Derivation of the principles of optimal expansion of bioenergy based on forest resources in combination with fossil fuels, CCS and combined heat and power production with consideration of economics and global warming

Lecture by Professor Dr. Peter Lohmander, Swedish University of Agricultural Sciences, SLU, Sweden,
http://www.Lohmander.com

Peter@Lohmander.com

Operations Research for the Future Forest Management,

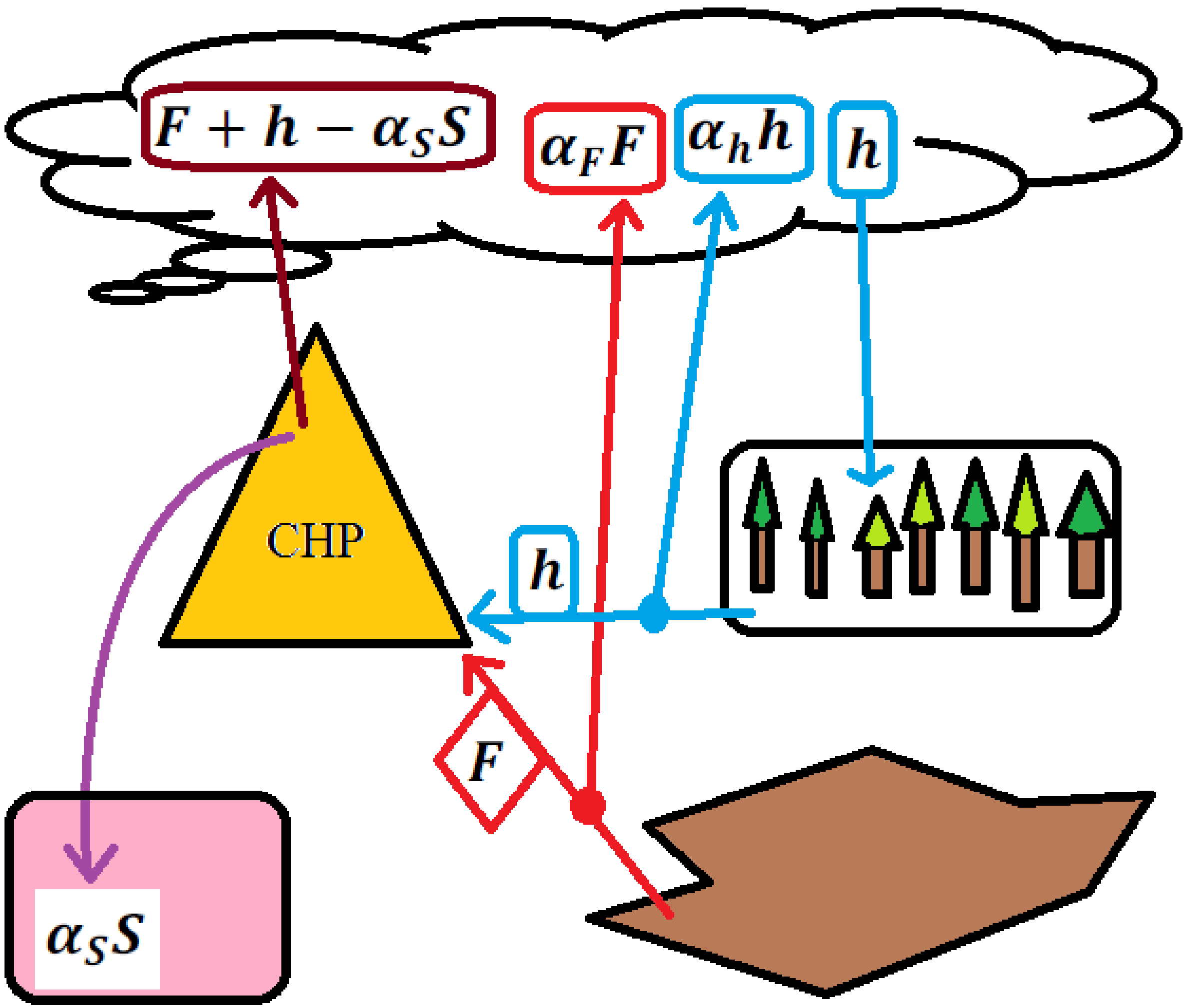
University of Guilan, Iran, March 8-12, 2014

Saturday March 8, 10.00-12.00

Derivation of the principles of optimal expansion of bioenergy based on forest resources in combination with fossil fuels, CCS and combined heat and power production with consideration of economics and global warming

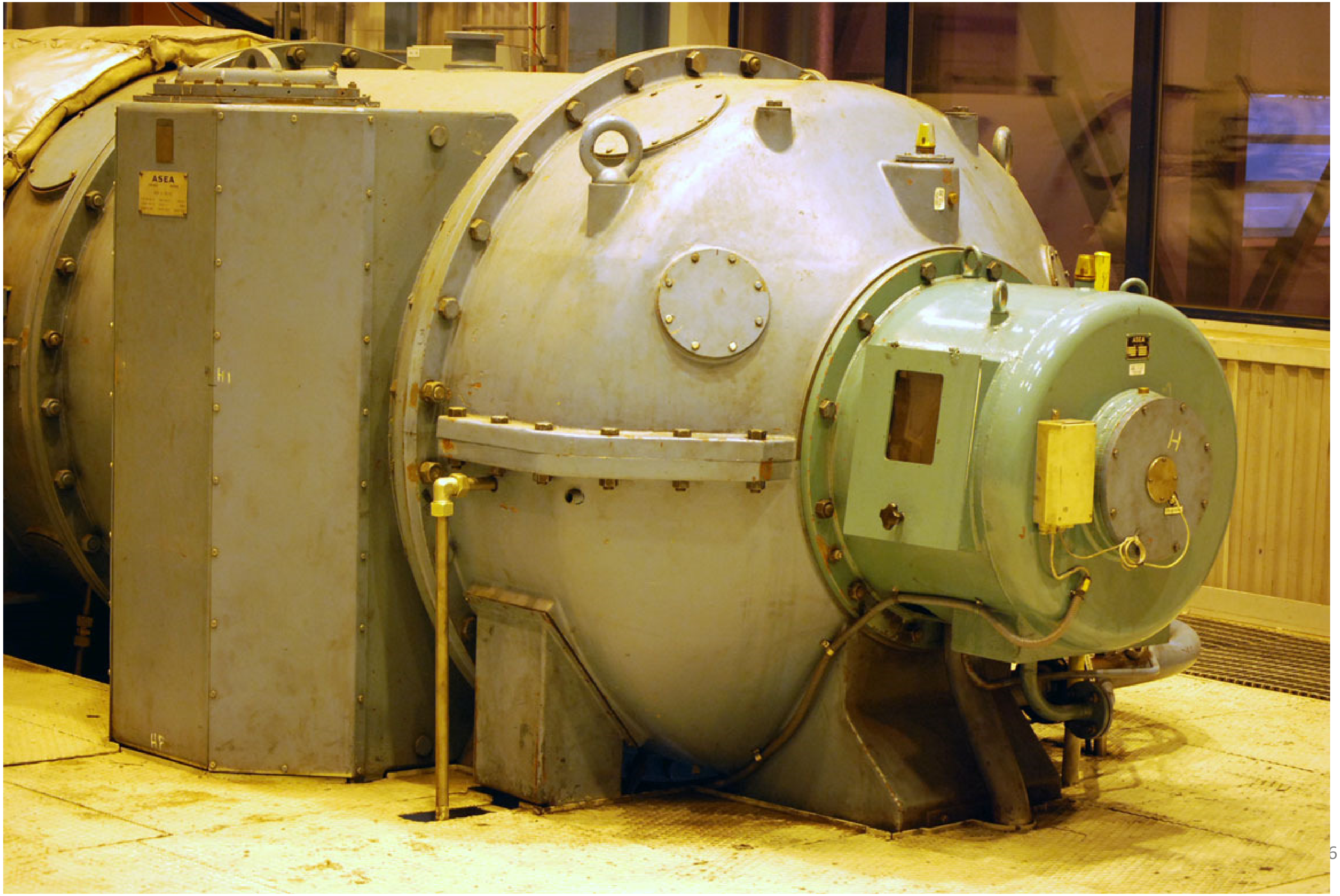
- In the production of district heating, electricity and many other energy outputs, we may use fossil fuels and renewable inputs, in different combinations. The optimal input mix is a function of technological options, prices of different inputs and costs of alternative levels of environmental consequences. Even with presently existing technology in combined heat and power plants, it is usually possible to reduce the amount of fossil fuels such as coal and strongly increase the level of forest based energy inputs. In large parts of the world, such as Russian Federation, forest stocks are close to dynamic equilibria, in the sense that the net growth (and net carbon uptake) is close to zero. If these forests will be partly harvested, the net growth can increase and a larger part of the CO_2 emitted from the CHP plants will be captured by the forests. Furthermore, with CCS, Carbon Capture and Storage, the rest of the emitted CO_2 can be permanently stored. The lecture incudes the definition of a general optimization model that can handle these problems in a consistent way. The model is used to derive general principles of optimal decisions in this problem area via comparative statics analysis with general functions.
- The lecture also includes case studies from different parts of the world. In several countries, it is presently profitable to replace coal by forest inputs in CHP plants. In Norway and UK, CCS has been applied and a commercially attractive option during many years and the physical potential is large. Carbon taxes on fossil fuels explain this development. With increasing carbon taxes in all parts of the world, such developments could be expected everywhere. With increasing levels of forest inputs in combination with CCS, it is possible to reduce the CO_2 in the atmosphere and the global warming problem can be managed. Furthermore, international trade in forest based energy can improve international relations, regional development and environmental conditions.

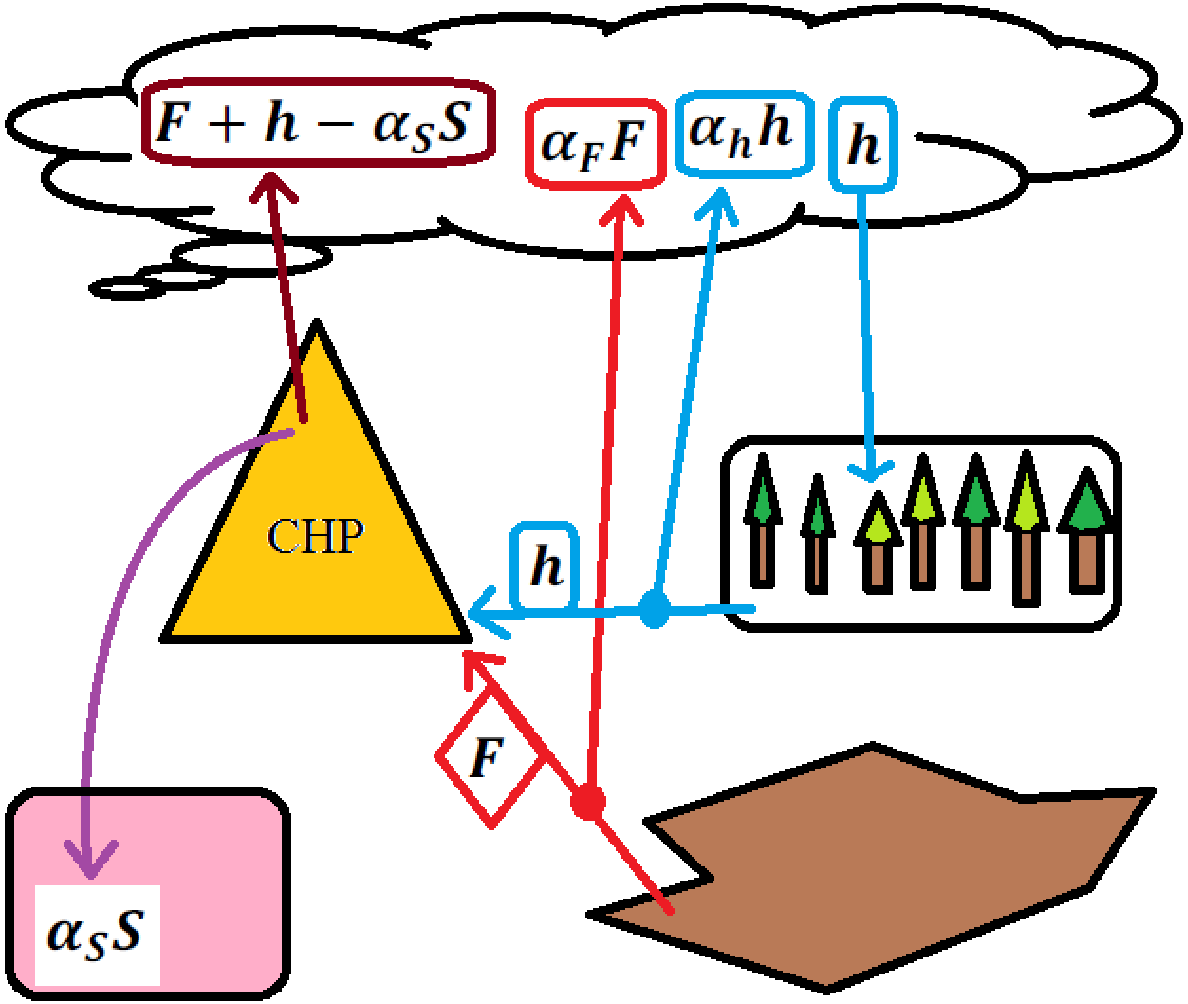
- Professor Dr. Peter Lohmander, Swedish University of Agricultural Sciences, SLU, Sweden, http://www.Lohmander.com Peter@Lohmander.com



