With expanded bioenergy based on forest resources, we may simultaneously and sustainably reduce global warming, improve economic results, international relations and environmental conditions

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With expanded bioenergy based on forest resources, we may simultaneously and sustainably reduce global warming, improve economic results, international relations and environmental conditions

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- 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 and CO2 uptake can increase.
- In Norway and UK, CCS has been applied and a commercially attractive option during many years and the physical potential is large. 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 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.

- **In the production of district heating, electricity and many other energy outputs, we may use fossil fuels and renewable inputs, in different combinations.**

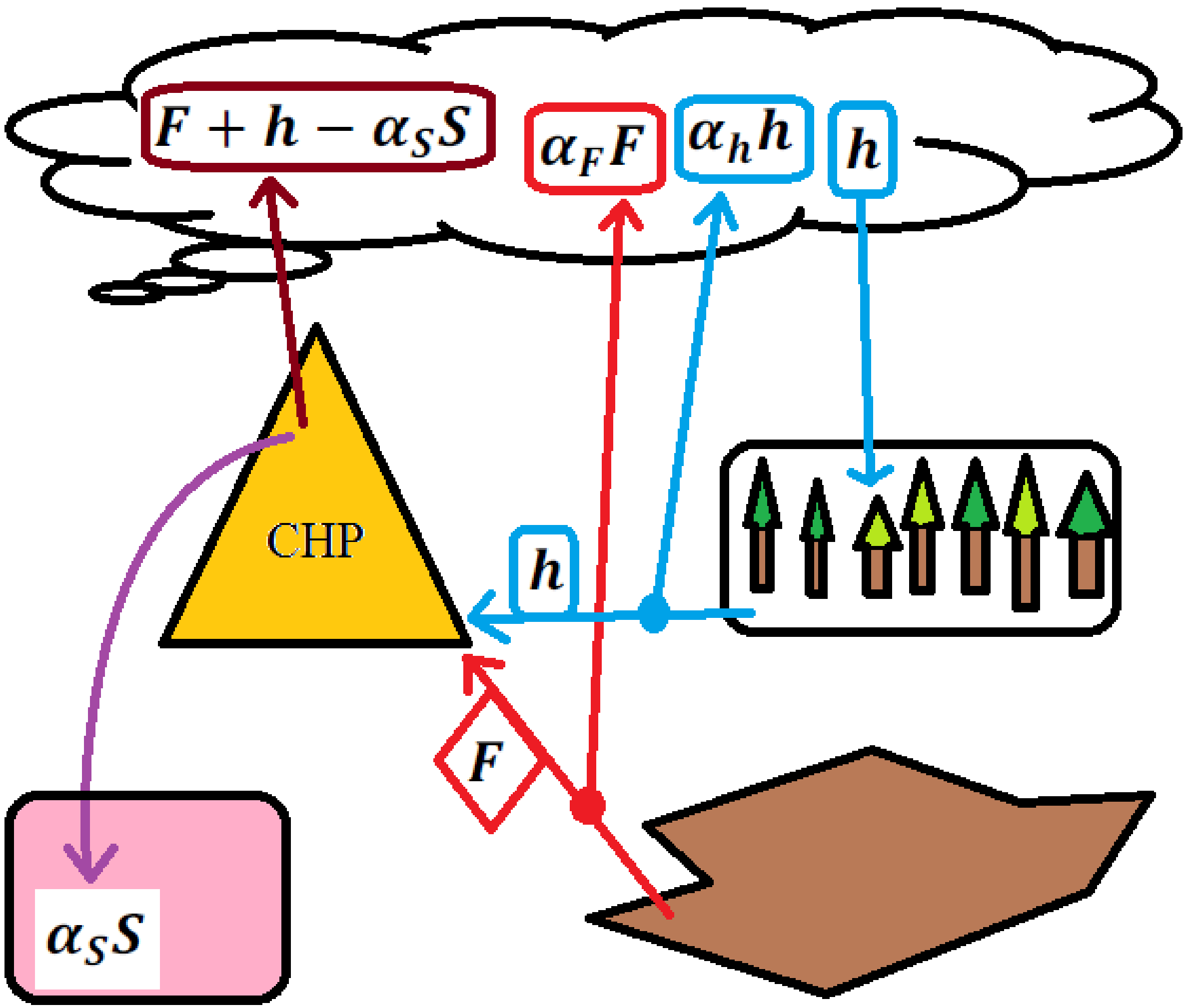
- **The optimal input mix is a function of technological options, prices of different inputs and costs of alternative levels of environmental consequences.**

Let us define a model that includes the most important parts of the global problem!

- **Include alternative energy sources and CO_2 effects.**
- **Include relevant production options.**
- **Make it possible to derive policy conclusions in a transparent way.**

OBSERVATION:

More details can easily be included in the model. Then, however, a transparent analysis and presentation are no longer possible.



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

$$Max \ \ Z =$$

Objective function

$$-k_{\pi}\left(C_F(F) + C_h(h) + C_S(S)\right)$$

Costs of operations

$$-k_G\left((1+\alpha_F)F + \alpha_h h - \alpha_S S\right)$$

Costs of CO2 in atmosphere

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

Energy input constraint

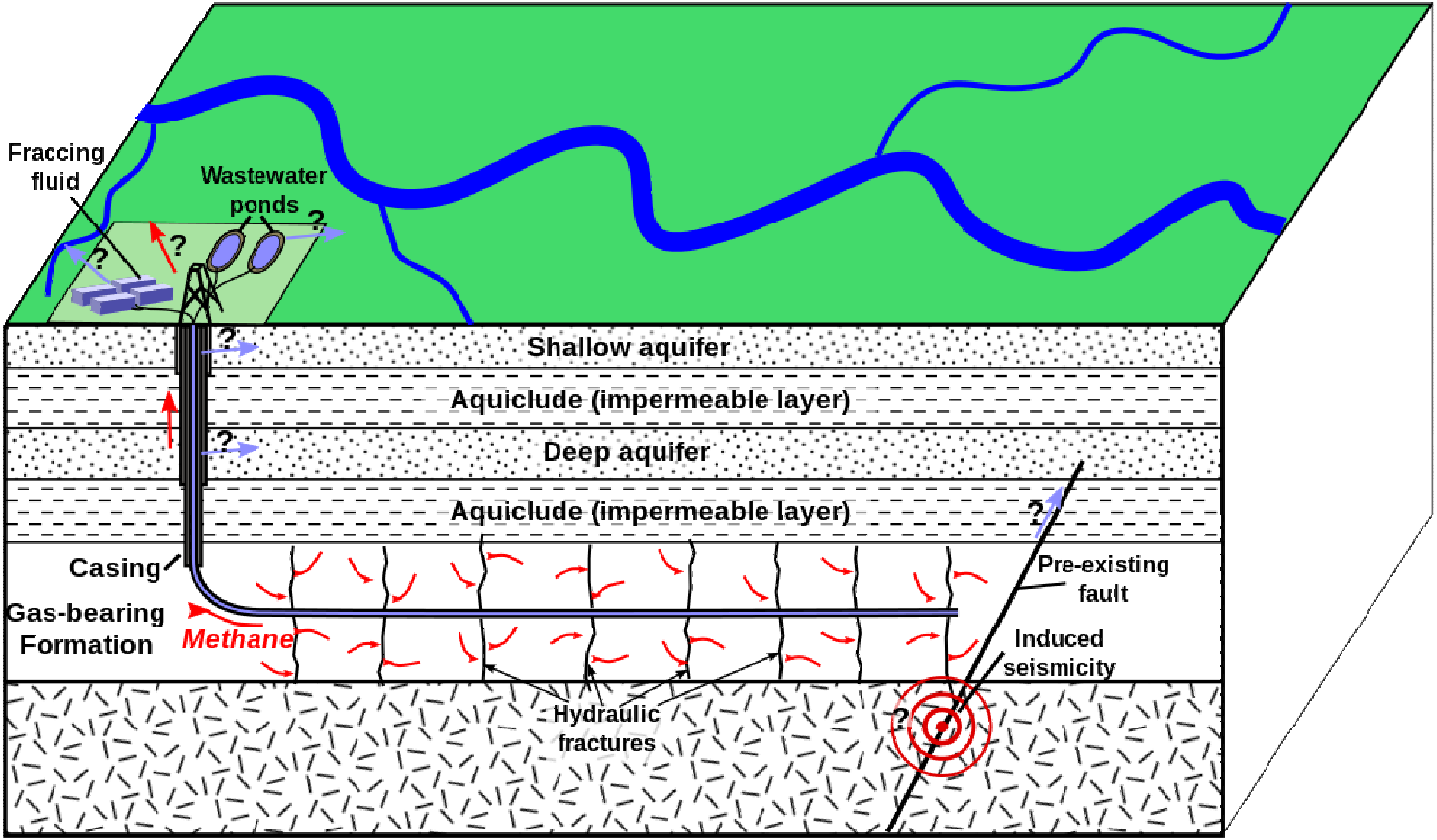
This presentation focuses on problem definition and a transparent derivation and summary of central results.

