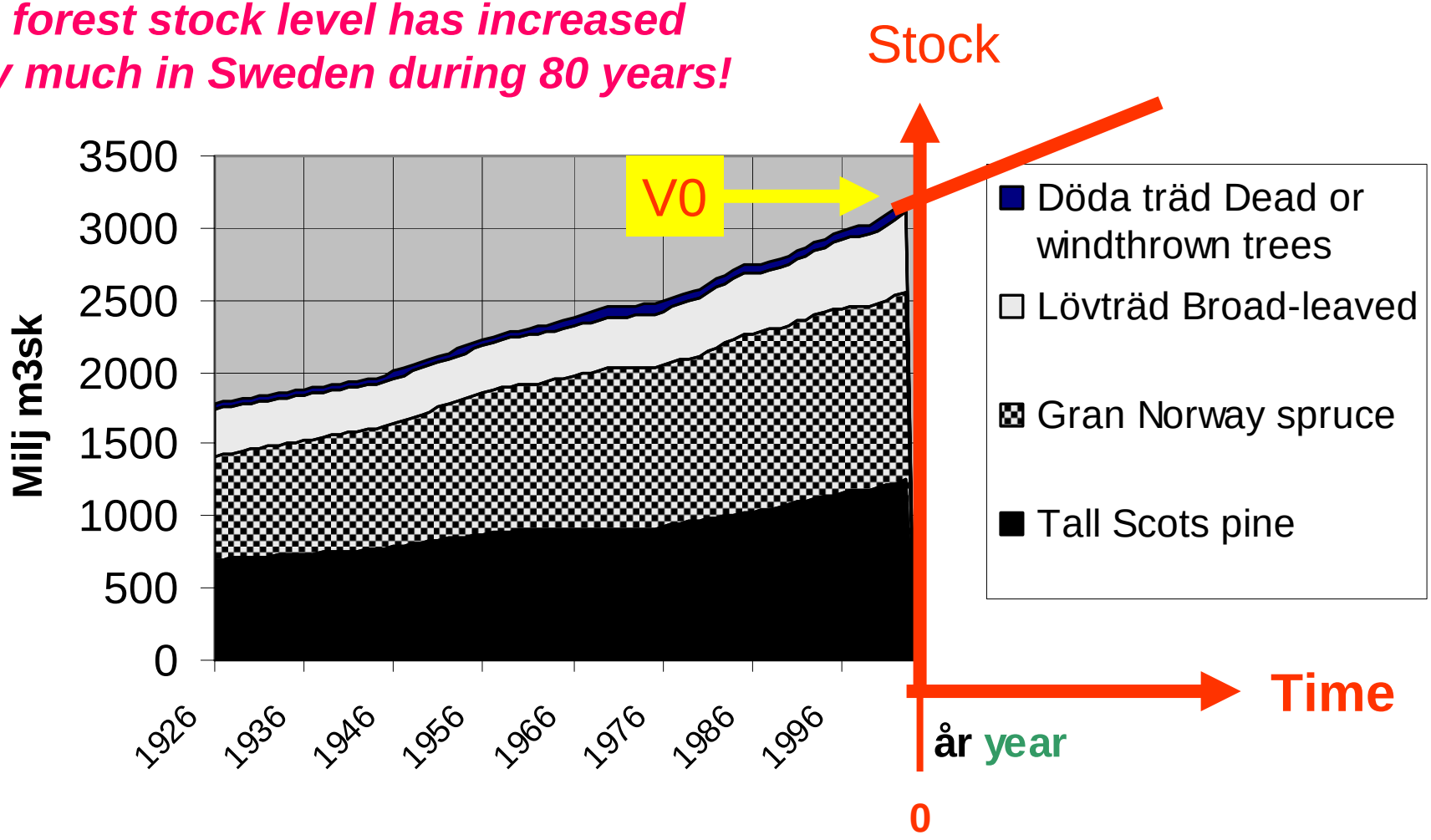


Initial stock level

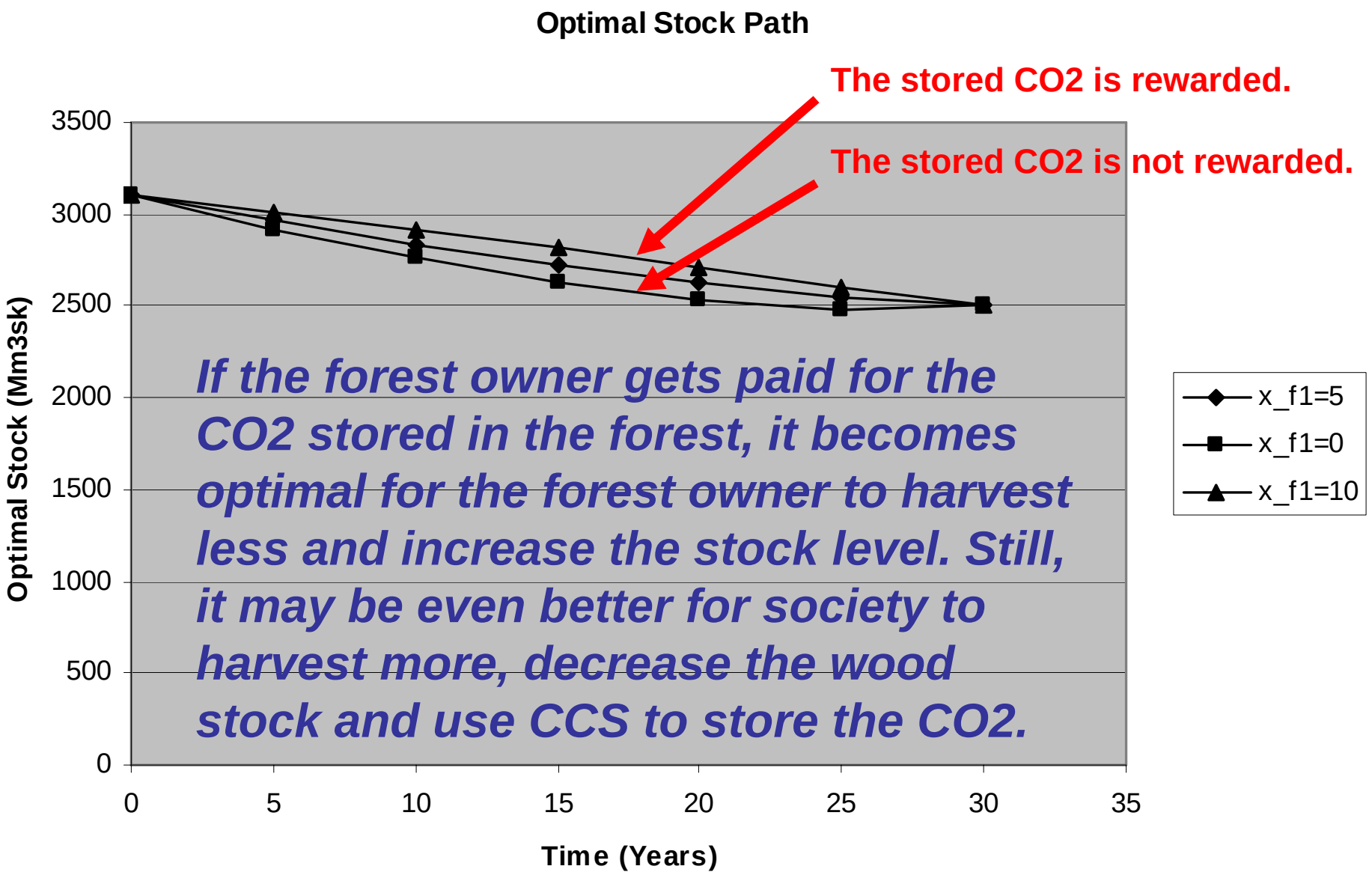


Terminal stock level

The forest stock level has increased very much in Sweden during 80 years!



1 Exkl. fjäll, fridlyst mark, militära impediment, bebyggd mark samt söt- och saltvatten.
Excl. high mountains, restricted military areas, urban land and water surfaces.
Milj. M3sk Millions cubic metre standing volume (stem volume over bark from stump to tip)


Optimal Stock Path
The stored CO2 is rewarded.
The stored CO2 is not rewarded.
If the forest owner gets paid for the CO2 stored in the forest, it becomes optimal for the forest owner to harvest less and increase the stock level. Still, it may be even better for society to harvest more, decrease the wood stock and use CCS to store the CO2.
Optimal Stock (Mm3sk)
3500
3000
2500
2000
1500
1000
500
0
0
5
10
15
20
25
30
35
Time (Years)
x_f1=5
x_f1=0
x_f1=10

#3. Optimal CCS, Carbon Capture and Storage, Under Risk

The stochastic optimal control derivations of CCS are found here:

- **Lohmander, P., Optimal CCS, Carbon Capture and Storage, Under Risk, *International Seminars in Life Sciences, Universidad Politécnica de Valencia, Thursday 2008-10-16***
- **http://www.Lohmander.com/OptCCS/OptCCS.ppt**

Optimal CCS, Carbon Capture and Storage, Under Risk

The objective function is the total present value of CO2 storage minus CCS costs.