The Lohmander Energy, Forest, Fossil Fuels, CCS and Climate System Optimization Model

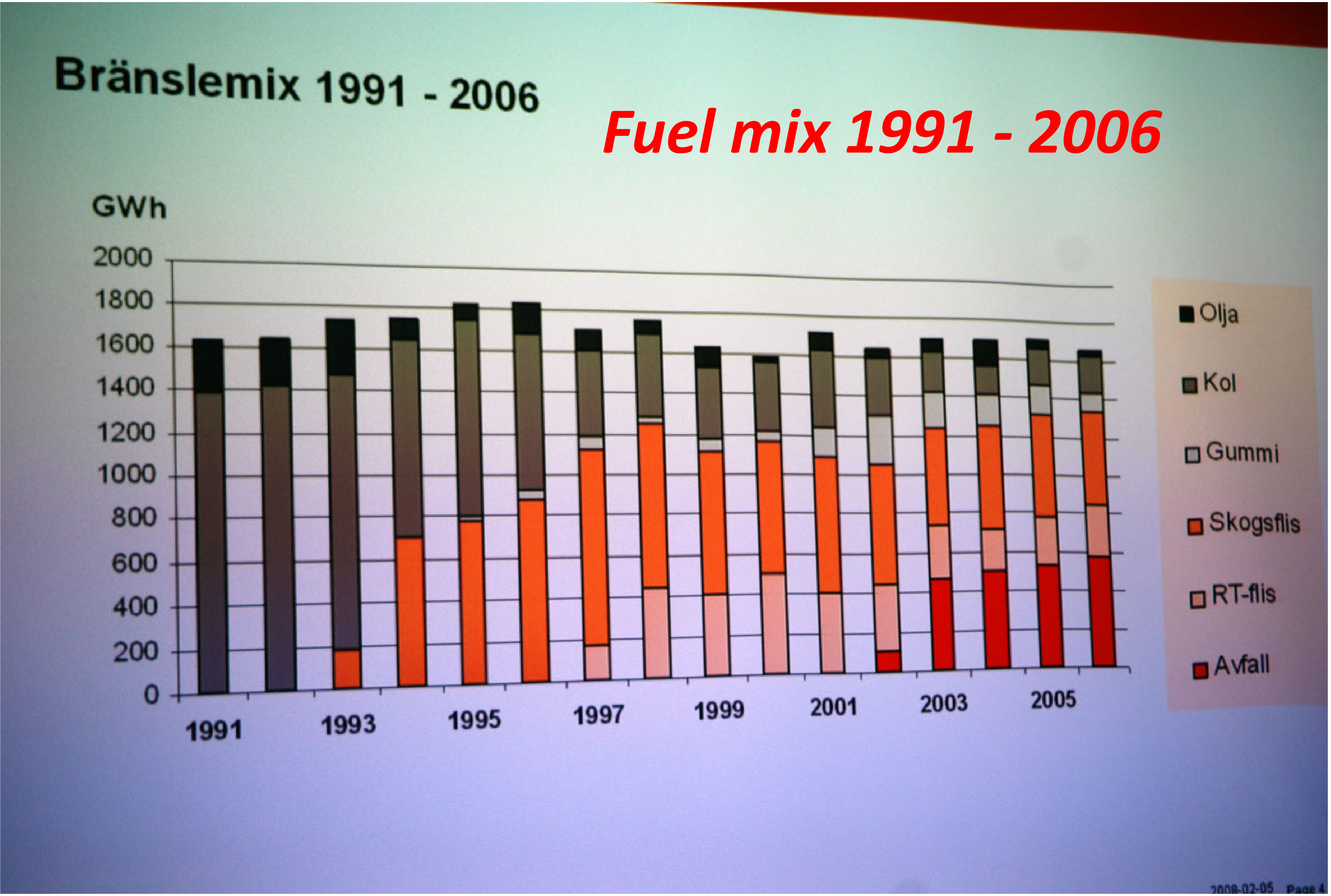

e.on
Händelö CHP
Norrköping, Sweden
Pictures by
Peter Lohmander
2008-12-11


ASEA



The Lohmander Energy, Forest, Fossil Fuels, CCS and Climate System Optimization Model


30
kraft



Oil (BLACK)

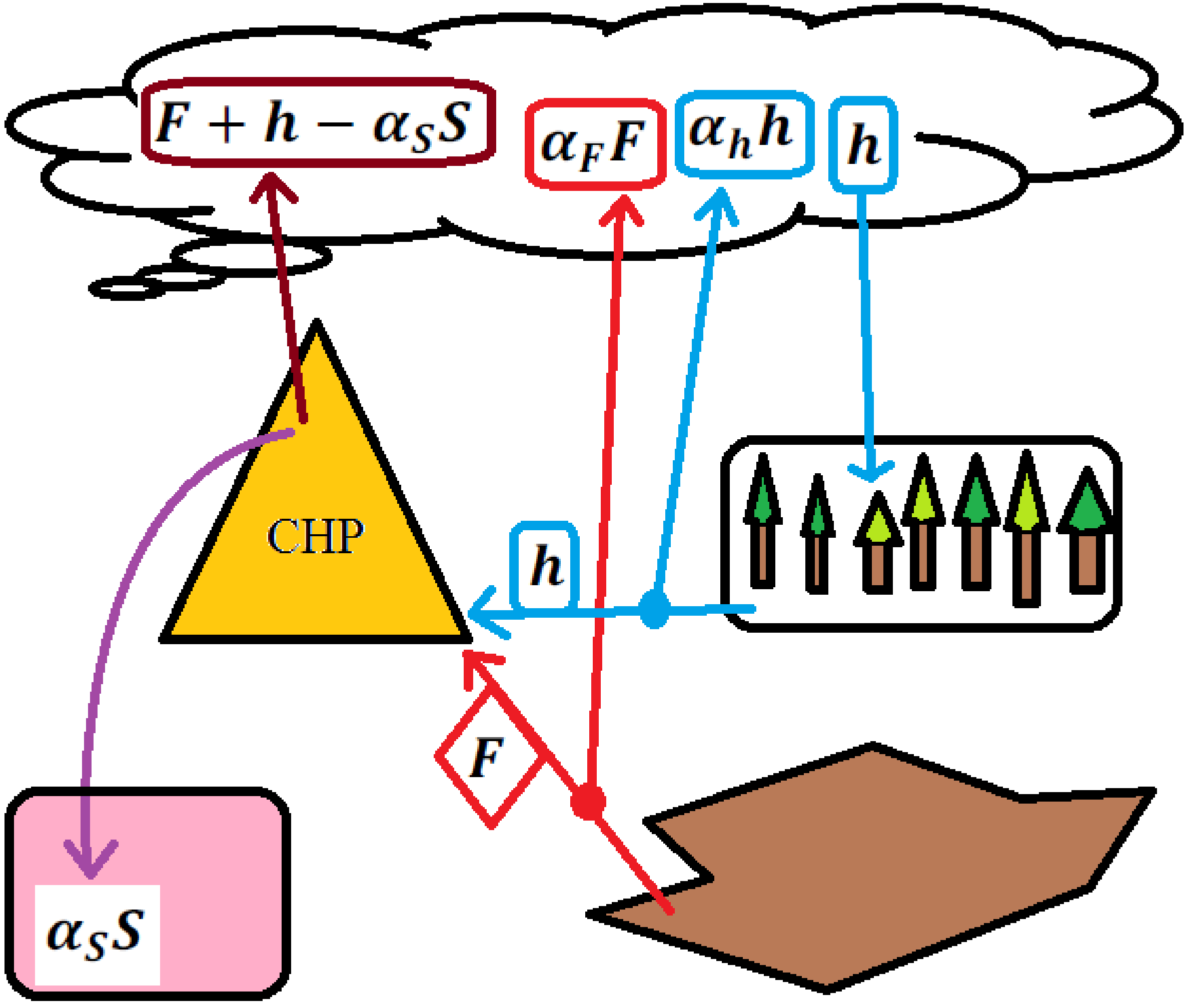
Coal (DARK GREY)

Ruber (LIGHT GREY)

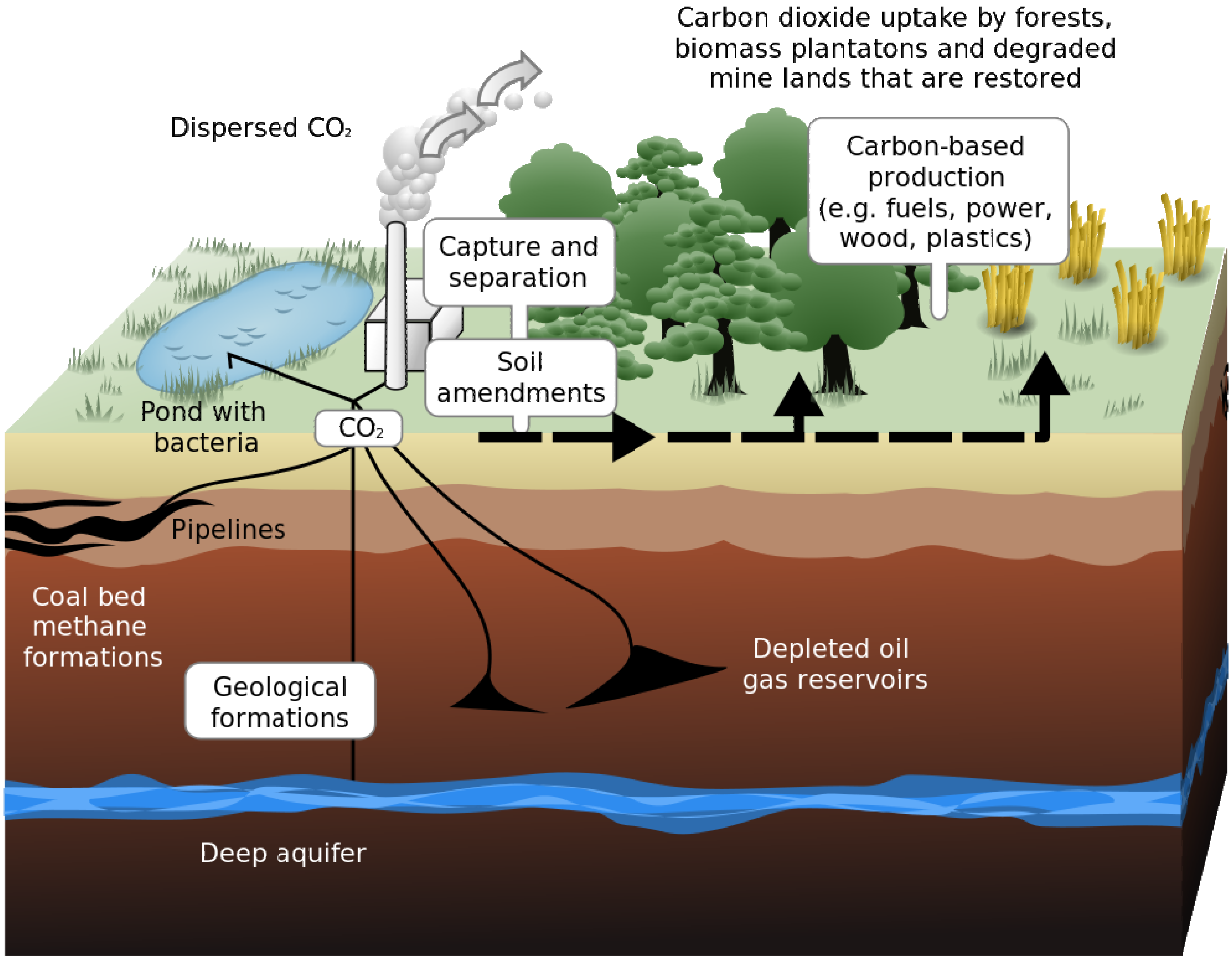
Forest chips (ORANGE)