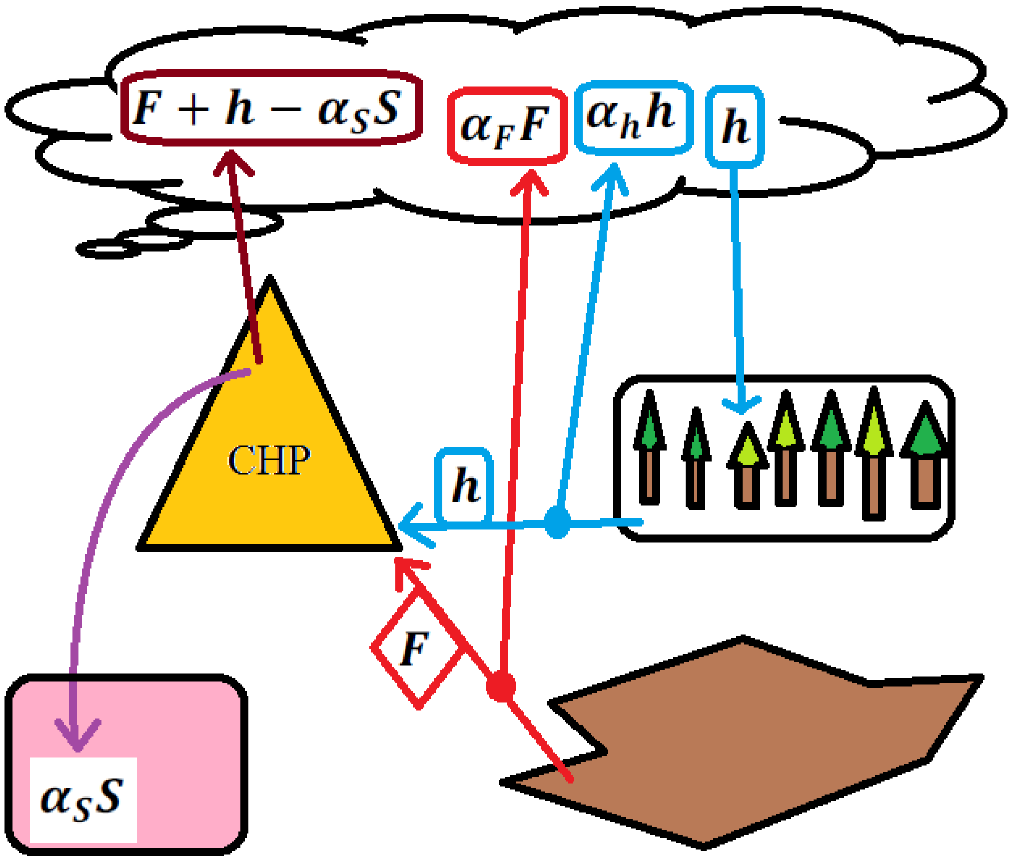
A complete mathematical analysis with a more detailed model is of course also possible but would take much more time.

The model does not include constraints on the total 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



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

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

Mathematical 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:

$$C_F' > 0$$

$$C_F'' > 0$$

$$C_h' > 0$$

$$C_h'' > 0$$

$$C_S' > 0$$

$$C_S'' > 0$$

The Lagrange function, L, is:

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

The Kuhn Tucker conditions are:

$$F \geq 0; h \geq 0; S \geq 0$$

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

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

$$\lambda \geq 0$$

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

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

Here, we have four of the constraints:

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

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

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

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

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 $(F, h \; and \; \lambda)$ and a separate equation with only one endogenous variable, S .

Stars denote optimal values.

First, we investigate S^*.

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

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

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 optimal level of CCS

decreases if we put more weight on the costs of operations.

increases if the marginal cost of global warming increases.

increases if the technical efficiency of CCS increases.

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

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

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

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

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

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

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

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

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

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 $F^*, h^*\, and\, \lambda^*$ with respect to M are determined via Cramer's rule:

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

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

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

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

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

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

If the total energy consumption increases

- **the optimal level of fossil energy input increases.**
- **the optimal level of forest energy input increases.**
- **the marginal cost of energy input increases.**

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

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

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

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

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

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

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

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

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

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

If the marginal cost of global warming increases

the optimal level of fossil energy input decreases.

the optimal level of forest energy input increases.

the marginal cost of energy input increases.

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

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

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

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 $\frac{dh^*}{dk_\pi} > 0$.

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

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

If the costs of operations are considered more important

the optimal level of fossil energy input increases (now) and decreases (later).

the optimal level of forest energy input decreases (now) and increases (later).

the marginal cost of energy input increases.

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

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

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

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

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

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

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

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

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

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

If the CO_2 emissions from fossil energy operations (per unit) increases, (α_F increases over time since you have to extract from deeper levels and in more remote places.)

the optimal level of fossil energy input decreases.

the optimal level of forest energy input increases.

the marginal cost of energy input increases.

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

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

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

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

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

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

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

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

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

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

If the CO2 emissions from forest operations (per unit) decrease, (α_h may decrease thanks to more railways in remote areas etc.)

the optimal level of fossil energy input decreases.

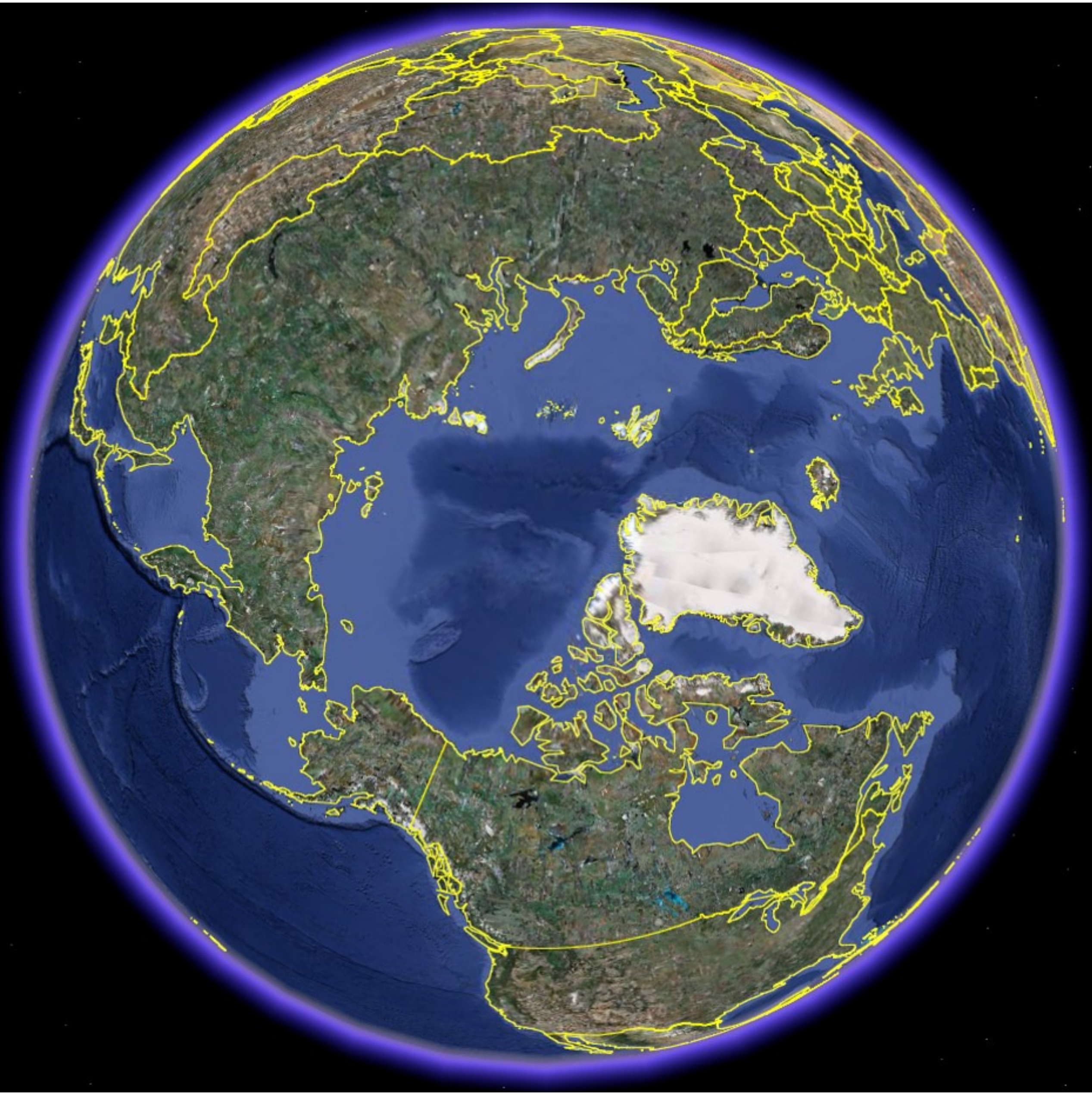
$$\frac{dF^*}{d\alpha_h} = \frac{k_G}{k_\pi(C_h'' + C_F'')} > 0$$

the optimal level of forest energy input increases.