$$\int_0^{\infty} e^{-rt}\left(k_1 u + k_2 u^2 + f_1 x + f_2 x^2\right) dt$$

Discounting factor

u = control = CCS level

x = The total storage level of CO2

The controlled storage

A stochastic differential equation:

$$dx = (u - Lx - S)\,dt + \sigma x\,dz$$

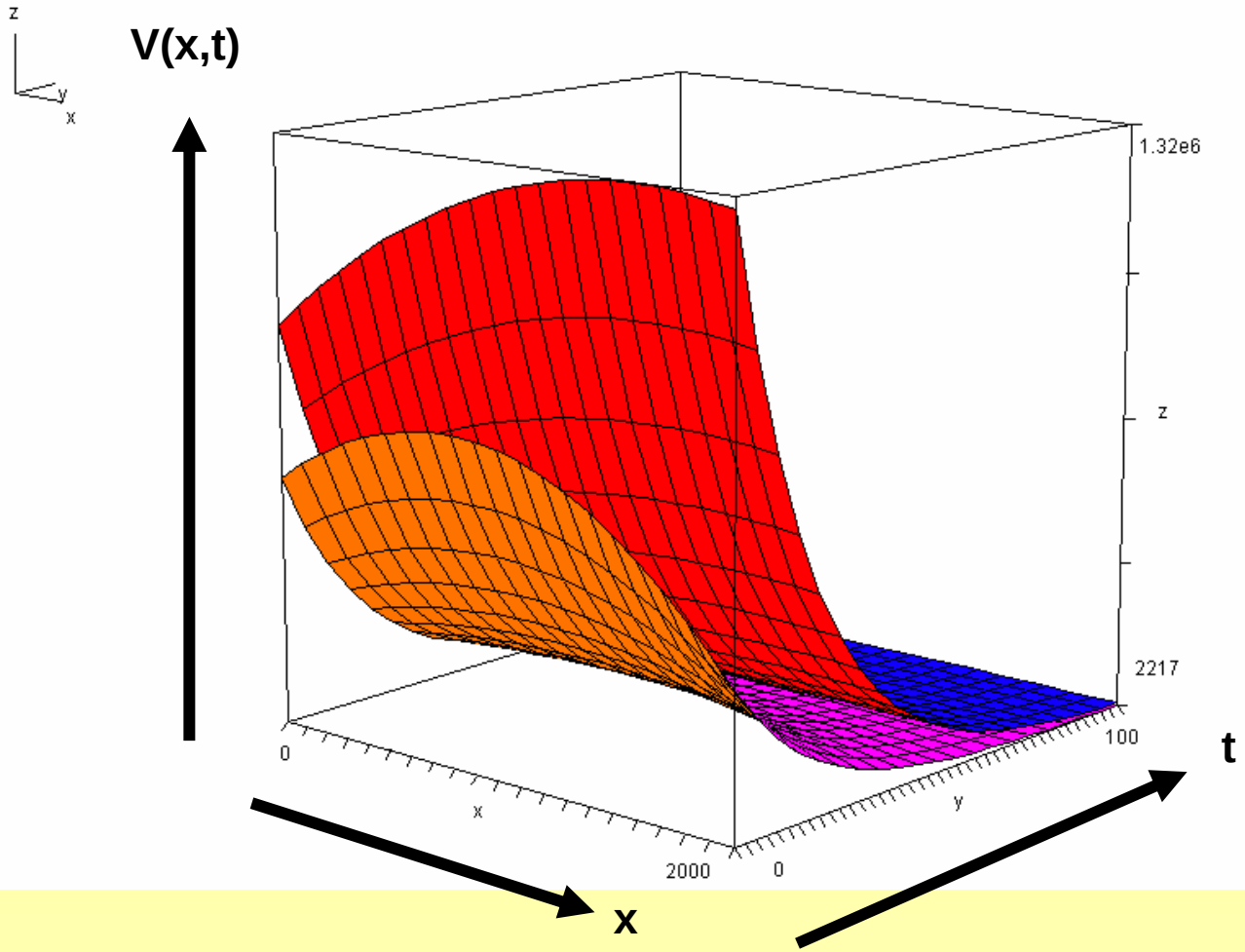
Change of the CO2 storage level.

Control = CCS level.

Expected CO2 leakage.

The CO2 storage level is to some extent affected by stochastic leakage and other stochastic events.
Z = standard Wiener process.

The optimal CCS objective function for different risk levels. The details are found in the reference.



#4. Conclusions

Optimal Forest management conclusions:

- **If the forest owner gets paid for the CO2 stored in the forest, it becomes optimal for the forest owner to harvest less and increase the stock level. Still, it may be even better for society to harvest more, decrease the present wood stock and use CCS to store the CO2.**
- **The best way to reduce the CO2 in the atmosphere may be to *increase harvesting of the presently existing forests (!)*, to produce energy with CCS and to increase forest production in the new forest generations.**

Optimal CCS Conclusions:

- **A mathematical approach to optimal CCS control has been developed that can handle risk.**
- **Possible leakage is an important issue that has to be carefully investigated in the future.**
- **It is important that the future management decisions are based on a decision model consistent with the structure of this model and that the parameter values are carefully estimated before practical management decisions are calculated.**

Future discussions:

Peter Lohmander is organizing the conference stream "Optimal Forest Management with Increasing Bioenergy Demand" within The 23rd European Conference on Operational Research (EURO XXIII), July 5-8, 2009, Bonn, Germany.

http://www.lohmander.com/Bonn2009/Bonn2009.pdf

Let us continue our discussions and meet there!

Thank you for listening!
Here you may reach me in the future:

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