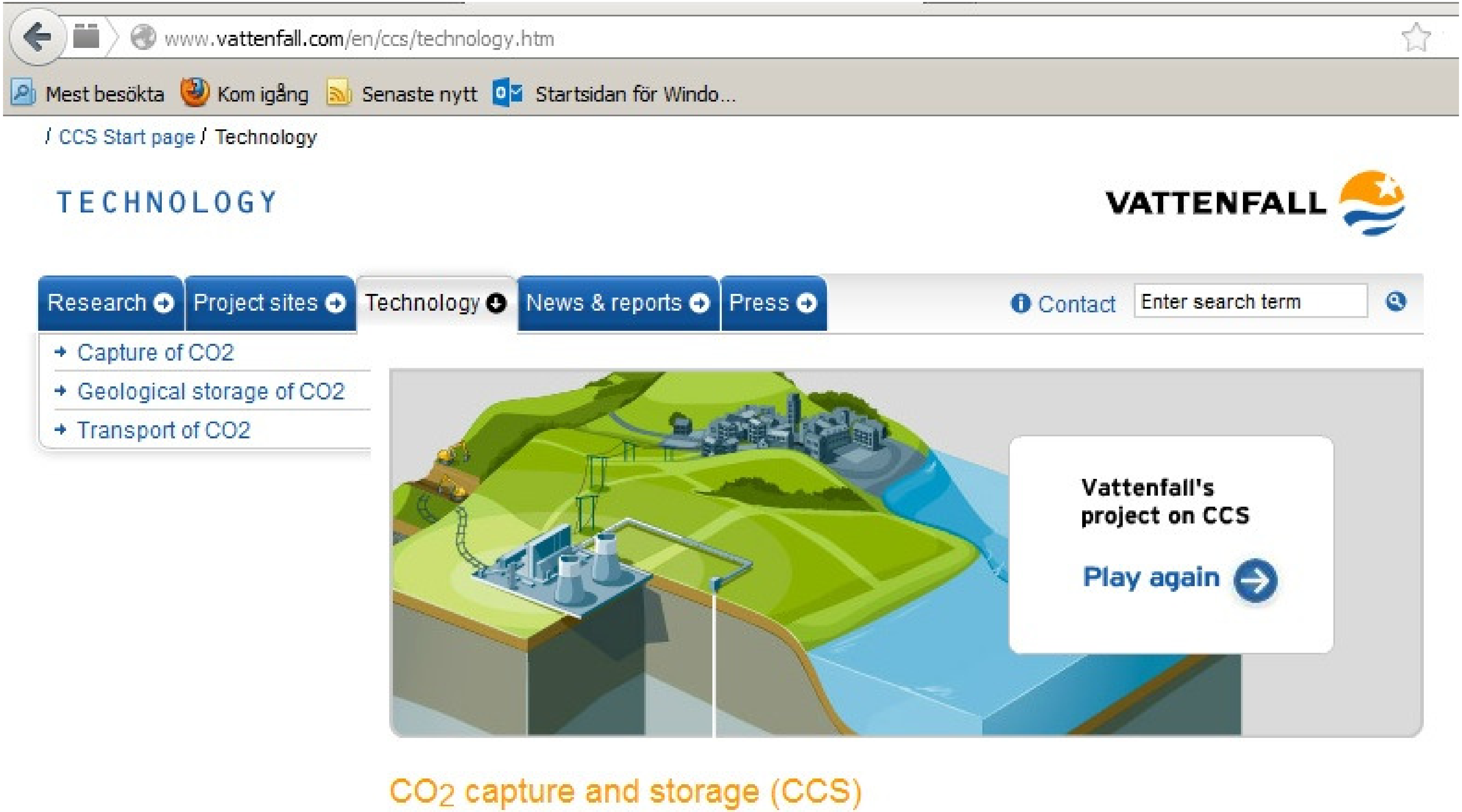
Waste wood (PINK)

Waste (RED)



The Lohmander Energy, Forest, Fossil Fuels, CCS and Climate System Optimization Model

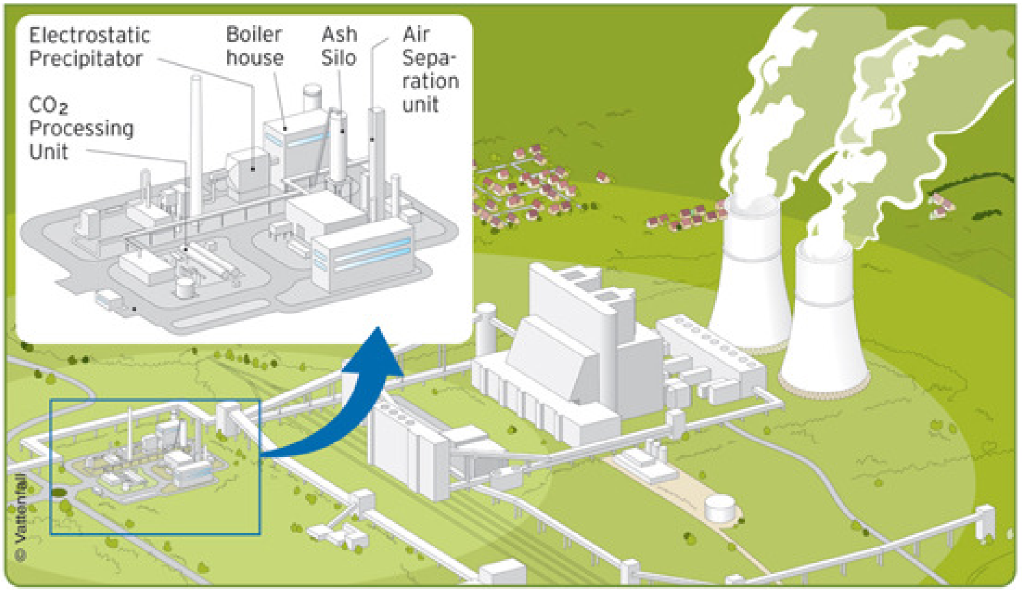

Carbon dioxide uptake by forests, biomass plantatons and degraded mine lands that are restored
Dispersed CO_2
Carbon-based production (e.g. fuels, power, wood, plastics)
Capture and separation
Soil amendments
Pond with bacteria
CO_2
Pipelines
Coal bed methane formations
Geological formations
Depleted oil gas reservoirs
Deep aquifer

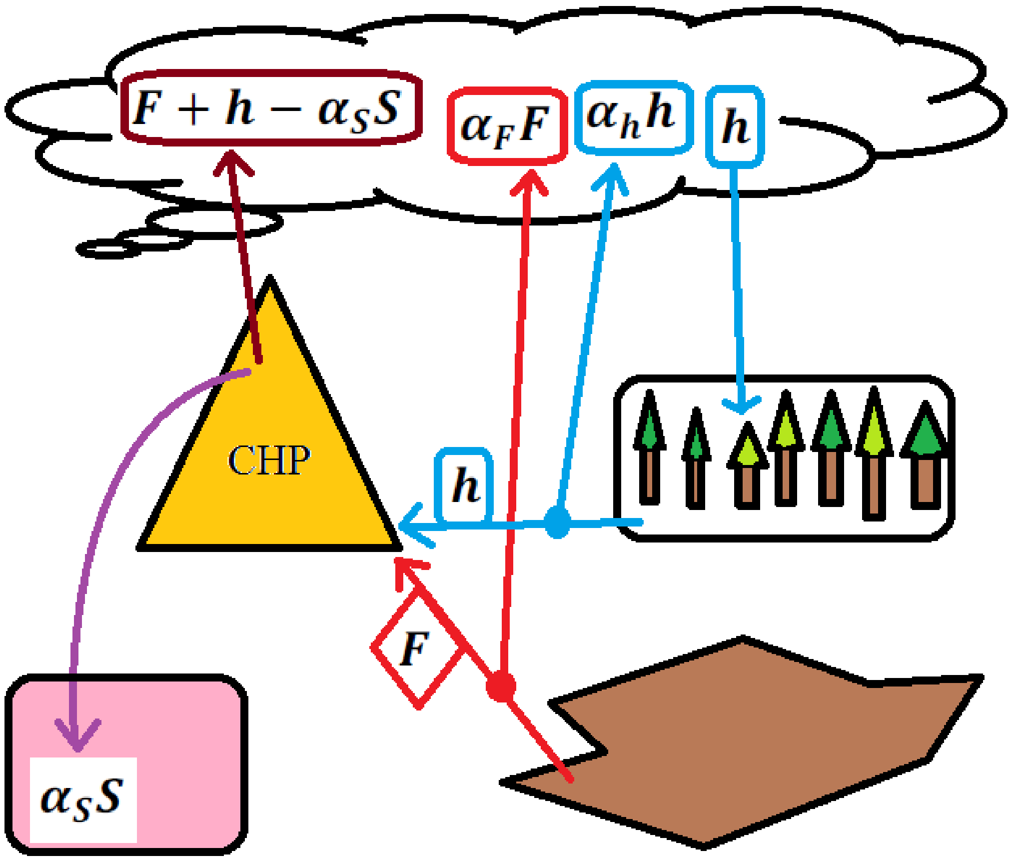

www.vattenfall.com/en/ccs/technology.htm
Mest besökta
Kom igång
Senaste nytt
Startsidan för Windo...
/ CCS Start page / Technology
TECHNOLOGY
VATTENFALL
Research
Project sites
Technology
News & reports
Press
Contact
Enter search term
Capture of CO2
Geological storage of CO2
Transport of CO2
Vattenfall's project on CCS
Play again
CO2 capture and storage (CCS)

Picture of the Oxyfuel pilot plant in Schwarze Pumpe - May 2008

Vattenfall and Carbon Capture and Storage

Carbon Capture and Storage - CCS - is the method of capturing carbon dioxide compressing it into liquid form and storing it deep underground in suitable geological formations.