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

the marginal cost of energy input decreases.

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



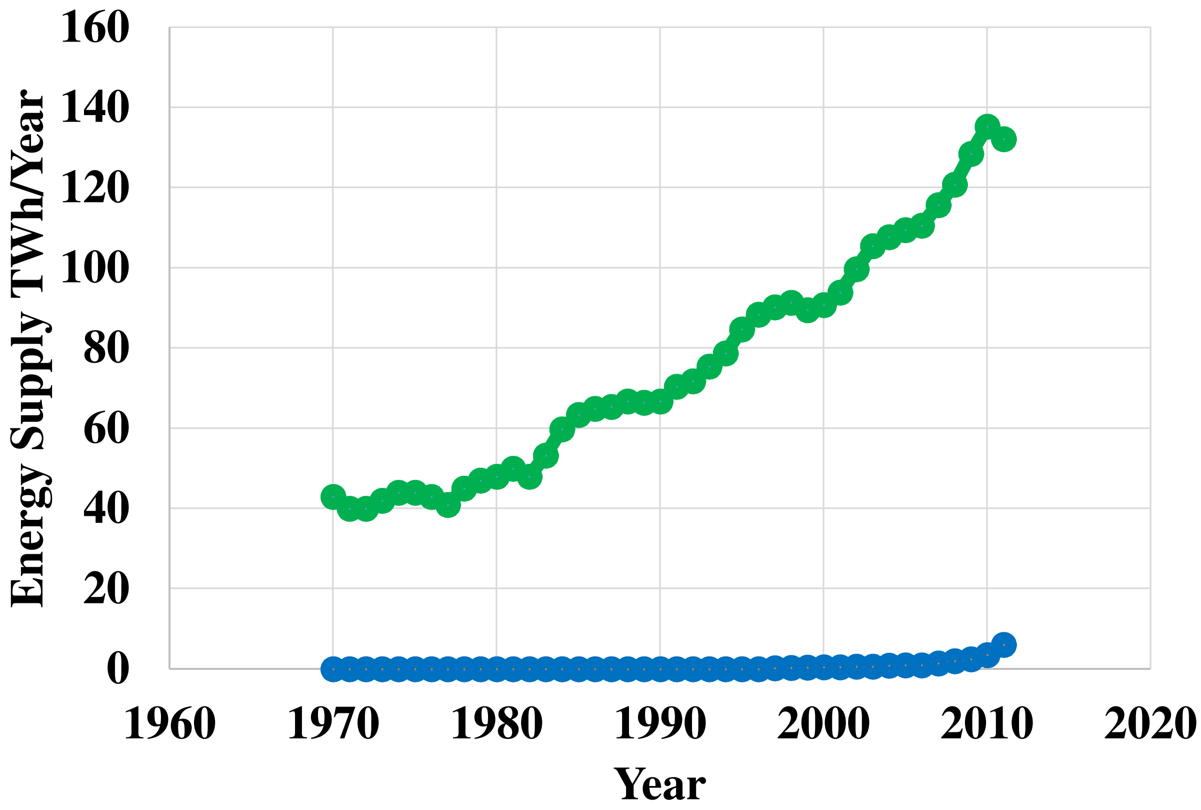
Now, we investigate the real world!

First, let us look at the ”total energy supply” in a small country, Sweden:

<u>Two sources of energy supply in Sweden</u>

Bioenergy = Green

Wind power = Blue

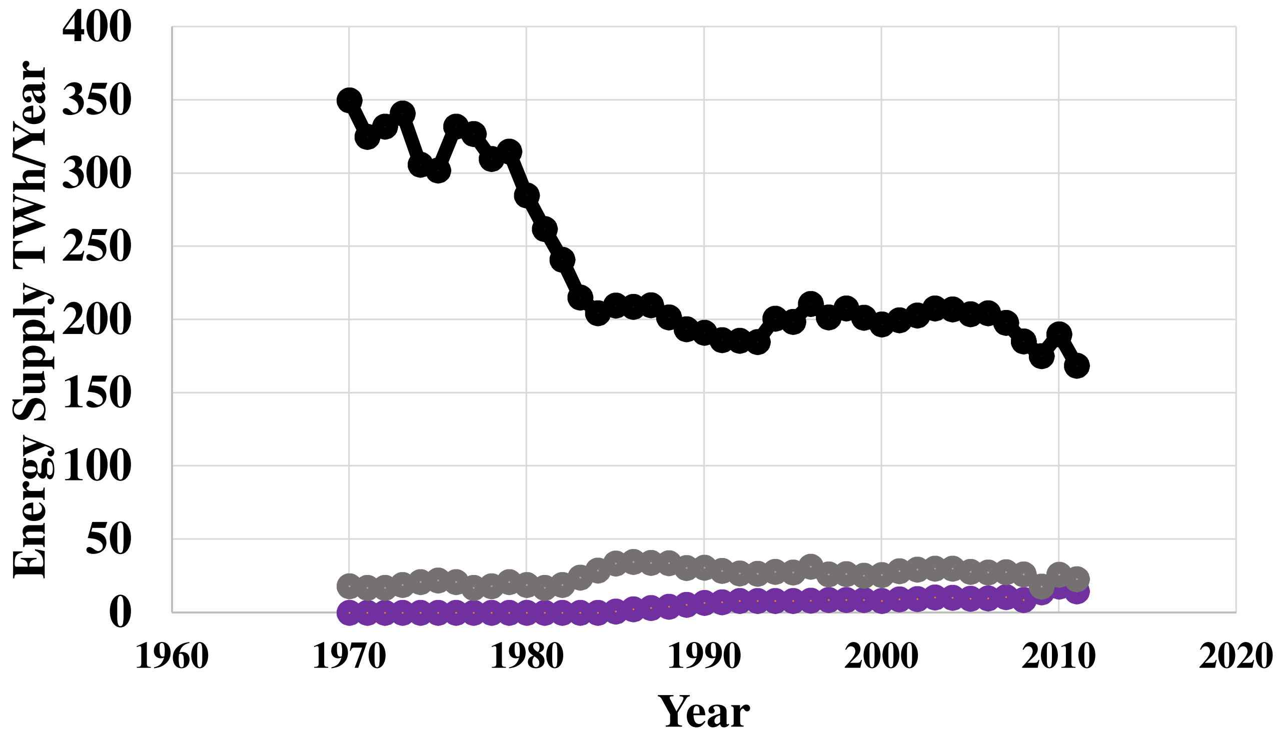


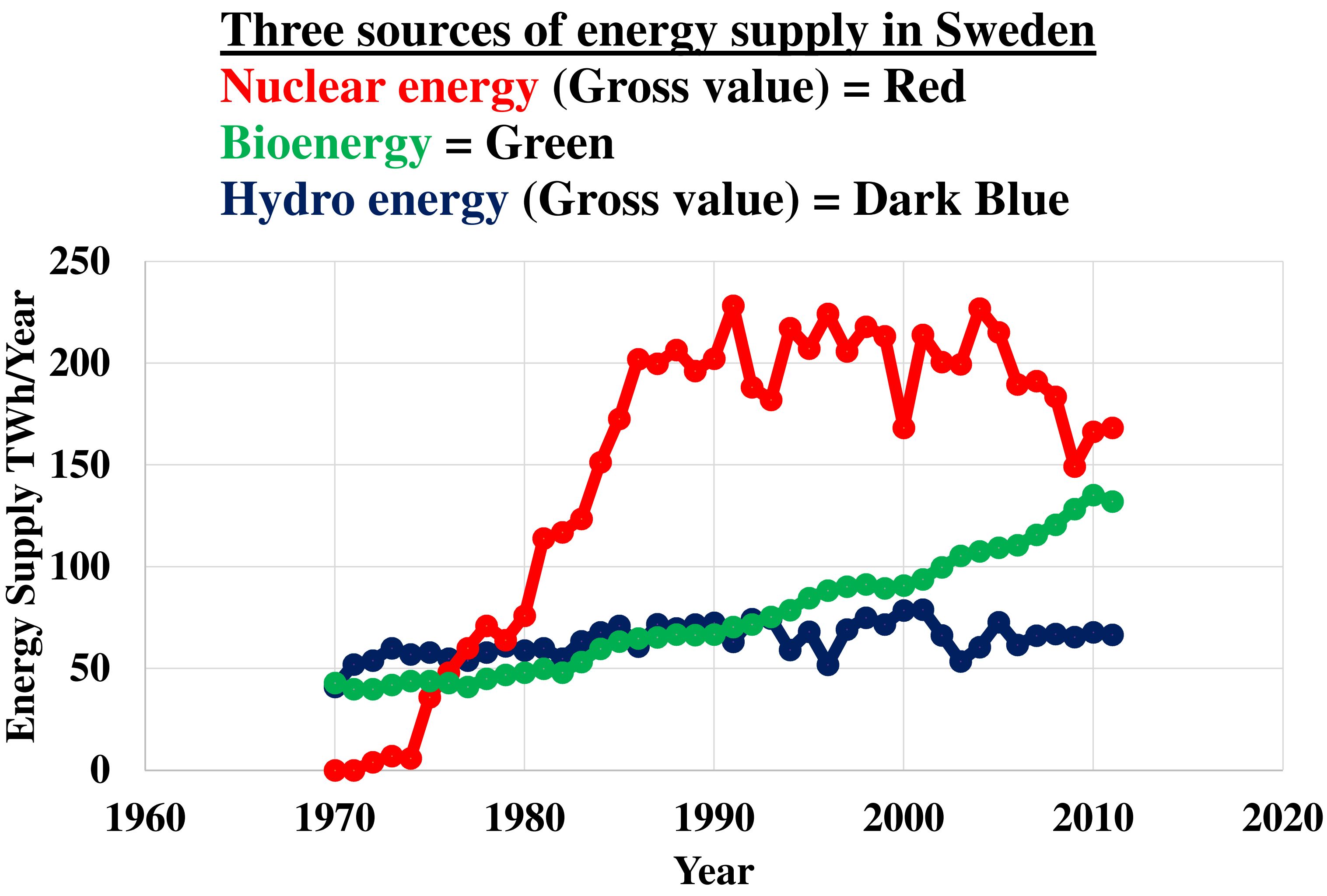
Three sources of energy supply in Sweden