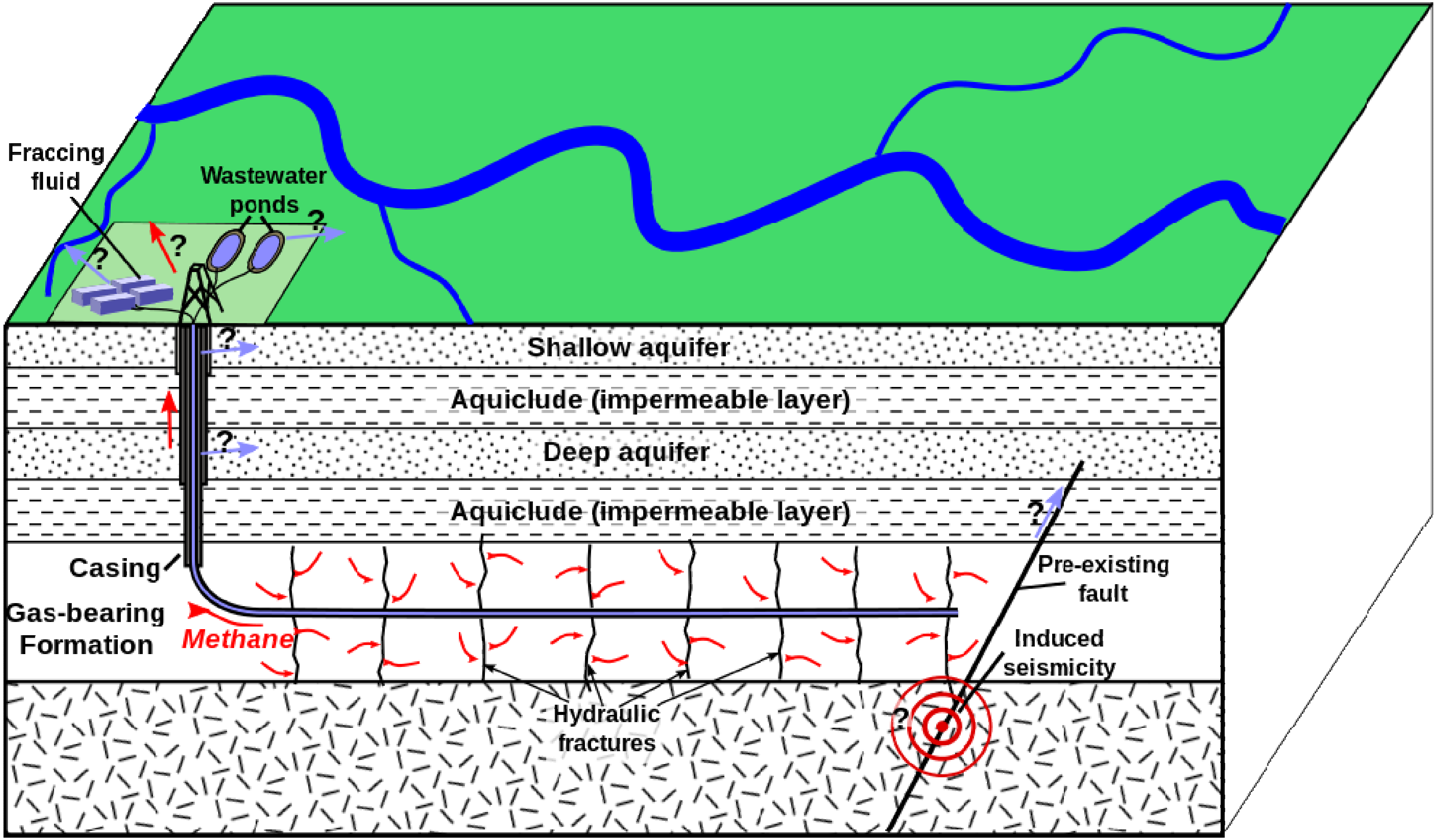
$$Max \quad Z \qquad = -k_\pi\big(C_F(F) + C_h(h) + C_S(S)\big) - k_G\big((1+\alpha_F)F + \alpha_h h - \alpha_S S\big)$$

s.t. $\quad F + h \geq M$

The model does not include absolute constraints on the availability of fossil fuels.

Motive:
Such constraints are assumed not to be binding in the optimal total solution.

Hydraulic fracturing also called fracturing and fracking has recently shown that there are very large quantitites of fossil fuels available in the world.


Fraccing fluid
Wastewater ponds
?
Shallow aquifer
Aquiclude (impermeable layer)
Deep aquifer
Aquiclude (impermeable layer)
Casing
Gas-bearing Formation
Methane
Pre-existing fault
Induced seismicity
Hydraulic fractures

Analysis:

$$Max\ Z = -k_{\pi}\left(C_F(F) + C_h(h) + C_S(S)\right) - k_G\left((1+\alpha_F)F + \alpha_h h - \alpha_S S\right)$$

s.t.

$$F + h \geq M$$

Parameter assumptions:

$$k_\pi > 0$$

$$k_G > 0$$

$$\alpha_F > 0$$

$$\alpha_h > 0$$

$$0 < \alpha_S < 1$$

$$\alpha_h < 1 + \alpha_F$$

This constraint is not binding:

$$S < F + h$$

Cost function assumptions:

$$C_F' > 0$$

$$C_F'' > 0$$

$$C_h' > 0$$

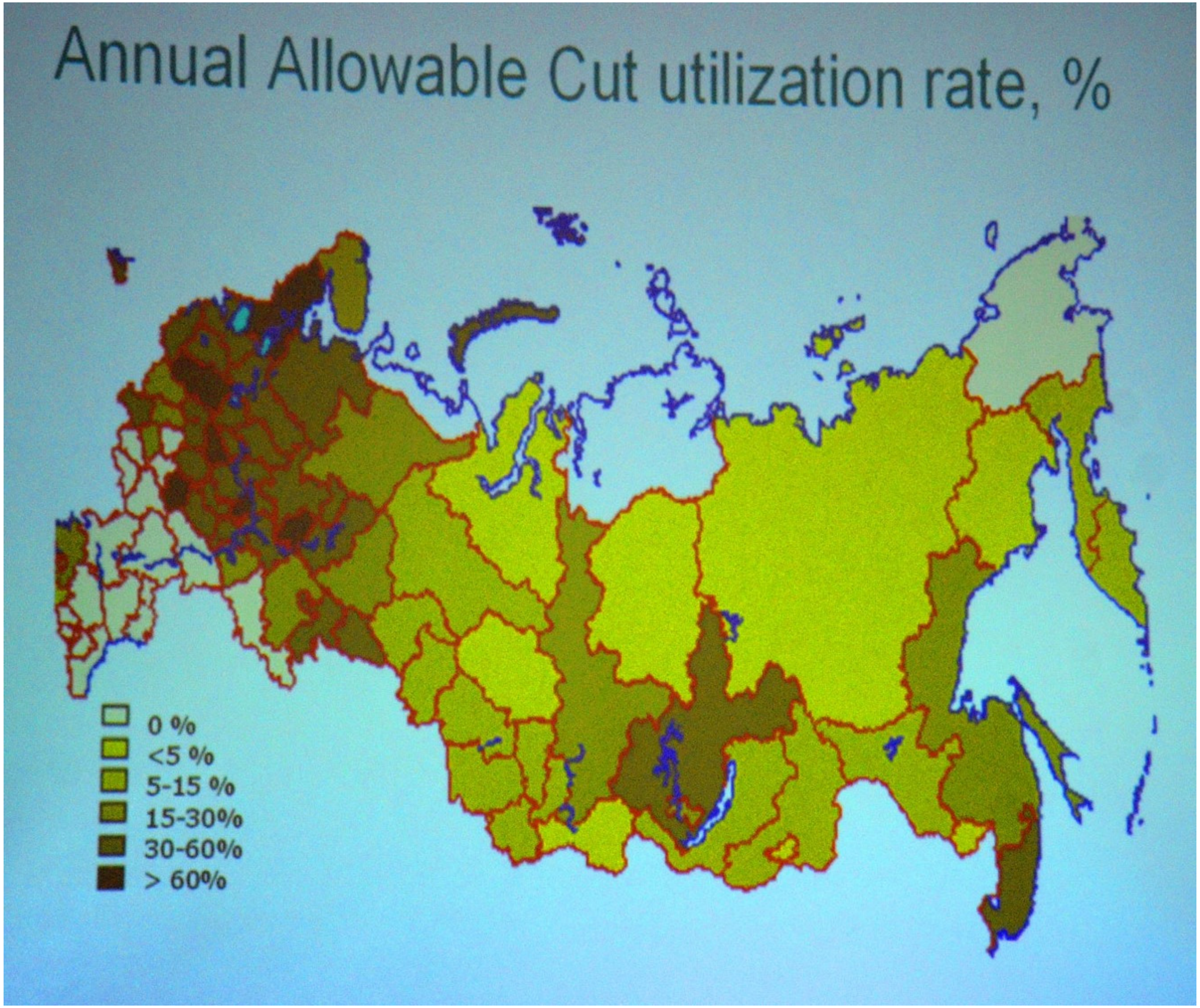
$$C_h'' > 0$$

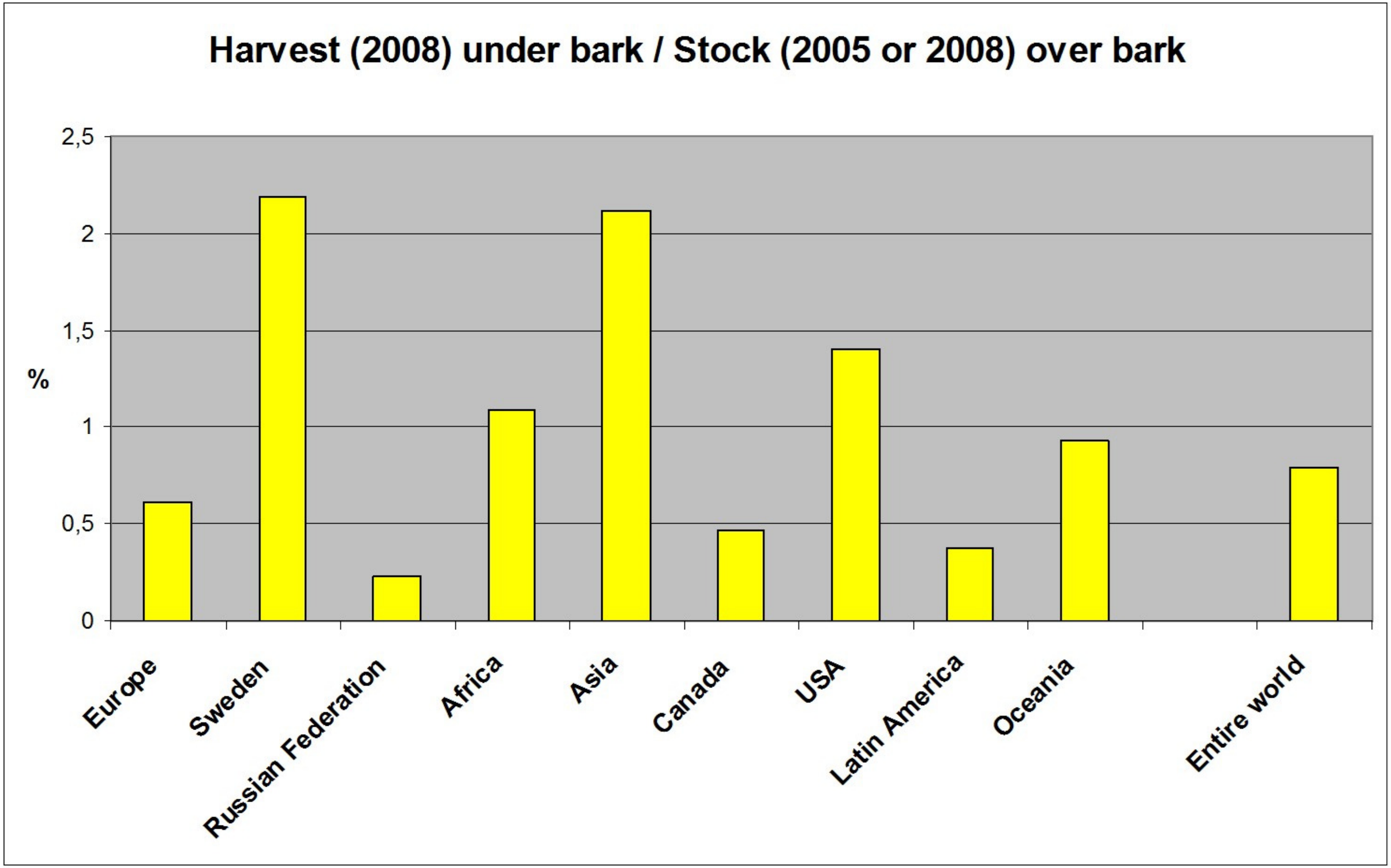
$$C_S' > 0$$

$$C_S'' > 0$$


Arctic Ocean


ЛЕСОТЕХНИЧЕСКАЯ АКАДЕМИЯ


Annual Allowable Cut utilization rate, %
0 %
<5 %
5-15 %
15-30%
30-60%
> 60%


Harvest (2008) under bark / Stock (2005 or 2008) over bark
%
2,5
2
1,5
1
0,5
0
Europe
Sweden
Russian Federation
Africa
Asia
Canada
USA
Latin America
Oceania
Entire world

The classical dynamic natural resource model:

$$\frac{dx}{dt} = sx\left(1 - \frac{x}{K}\right)$$

$$x(t) = \frac{K}{1 + Ce^{-st}}$$

$$\lim_{\substack{t \to \infty \\ (s>0)}} x(t) = K$$

$$\frac{dx}{dt} = \frac{KsCe^{-st}}{(1 + Ce^{-st})^2}$$

$$\lim_{\substack{t \to \infty \\ (s>0)}} \left(\frac{dx}{dt} \right) = 0$$

Such forests do not change the carbon levels of the atmosphere.

The Lagrange function, L, is:

$$= -k_{\pi}\Big(C_F(F) + C_h(h) + C_S(S)\Big)$$
$$- k_G\Big((1 + \alpha_F)F + \alpha_h h - \alpha_S S\Big)$$
$$+\lambda(F + h - M)$$

The Kuhn Tucker conditions are:

$$\boldsymbol{F \geq 0; h \geq 0; S \geq 0}$$

$$\boldsymbol{\frac{dL}{dF} \leq 0;\ \frac{dL}{dh} \leq 0; \frac{dL}{dS} \leq 0}$$

$$\boldsymbol{F\frac{dL}{dF} = 0; h\frac{dL}{dh} = 0; S\frac{dL}{dS} = 0}$$

$$\boldsymbol{\lambda \geq 0}$$

$$\boldsymbol{\frac{dL}{d\lambda} \geq 0}$$

$$\boldsymbol{\lambda\frac{dL}{d\lambda} = 0}$$

Here, we have four of the constraints:

$$\frac{dL}{d\lambda} = F + h - M \geq 0$$

$$\frac{dL}{dF} = -k_\pi C'_F(F) - k_G(1 + \alpha_F) + \lambda \leq 0$$

$$\frac{dL}{dh} = -k_\pi C'_h(h) - k_G \alpha_h + \lambda \leq 0$$

$$\frac{dL}{dS} = -k_\pi C'_S(S) + k_G \alpha_S \leq 0$$

Assumption:

The optimal solution is an interior solution.

$$F > 0; h > 0; S > 0; \lambda > 0$$

As a consequence, we know that:

$$\frac{dL}{d\lambda} = 0; \frac{dL}{dF} = 0; \frac{dL}{dh} = 0; \frac{dL}{dS} = 0$$

This means that the following equation system should be solved:

$$\frac{dL}{d\lambda} = F + h - M = 0$$

$$\frac{dL}{dF} = -k_\pi C_F'(F) - k_G(1 + \alpha_F) + \lambda = 0$$

$$\frac{dL}{dh} = -k_\pi C_h'(h) - k_G \alpha_h + \lambda = 0$$

$$\frac{dL}{dS} = -k_\pi C_S'(S) + k_G \alpha_S = 0$$

The system with four equations and four endogenous variables is partly separable.

It may be split into one system with tree equations and three endogenous variables $(F, h \text{ } and \text{ } \lambda)$ and a separate equation with only one endogenous variable, S .

Stars denote optimal values.

First, we investigate S^* .

$$\frac{dL}{dS} = -k_\pi C'_S(S) + k_G \alpha_S \leq 0$$

$$\left(\frac{dL}{dS} = 0\right) \Rightarrow \left(C'_S(S) = \frac{k_G \alpha_S}{k_\pi}\right)$$

We differentiate the first order optimum condition:

$$-k_\pi C_S''(S)dS^* - C_S'(S)dk_\pi + \alpha_S dk_G + k_G d\alpha_S = 0$$

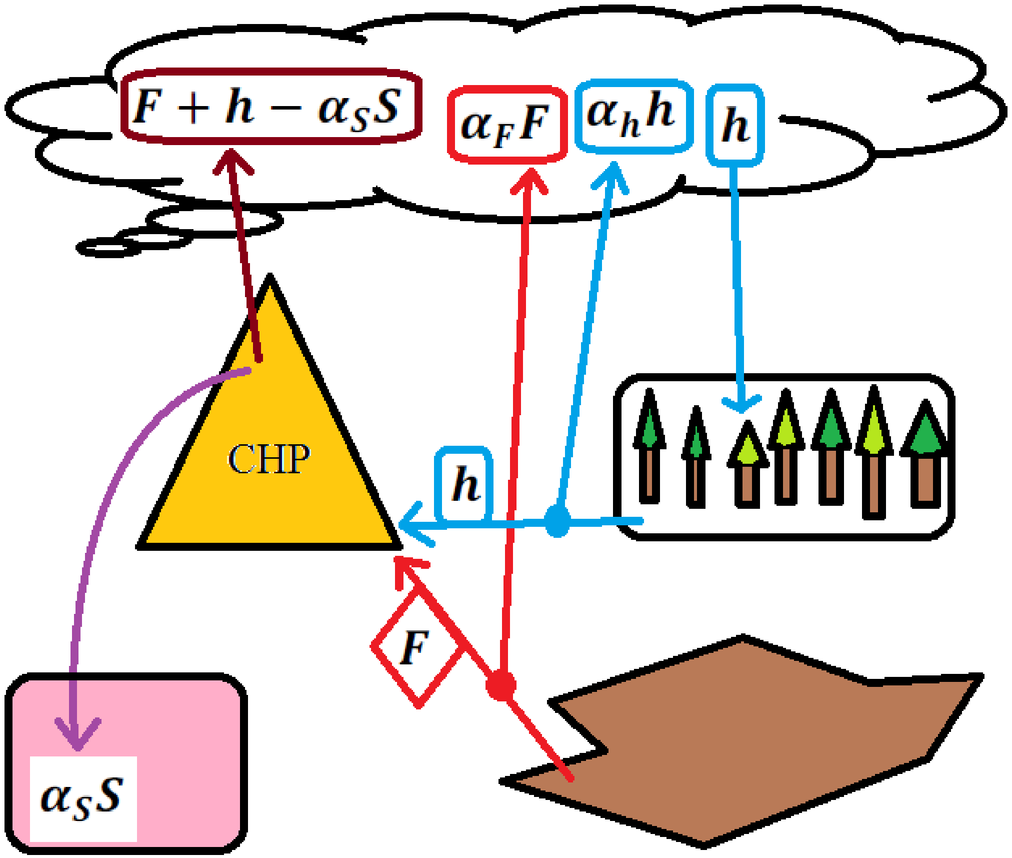
$$dS^* = \frac{1}{k_\pi C_S''(S)}\left(-C_S'(S)dk_\pi + \alpha_S dk_G + k_G d\alpha_S\right)$$

The derivatives of S^* with respect to the parameters are the following:

$$\frac{dS^*}{dk_\pi} = \frac{-C'_S(S)}{k_\pi C''_S(S)} < 0$$

$$\frac{dS^*}{dk_G} = \frac{\alpha_S}{k_\pi C''_S(S)} > 0$$

$$\frac{dS^*}{d\alpha_S} = \frac{k_G}{k_\pi C''_S(S)} > 0$$



$$\frac{dS^*}{dk_\pi} = \frac{-C_S'(S)}{k_\pi C_S''(S)} < 0$$

$$\frac{dS^*}{dk_G} = \frac{\alpha_S}{k_\pi C_S''(S)} > 0$$

$$\frac{dS^*}{d\alpha_S} = \frac{k_G}{k_\pi C_S''(S)} > 0$$

$$Max \quad Z = -k_\pi\big(C_F(F) + C_h(h) + C_S(S)\big) - k_G\big((1+\alpha_F)F + \alpha_h h - \alpha_S S\big)$$

s.t. $\quad F + h \geq M$

Next, we investigate $F^*, h^*\, and\ \lambda^*$.

The first order optimum conditions are found from this three dimensional equation system:

$$\frac{dL}{d\lambda} = F + h - M = 0$$

$$\frac{dL}{dF} = -k_\pi C'_F(F) - k_G(1 + \alpha_F) + \lambda = 0$$

$$\frac{dL}{dh} = -k_\pi C'_h(h) - k_G \alpha_h + \lambda = 0$$

We differentiate the equations:

$$\begin{bmatrix} 1 & 1 & 0 \\ -k_\pi C_F'' & 0 & 1 \\ 0 & -k_\pi C_h'' & 1 \end{bmatrix} \begin{bmatrix} dF^* \\ dh^* \\ d\lambda^* \end{bmatrix} = \begin{bmatrix} dM \\ C_F' dk_\pi + (1+\alpha_F) dk_G + k_G d\alpha_F \\ C_h' dk_\pi + \alpha_h dk_G + k_G d\alpha_h \end{bmatrix}$$

When we apply Cramer's rule, we need to know $|D|$.

$$|D| = \begin{vmatrix} 1 & 1 & 0 \\ -k_{\pi}C_F'' & 0 & 1 \\ 0 & -k_{\pi}C_h'' & 1 \end{vmatrix}$$

$$|D| = k_{\pi}(C_h'' + C_F'') > 0$$

The derivatives of F^*, h^* *and* λ^* with respect to M are determined via Cramer's rule:

$$\frac{dF^*}{dM} = \frac{\begin{vmatrix} 1 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & -k_\pi C_h'' & 1 \end{vmatrix}}{|D|}$$

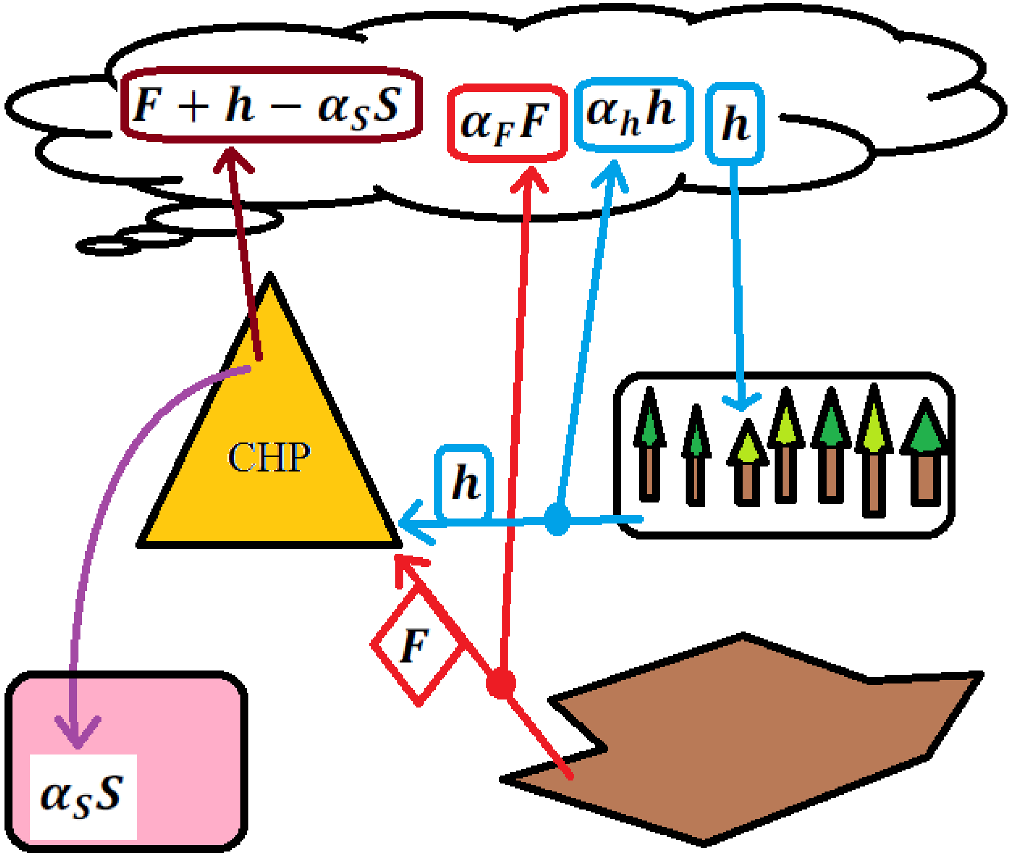
$$\frac{dF^*}{dM} = \frac{C_h''}{C_h'' + C_F''} > 0$$

$$\frac{dh^*}{dM} = \frac{\begin{vmatrix} 1 & 1 & 0 \\ -k_\pi C_F'' & 0 & 1 \\ 0 & 0 & 1 \end{vmatrix}}{|D|}$$

$$\frac{dh^*}{dM} = \frac{C_F''}{C_h'' + C_F''} > 0$$

$$\frac{d\lambda^*}{dM} = \frac{\begin{vmatrix} 1 & 1 & 1 \\ -k_\pi C_F'' & 0 & 0 \\ 0 & -k_\pi C_h'' & 0 \end{vmatrix}}{|D|}$$

$$\frac{d\lambda^*}{dM} = \frac{k_\pi C_F'' C_h''}{C_h'' + C_F''} > 0$$



$$\frac{dF^*}{dM} = \frac{C_h''}{C_h'' + C_F''} > 0$$

$$\frac{dh^*}{dM} = \frac{C_F''}{C_h'' + C_F''} > 0$$

$$\frac{d\lambda^*}{dM} = \frac{k_\pi C_F'' C_h''}{C_h'' + C_F''} > 0$$

$$Max \quad Z = -k_\pi\big(C_F(F) + C_h(h) + C_S(S)\big) - k_G\big((1+\alpha_F)F + \alpha_h h - \alpha_S S\big)$$

s.t. $\quad F + h \geq M$

The derivatives of F^*, h^* *and* λ^* with respect to k_G are:

$$\frac{dF^*}{dk_G} = \frac{\begin{vmatrix} 0 & 1 & 0 \\ (1+\alpha_F) & 0 & 1 \\ \alpha_h & -k_\pi C_h'' & 1 \end{vmatrix}}{|D|}$$