Oil = Black

Coal = Grey

Natural Gas = Purple

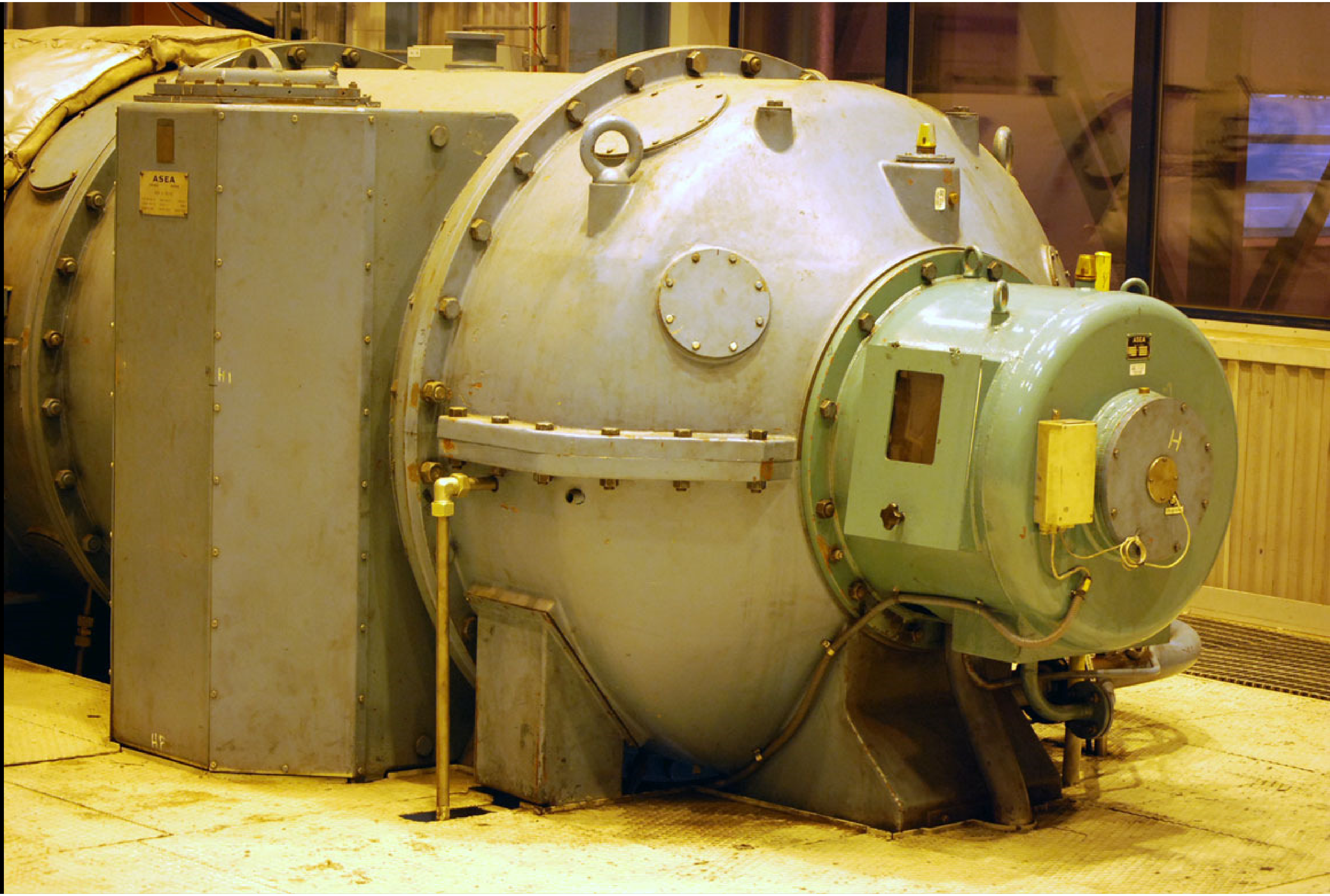


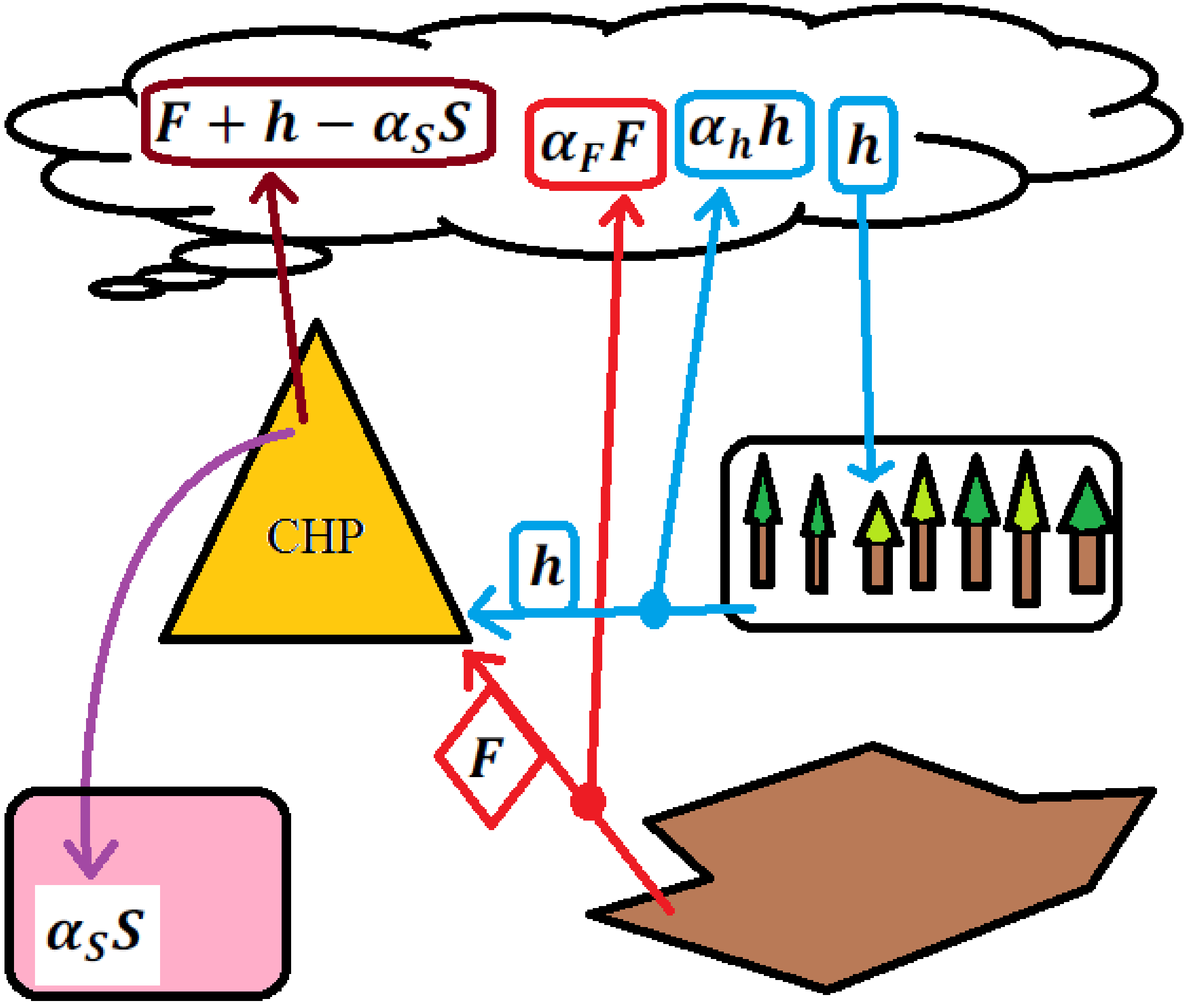


Three sources of energy supply in Sweden
Nuclear energy (Gross value) = Red
Bioenergy = Green
Hydro energy (Gross value) = Dark Blue
Energy Supply TWh/Year
250
200
150
100
50
0
1960
1970
1980
1990
2000
2010
2020
Year