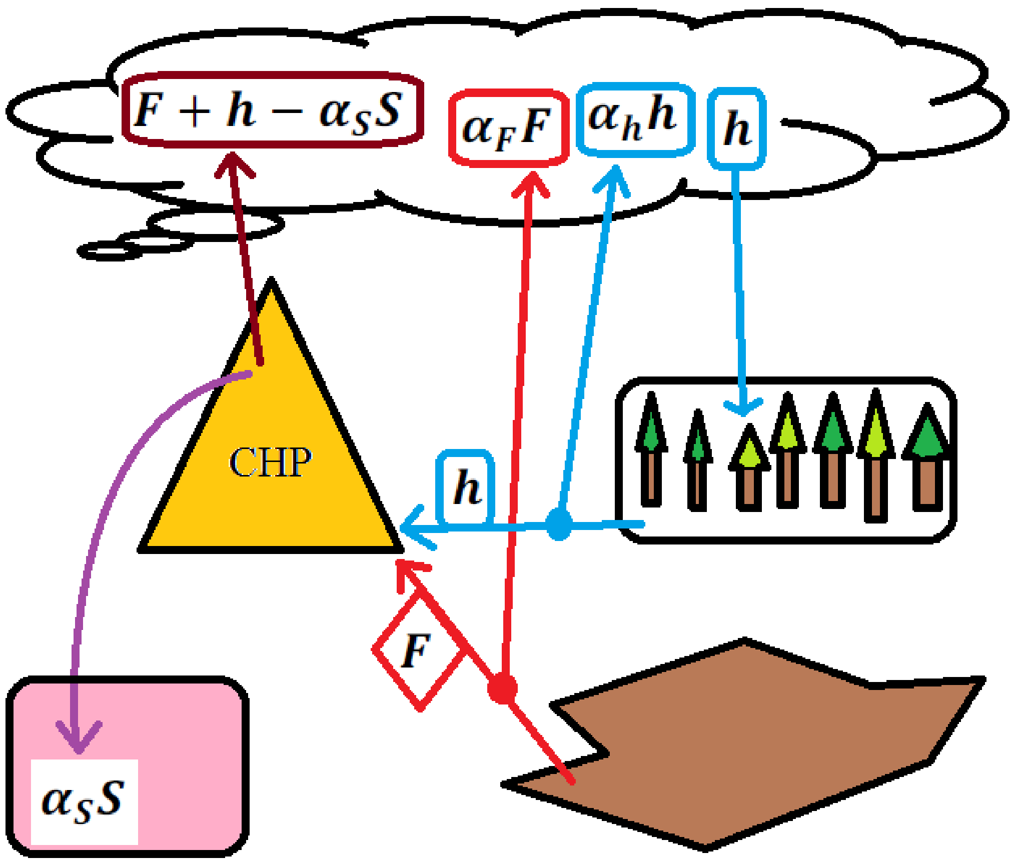
$$\frac{dF^*}{dk_G} = \frac{\alpha_h - (1+\alpha_F)}{k_\pi (C_h'' + C_F'')} < 0$$

$$\frac{dh^*}{dk_G} = \frac{\begin{vmatrix} 1 & 0 & 0 \\ -k_\pi C_F'' & (1+\alpha_F) & 1 \\ 0 & \alpha_h & 1 \end{vmatrix}}{|D|}$$

$$\frac{dh^*}{dk_G} = \frac{(1+\alpha_F) - \alpha_h}{k_\pi (C_h'' + C_F'')} > 0$$

$$\frac{d\lambda^*}{dk_G} = \frac{\begin{vmatrix} 1 & 1 & 0 \\ -k_\pi C_F'' & 0 & (1+\alpha_F) \\ 0 & -k_\pi C_h'' & \alpha_h \end{vmatrix}}{|D|}$$

$$\frac{d\lambda^*}{dk_G} = \frac{C_h''(1+\alpha_F) + C_F''\alpha_h}{C_h'' + C_F''} > 0$$



$$\frac{dF^*}{dk_G} = \frac{\alpha_h - (1 + \alpha_F)}{k_\pi (C_h'' + C_F'')} < 0$$

$$\frac{dh^*}{dk_G} = \frac{(1 + \alpha_F) - \alpha_h}{k_\pi (C_h'' + C_F'')} > 0$$

$$\frac{d\lambda^*}{dk_G} = \frac{C_h''(1 + \alpha_F) + C_F''\alpha_h}{C_h'' + C_F''} > 0$$

$$Max\ \ Z \quad = -k_\pi\big(C_F(F) + C_h(h) + C_S(S)\big) - k_G\big((1 + \alpha_F)F + \alpha_h h - \alpha_S S\big)$$

s.t. $\quad F + h \geq M$

The derivatives of F^*, h^* *and* λ^* with respect to k_π :

$$\frac{dF^*}{dk_\pi} = \frac{\begin{vmatrix} 0 & 1 & 0 \\ C'_F & 0 & 1 \\ C'_h & -k_\pi C''_h & 1 \end{vmatrix}}{|D|}$$

$$\frac{dF^*}{dk_\pi} = \frac{C'_h - C'_F}{k_\pi (C''_h + C''_F)} \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} 0$$

Observation:

The sign of $\frac{dF^*}{dk_\pi}$ is expected to change over time, since fossil fuels in the long run become more scarce and more costly to extract.

In most cases, it is assumed that $\frac{dF^*}{dk_\pi} > 0$ in the year 2014. At some future point in time, $\frac{dF^*}{dk_\pi} = 0$ and at later points in time $\frac{dF^*}{dk_\pi} < 0$.

$$\frac{dh^*}{dk_\pi} = \frac{\begin{vmatrix} 1 & 0 & 0 \\ -k_\pi C_F'' & C_F' & 1 \\ 0 & C_h' & 1 \end{vmatrix}}{|D|}$$

$$\frac{dh^*}{dk_\pi} = \frac{C_F' - C_h'}{k_\pi(C_h'' + C_F'')} \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} 0$$

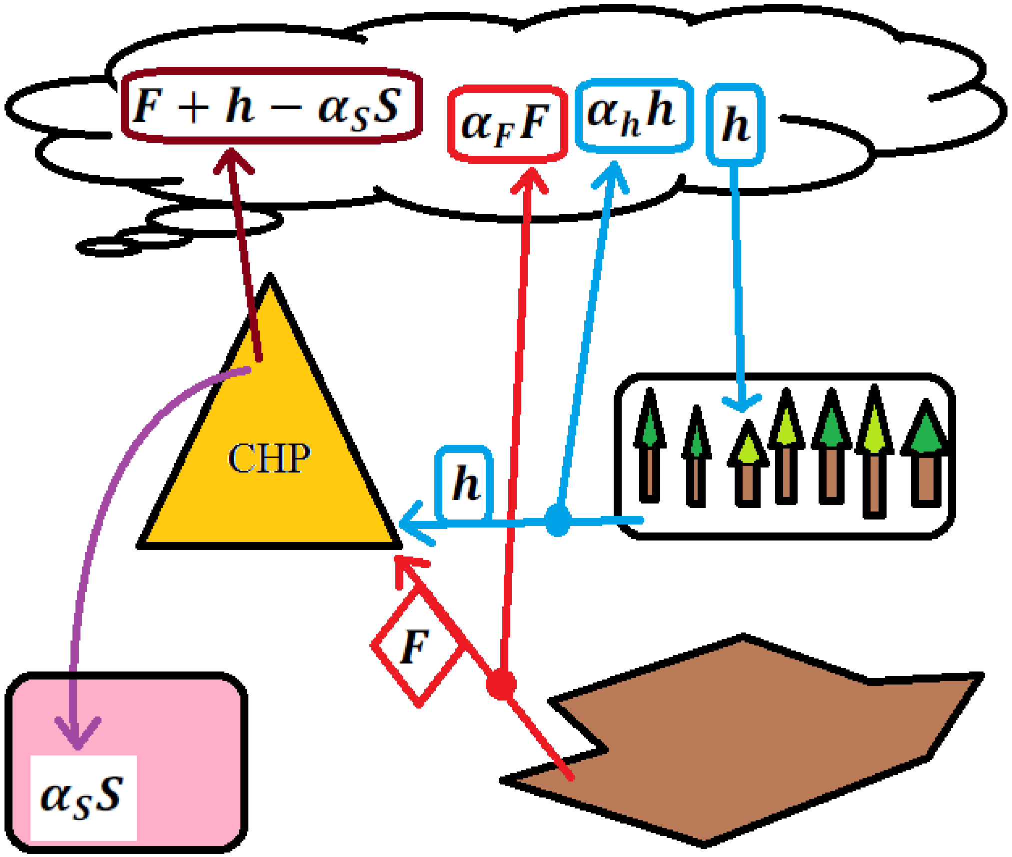
Observation:

The sign of $\frac{dh^*}{dk_\pi}$ is expected to change over time, since fossil fuels in the long run become more scarce and more costly to extract.

In most cases, it is assumed that $\frac{dh^*}{dk_\pi} < 0$ in the year 2014. At some future point in time, $\frac{dh^*}{dk_\pi} = 0$ and at later points in time $\frac{dh^*}{dk_\pi} > 0$.

$$\frac{d\lambda^*}{dk_\pi} = \frac{\begin{vmatrix} 1 & 1 & 0 \\ -k_\pi C_F'' & 0 & C_F' \\ 0 & -k_\pi C_h'' & C_h' \end{vmatrix}}{|D|}$$

$$\frac{d\lambda^*}{dk_\pi} = \frac{C_h'' C_F' + C_F'' C_h'}{C_h'' + C_F''} > 0$$



$$\frac{dF^*}{dk_\pi} = \frac{C'_h - C'_F}{k_\pi(C''_h + C''_F)} \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} 0$$

$$\frac{dh^*}{dk_\pi} = \frac{C'_F - C'_h}{k_\pi(C''_h + C''_F)} \begin{Bmatrix} > \\ = \\ < \end{Bmatrix} 0$$

$$\frac{d\lambda^*}{dk_\pi} = \frac{C''_h C'_F + C''_F C'_h}{C''_h + C''_F} > 0$$

$$Max \;\; Z = -k_\pi\big(C_F(F) + C_h(h) + C_S(S)\big) - k_G\big((1+\alpha_F)F + \alpha_h h - \alpha_S S\big)$$

$$\text{s.t.} \quad F + h \geq M$$

The derivatives of $F^*, h^* \, and \, \lambda^*$ with respect to α_F are:

$$\frac{dF^*}{d\alpha_F} = \frac{\begin{vmatrix} 0 & 1 & 0 \\ k_G & 0 & 1 \\ 0 & -k_\pi C_h'' & 1 \end{vmatrix}}{|D|}$$