Now, let us look at the ”total energy supply” in combined heat and power plants in Sweden:

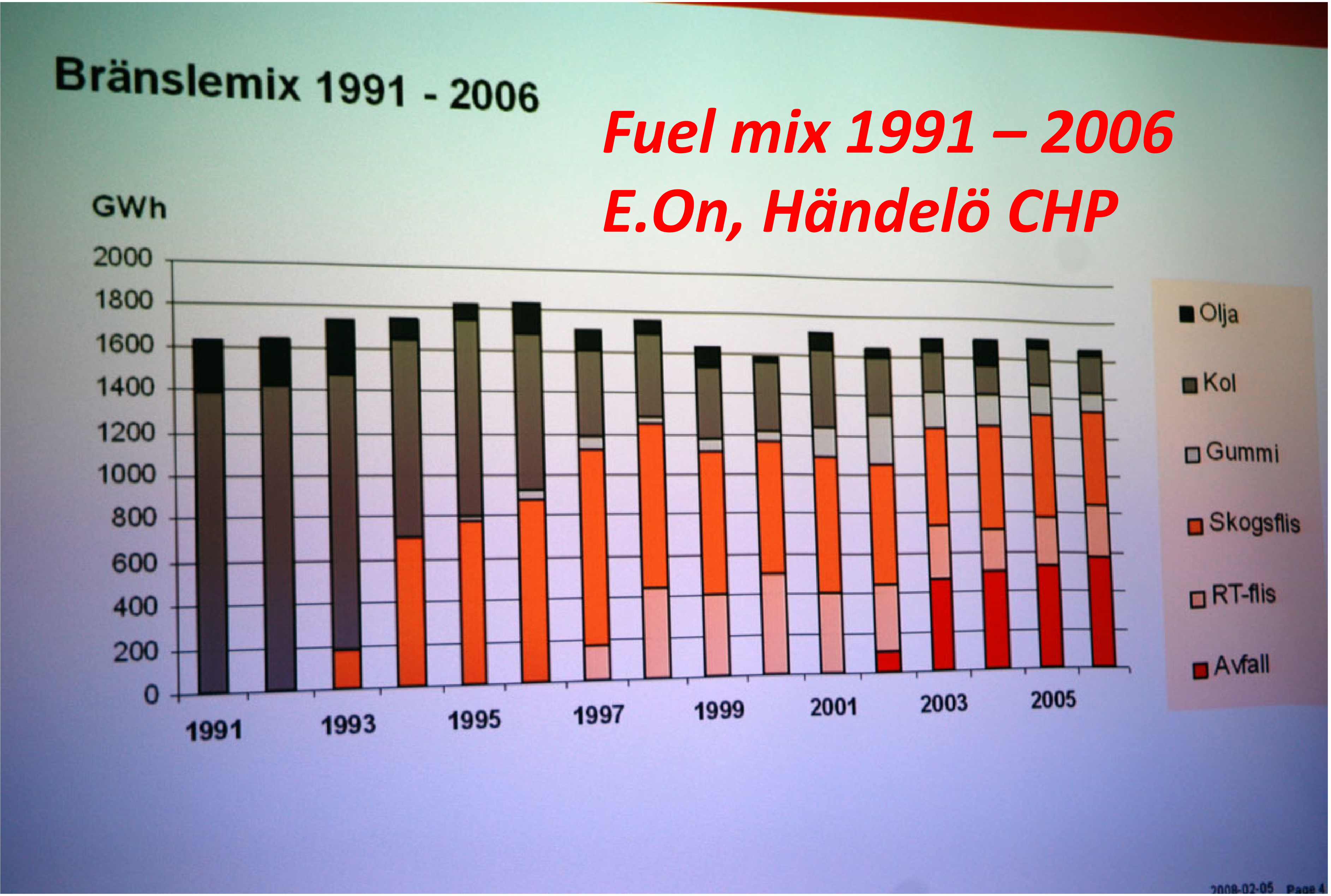

e.on
Händelö CHP
Norrköping, Sweden
Pictures by
Peter Lohmander
2008-12-11
e.on


ASEA
H



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


30
kraft



Oil (BLACK)

Coal (DARK GREY)

Rubber (LIGHT GREY)

Forest chips (ORANGE)

Waste wood (PINK)

Waste from households and industries (RED)

The increasing use of bioenergy and decreasing use of coal and oil can be explained by the increasing tax on fossil fuels (”CO2 taxation”).

Summary of the CO2 tax policy in Sweden from the International Institute for Sustainable Development http://www.iisd.org/greenbud/sweden.htm

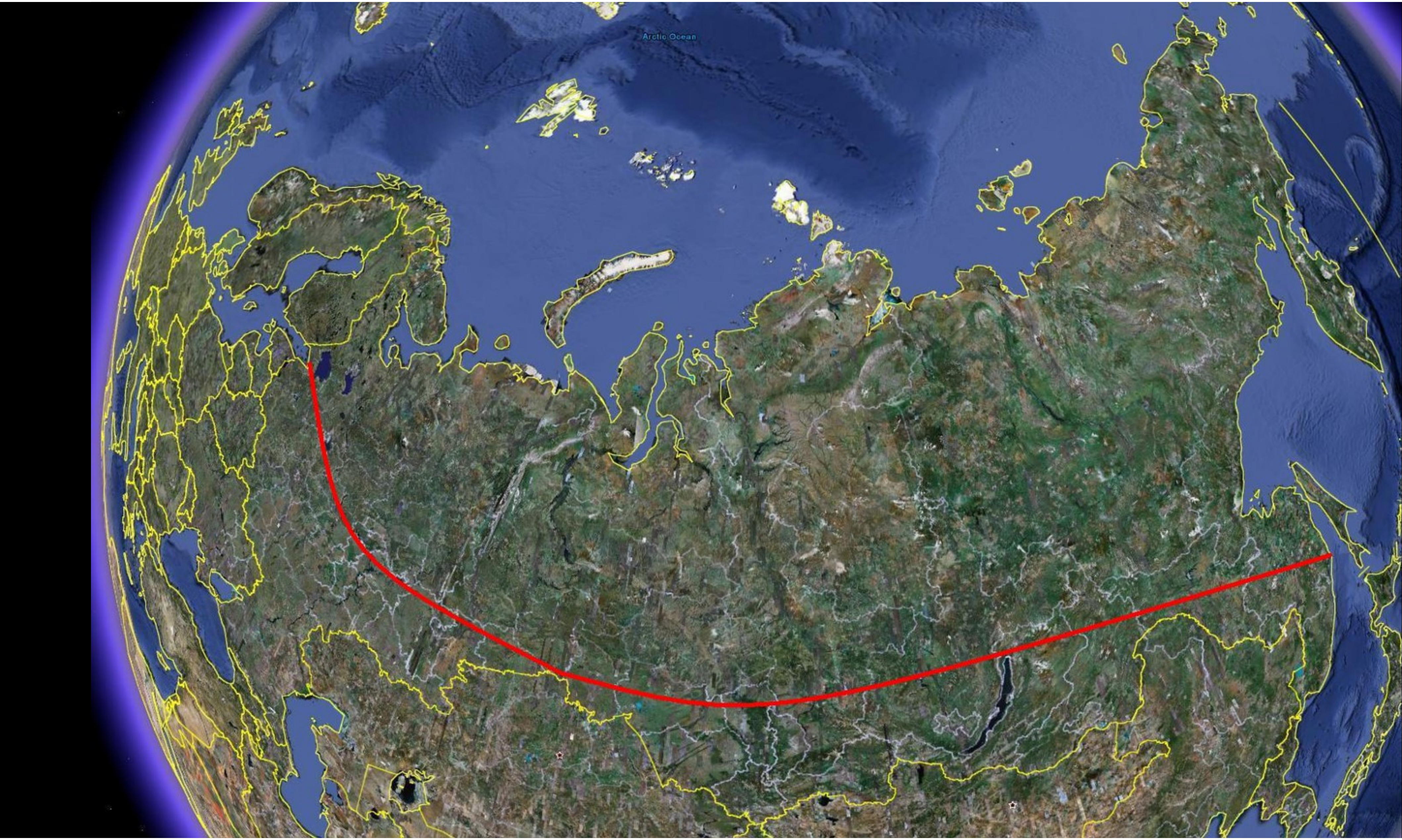
The Policy in Brief

- Economic Instrument: Carbon dioxide tax.
- Problem: Emissions of greenhouse gases which may induce global warming.
- Goal: Reduce or stabilize CO2 emissions, generate revenue for the national budget and serve as a model for applications internationally.
- Description: A tax on CO2, levied primarily on fossil fuels including oil, coal, natural gas, LPG and gasoline. Part of the wider energy taxation system, the tax is generally higher for the household sector than for the industrial one so as not to hamper competitiveness on international markets.
- Administering Institution: National Tax Board (Sweden).

Can we increase the bioenergy supply from forests without negative effects on the CO_2 net uptake?

- **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 and CO_2 uptake can increase.**


Arctic Ocean

The classical dynamic natural resource model (Verhulst 1837):

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

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

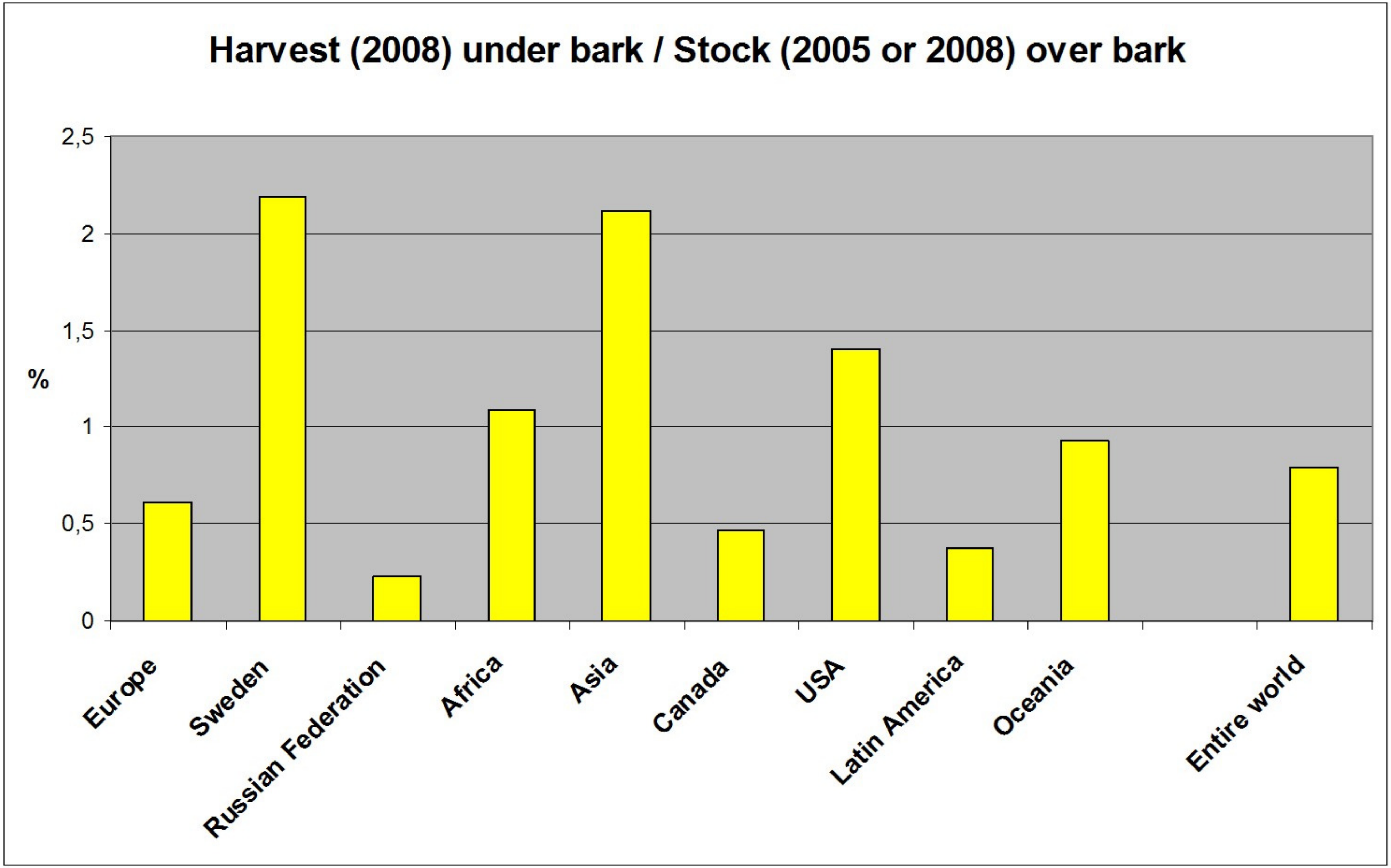
$$\lim_{\substack{t \to \infty \\ (s>0)}} x(t) = K$$

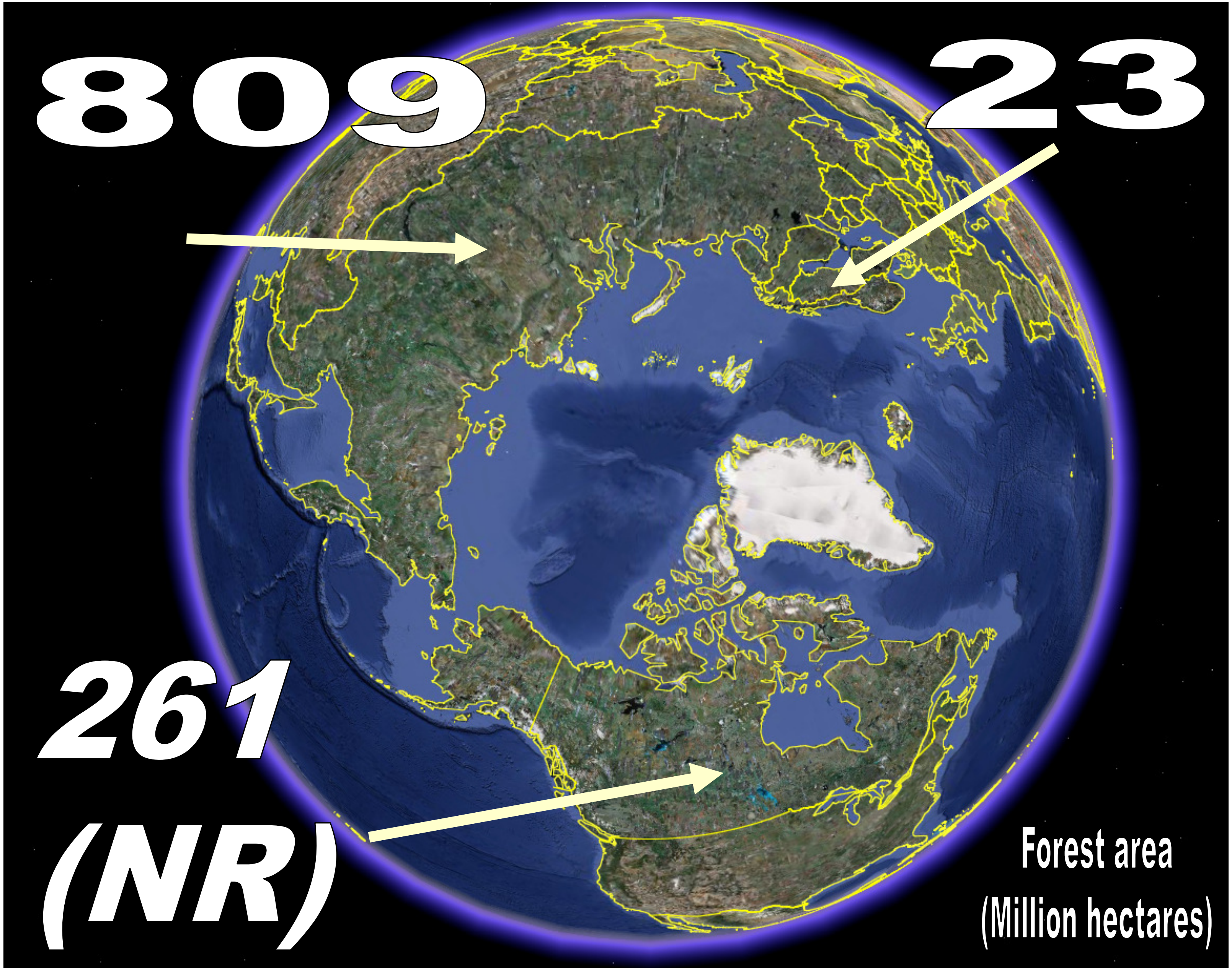
$$\lim_{\substack{t \to \infty \\ (s>0)}} \left(\frac{dx}{dt} \right) = 0$$