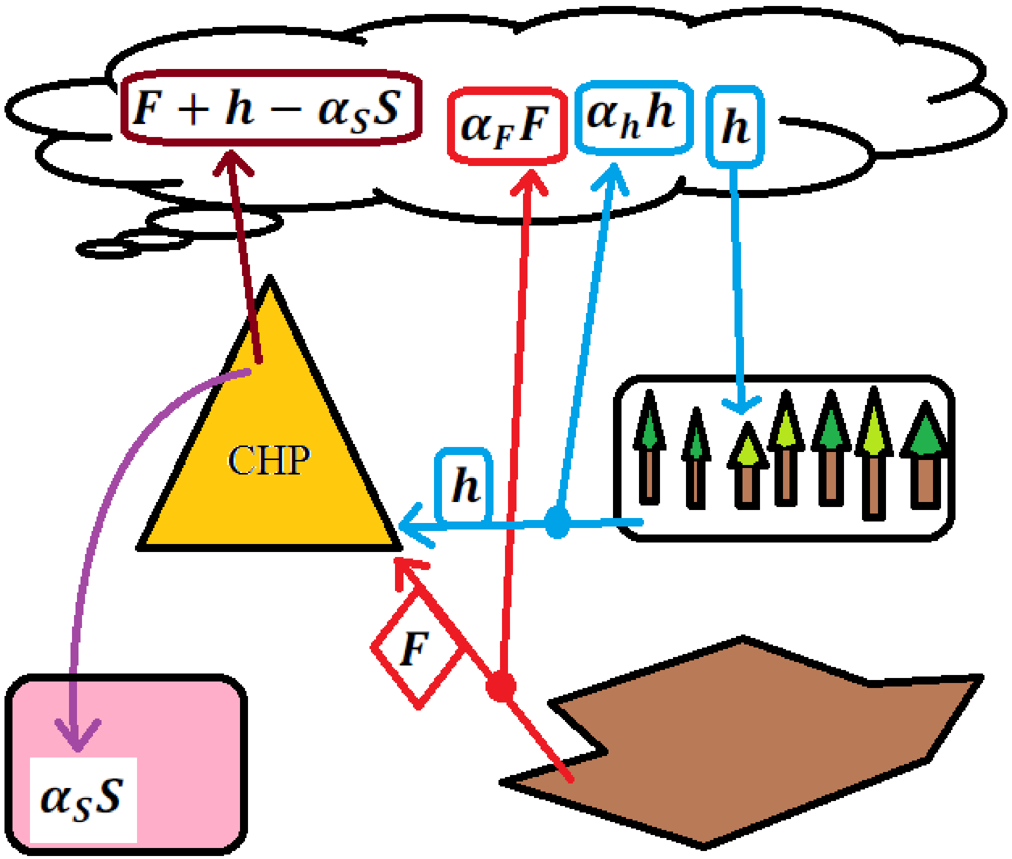
$$\frac{dF^*}{d\alpha_F} = \frac{-k_G}{k_\pi (C_h'' + C_F'')} < 0$$

$$\frac{dh^*}{d\alpha_F} = \frac{\begin{vmatrix} 1 & 0 & 0 \\ -k_\pi C_F'' & k_G & 1 \\ 0 & 0 & 1 \end{vmatrix}}{|D|}$$

$$\frac{dh^*}{d\alpha_F} = \frac{k_G}{k_\pi(C_h'' + C_F'')} > 0$$

$$\frac{d\lambda^*}{d\alpha_F} = \frac{\begin{vmatrix} 1 & 1 & 0 \\ -k_\pi C_F'' & 0 & k_G \\ 0 & -k_\pi C_h'' & 0 \end{vmatrix}}{|D|}$$

$$\frac{d\lambda^*}{d\alpha_F} = \frac{C_h'' k_G}{C_h'' + C_F''} > 0$$



$$\frac{dF^*}{d\alpha_F} = \frac{-k_G}{k_\pi(C_h'' + C_F'')} < 0$$

$$\frac{dh^*}{d\alpha_F} = \frac{k_G}{k_\pi(C_h'' + C_F'')} > 0$$

$$\frac{d\lambda^*}{d\alpha_F} = \frac{C_h'' k_G}{C_h'' + C_F''} > 0$$

$$Max \ \ Z = -k_\pi\big(C_F(F) + C_h(h) + C_S(S)\big) - k_G\big((1+\alpha_F)F + \alpha_h h - \alpha_S S\big)$$

s.t. $F + h \geq M$

The derivatives of F^*, h^* and λ^* with respect to α_h are:

$$\frac{dF^*}{d\alpha_h} = \frac{\begin{vmatrix} 0 & 1 & 0 \\ 0 & 0 & 1 \\ k_G & -k_\pi C_h'' & 1 \end{vmatrix}}{|D|}$$

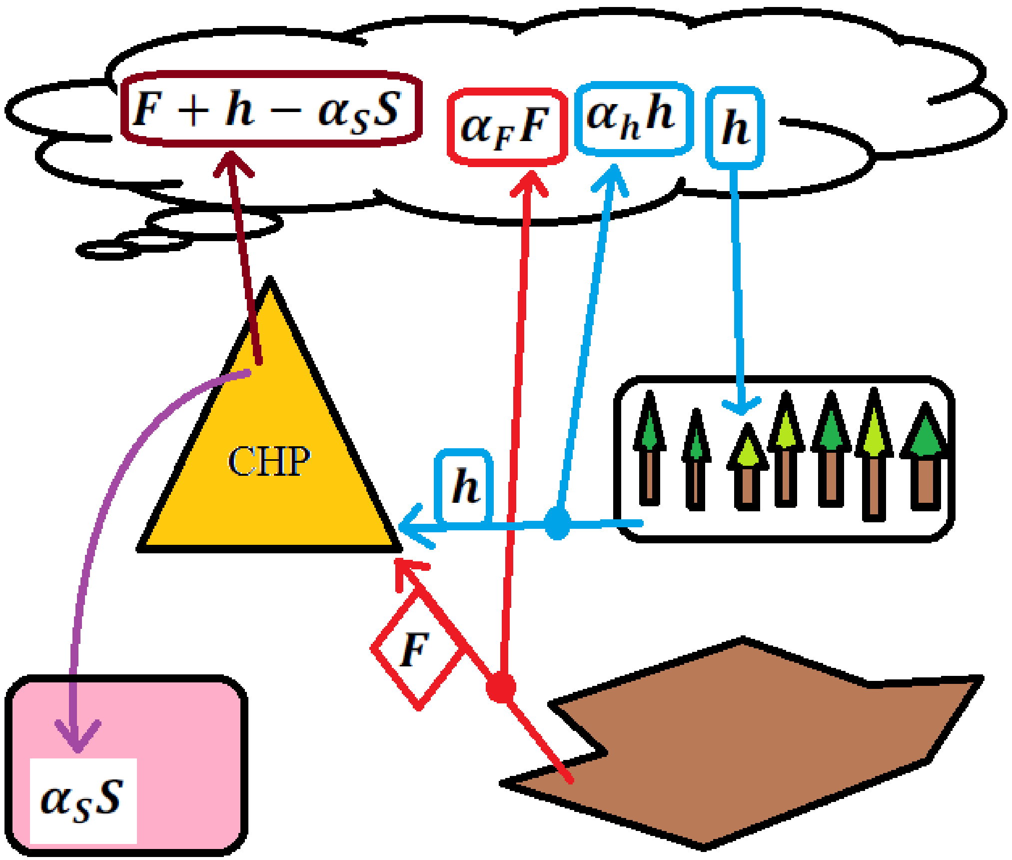
$$\frac{dF^*}{d\alpha_h} = \frac{k_G}{k_\pi (C_h'' + C_F'')} > 0$$

$$\frac{dh^*}{d\alpha_h} = \frac{\begin{vmatrix} 1 & 0 & 0 \\ -k_\pi C_F'' & 0 & 1 \\ 0 & k_G & 1 \end{vmatrix}}{|D|}$$

$$\frac{dh^*}{d\alpha_h} = \frac{-k_G}{k_\pi (C_h'' + C_F'')} < 0$$

$$\frac{d\lambda^*}{d\alpha_h} = \frac{\begin{vmatrix} 1 & 1 & 0 \\ -k_\pi C_F'' & 0 & 0 \\ 0 & -k_\pi C_h'' & k_G \end{vmatrix}}{|D|}$$

$$\frac{d\lambda^*}{d\alpha_h} = \frac{C_F'' k_G}{C_h'' + C_F''} > 0$$



$$\frac{dF^*}{d\alpha_h} = \frac{k_G}{k_\pi (C_h'' + C_F'')} > 0$$

$$\frac{dh^*}{d\alpha_h} = \frac{-k_G}{k_\pi (C_h'' + C_F'')} < 0$$

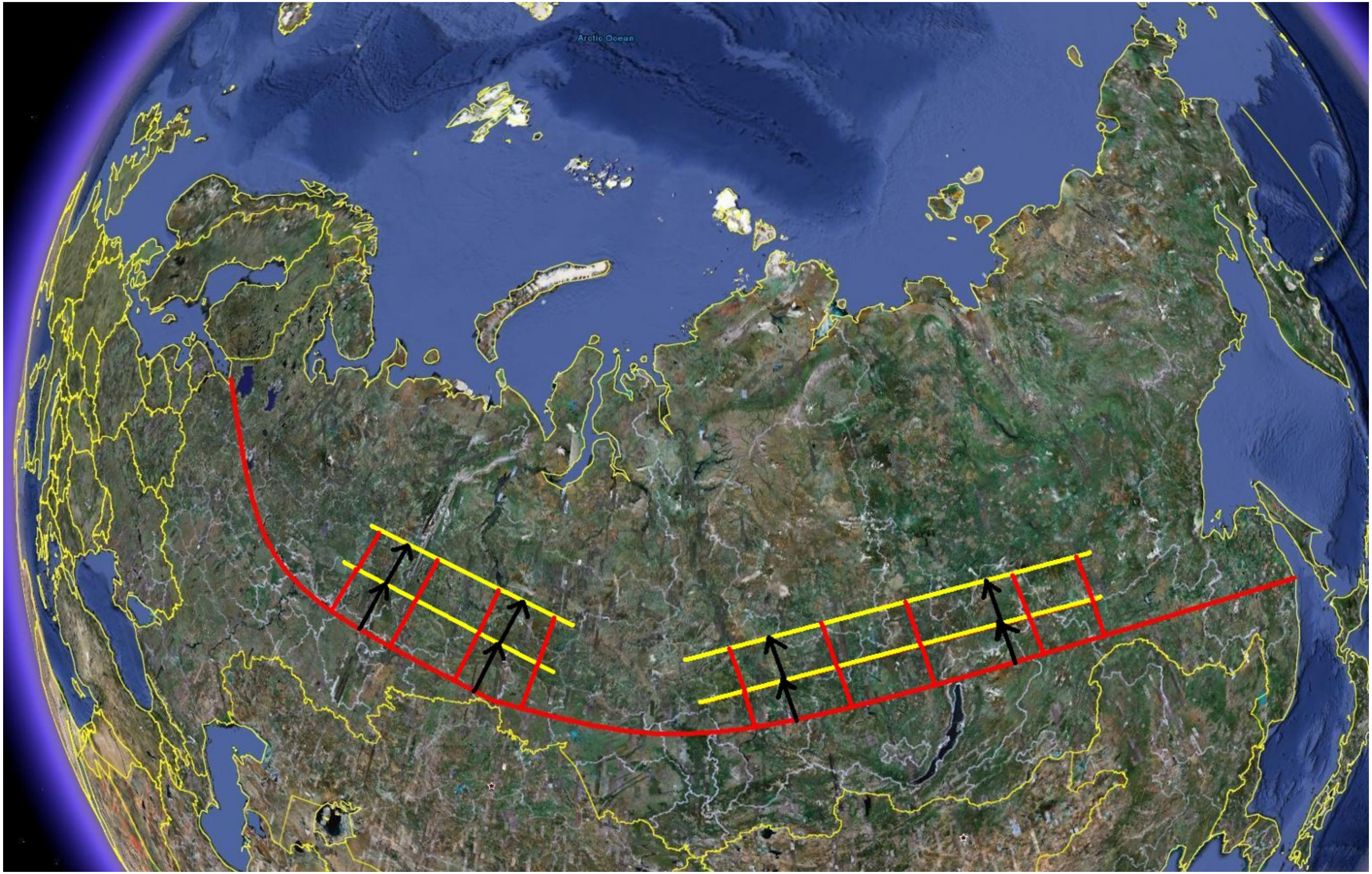
$$\frac{d\lambda^*}{d\alpha_h} = \frac{C_F'' k_G}{C_h'' + C_F''} > 0$$