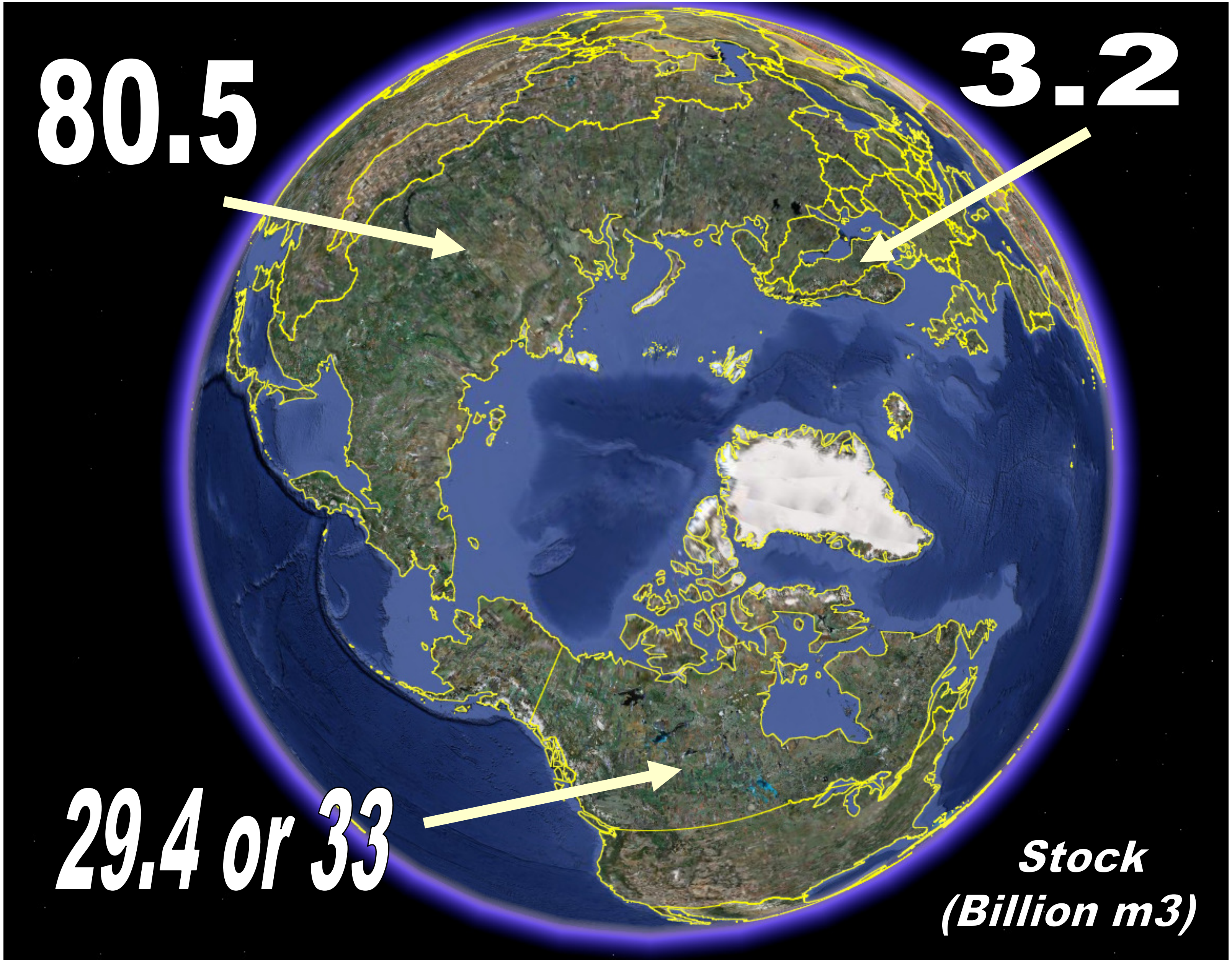
Such forests do not change the carbon level of the atmosphere.

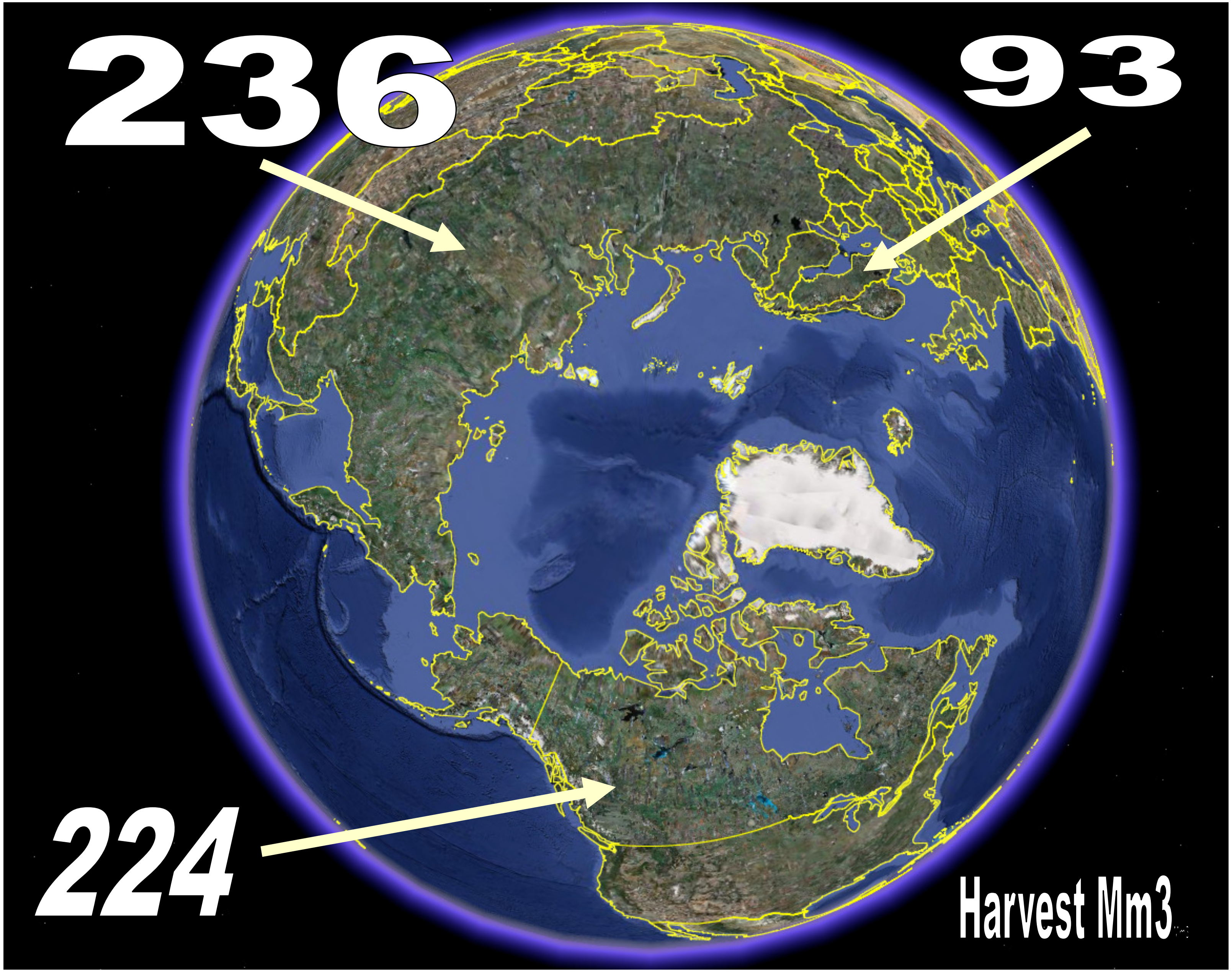
Conclusion:

Yes, we can increase the bioenergy supply from the forests very much without negative effects on the CO2 net uptake!


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


809
23
261
(NR)
Forest area
(Million hectares)


80.5
3.2
29.4 or 33
Stock
(Billion m3)


236
93
224
Harvest Mm3


ЛЕСОТЕХНИЧЕСКАЯ АКАДЕМИЯ

Annual Allowable Cut utilization rate, %

Conclusion:

The sustainable bioenergy supply from the forests of Russian Federation can increase very much.