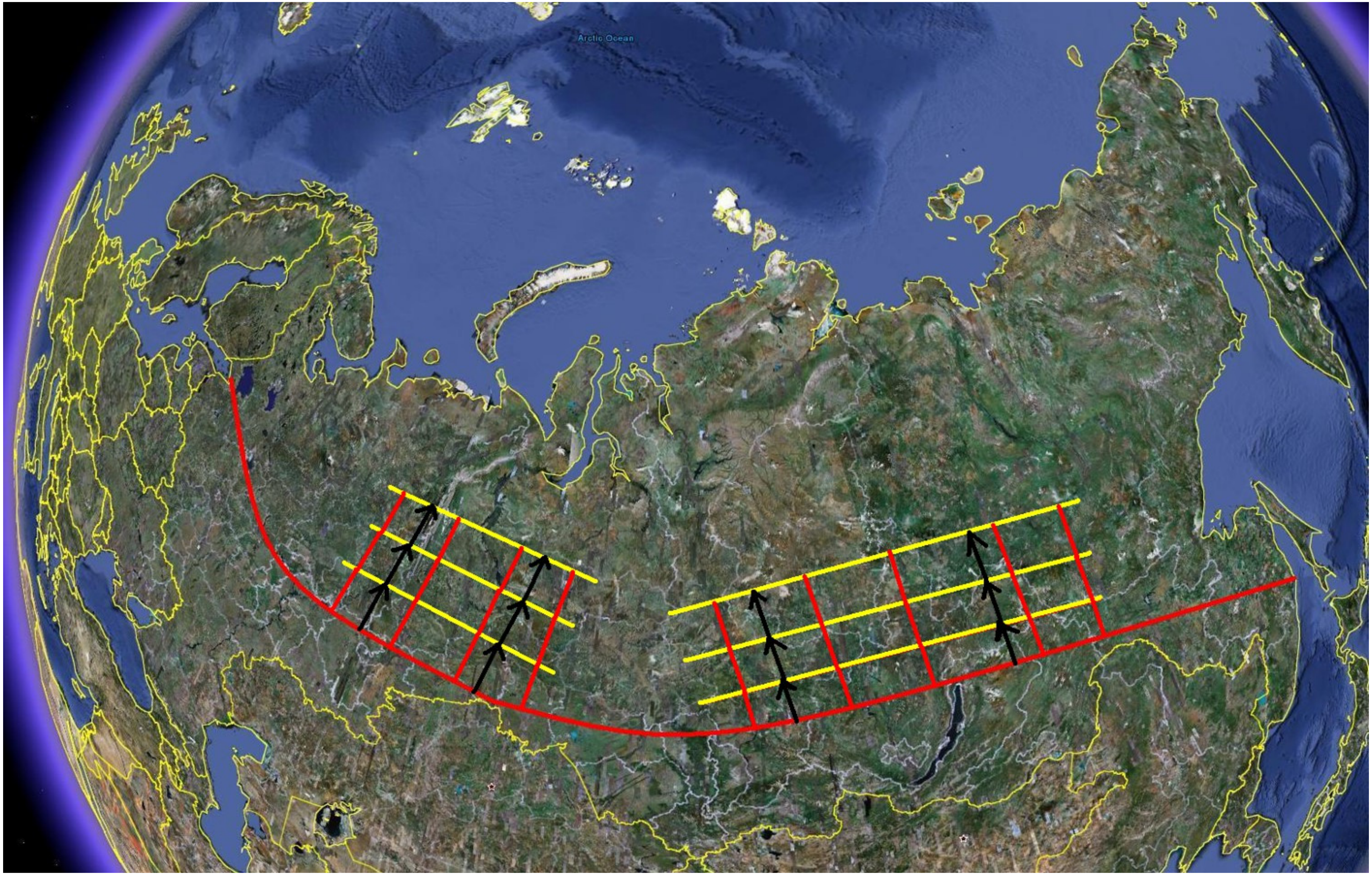
$$Max \quad Z = -k_\pi\big(C_F(F) + C_h(h) + C_S(S)\big) - k_G\big((1 + \alpha_F)F + \alpha_h h - \alpha_S S\big)$$

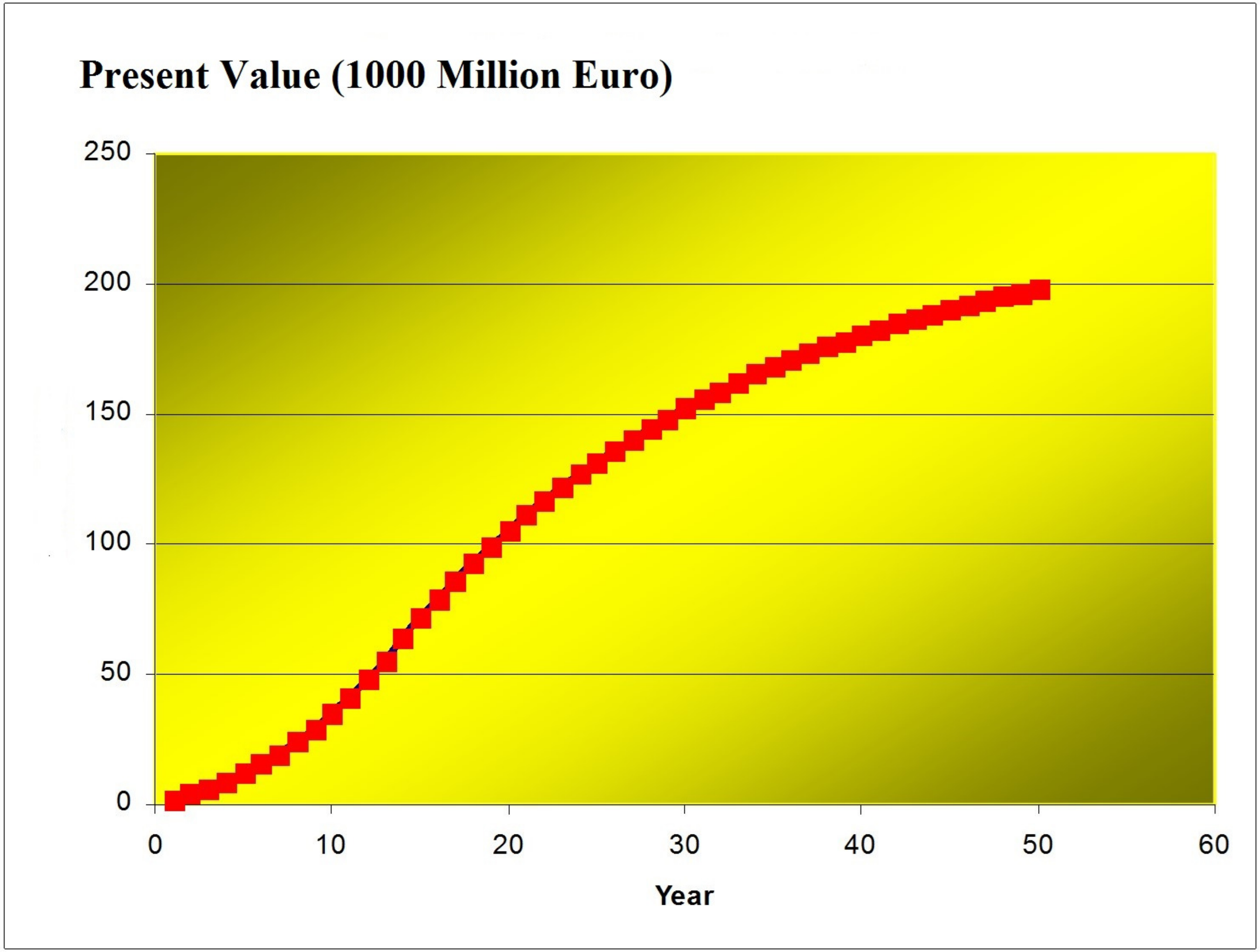
s.t. $F + h \geq M$


Arctic Ocean


Arctic Ocean


Arctic Ocean


Arctic Ocean


Present Value (1000 Million Euro)
250
200
150
100
50
0
0
10
20
30
40
50
60
Year

References

http://www.lohmander.com/Information/Ref.htm

**Lohmander, P. (Chair) TRACK 1: Global Bioenergy, Economy and Policy, BIT's 2nd World Congress on Bioenergy,
Xi'an, China, April 25-28, 2012**
http://www.Lohmander.com/Schedule_China_2012.pdf
http://www.Lohmander.com/PLWCBE12intro.ppt

**Lohmander, P., Economic optimization of sustainable energy systems based on forest resources with consideration of the global warming problem: International perspectives,
BIT's 2nd World Congress on Bioenergy,
Xi'an, China, April 25-28, 2012**
http://www.Lohmander.com/WorldCongress12_PL.pdf
http://www.Lohmander.com/WorldCongress12_PL.doc
http://www.Lohmander.com/PLWCBE12.ppt

Lohmander, P., Lectures at Shandong Agricultural University,
April 29 - May 1, 2012, Jinan, China,
http://www.Lohmander.com/PLJinan12.ppt

Lohmander, P. (Chair) TRACK: Finance, Strategic Planning,
Industrialization and Commercialization, BIT's 1st World Congress on Bioenergy,
Dalian World Expo Center,
Dalian, China, April 25-30, 2011
http://www.bitlifesciences.com/wcbe2011/fullprogram_track5.asp
http://www.lohmander.com/PRChina11/Track_WorldCongress11_PL.pdf
http://www.lohmander.com/ChinaPic11/Track5.ppt

Lohmander, P., Economic forest management with consideration
of the forest and energy industries, BIT's 1st World Congress on Bioenergy, Dalian
World Expo Center, Dalian, China, April 25-30, 2011
http://www.lohmander.com/PRChina11/WorldCongress11_PL.pdf
http://www.lohmander.com/ChinaPic11/LohmanderTalk.ppt

CONCLUSIONS:

With increasing levels of forest inputs in combination with CCS, it is possible to reduce the CO2 in the atmosphere and the global warming problem can be managed.

Furthermore, international trade in forest based energy can improve international relations, regional development and environmental conditions.

All suggestions concerning future cooperation projects are welcome!

Thank you!

Peter Lohmander

APPENDIX

The classical dynamic natural resource model:

$$\frac{dx}{dt} = sx\left(1 - \frac{x}{K}\right)$$

$$\frac{dx}{dt} = sx - \frac{s}{K}x^2$$

$$\frac{dx}{dt} = sx(1 + \gamma x), \qquad \gamma = -K^{-1}$$

$$\frac{1}{x(1 + \gamma x)}dx = sdt$$

$$\frac{1}{x(1 + \gamma x)} = \frac{m}{x} + \frac{n}{1 + \gamma x}$$

$$\frac{m}{x} + \frac{n}{1 + \gamma x} = \frac{(1 + \gamma x)m + nx}{x(1 + \gamma x)}$$

$$\frac{(1 + \gamma x)m + nx}{x(1 + \gamma x)} = \frac{1}{x(1 + \gamma x)}$$

$$(1 + \gamma x)m + nx = 1$$

$$m + m\gamma x + nx = 1$$

$$m + (m\gamma + n)x = 1$$

Observation:

$$m + (m\gamma + n)x = 1 \forall x$$

$$\begin{cases} m = 1 \\ m\gamma + n = 0 \end{cases}$$

Solution:

$$(m, n) = (1, -\gamma)$$

$$\frac{1}{x(1 + \gamma x)}dx = sdt$$

$$\left(\frac{m}{x} + \frac{n}{1 + \gamma x}\right)dx = sdt$$

$$\left(\frac{1}{x} - \frac{\gamma}{1 + \gamma x}\right)dx = sdt$$

$$\frac{dLN(1 + \gamma x)}{dx} = \frac{\gamma}{1 + \gamma x}$$

$$\frac{1}{x}dx - \frac{\gamma}{1+\gamma x}dx = sdt$$

$$\int \frac{1}{x}dx - \int \frac{\gamma}{1+\gamma x}dx = \int sdt$$

$$LN(x) - LN(1+\gamma x) = st + C_1$$

$$LN\left(\frac{x}{1+\gamma x}\right) = st + C_1$$

$$e^{LN\left(\frac{x}{1+\gamma x}\right)} = e^{st+C_1}$$

$$\frac{x}{1+\gamma x} = C_2 e^{st}$$

$$x = (1+\gamma x)C_2 e^{st}$$

$$x(1 - C_2\gamma e^{st}) = C_2 e^{st}$$

$$x = \frac{C_2 e^{st}}{1 - C_2 \gamma e^{st}}$$

$$x = \frac{1}{\frac{1}{C_2}e^{-st} - \gamma}$$

$$\gamma = -K^{-1}$$

$$x = \frac{1}{\frac{1}{C_2}e^{-st} + \frac{1}{K}}$$

$$x(t) = \frac{K}{1 + Ce^{-st}}$$

$$\lim_{\substack{t\to\infty \\ (s>0)}} x(t) = K$$

$$\frac{dx}{dt} = \frac{KsCe^{-st}}{(1+Ce^{-st})^2}$$

$$\lim_{\substack{t\to\infty \\ (s>0)}} \left(\frac{dx}{dt}\right) = 0$$