Focus on Canada

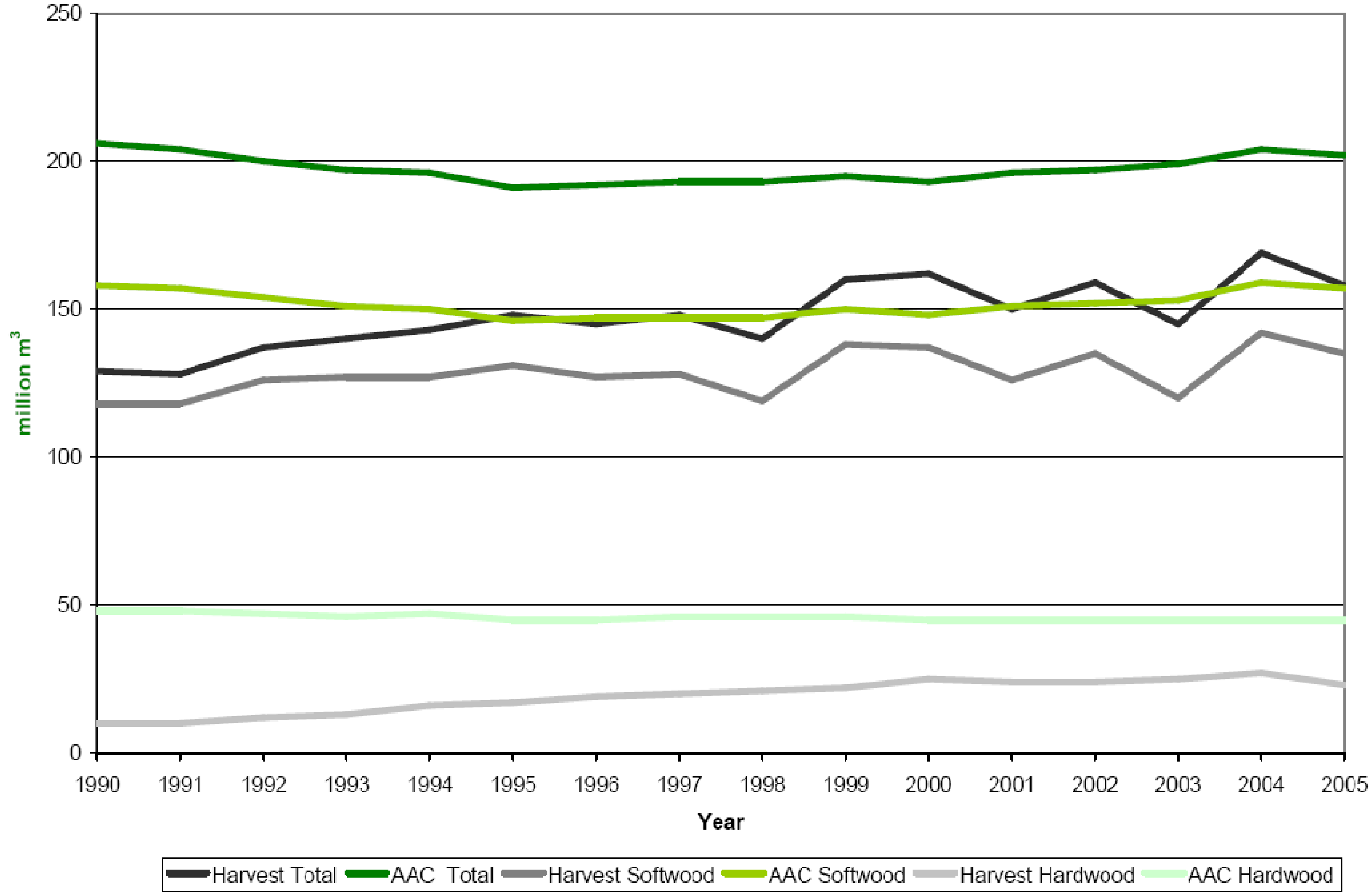


Figure 5.3a Allowable annual cut versus actual harvest (provincial crown land), 1990–2005 (million m3) (CCFM, 2008).

Criteria and Indicators of Sustainable Forest Management in Canada: National Status 2005
Data updated: January 2008

http://www.ccfm.org/ci/rprt2005/English/pdf/5.3a.pdf

Natural Resources Canada   Ressources naturelles Canada

http://www.canadaforests.nrcan.gc.ca/articletopic/14

A global endowment

Article Date: 2005-09-01

About 750 000 hectares—or 0.2 percent of the total boreal forest —are harvested each year.

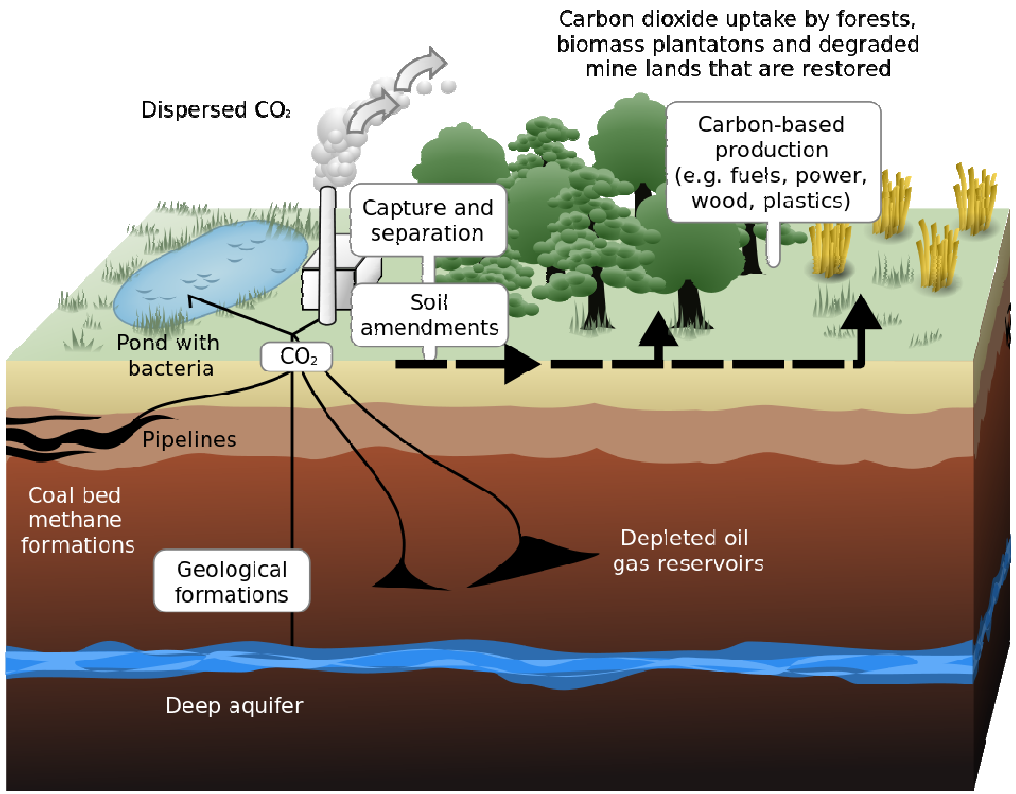
The part not managed for timber production is either unavailable because it has been designated as protected areas and reserves, or currently considered inaccessible.

Unlike the forests of the United States, Scandinavia and the majority of other nations, most of Canada's forests (93 percent) are publicly owned. The remaining 7 percent are held by private owners.

Conclusion:

The sustainable bioenergy supply from the forests of Canada can increase very much.

Maybe CCS (Carbon Capture and Storage) is also a useful component in our problem?



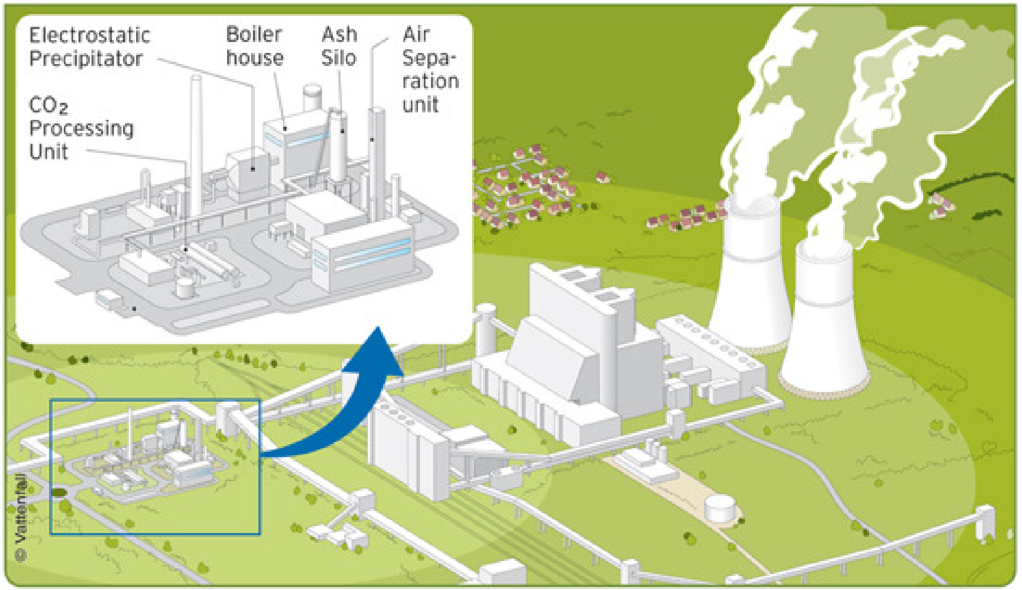
- **In Norway (Statoil) and UK (British Petroleum) , CCS (Carbon Capture and Storage) has been applied and a commercially attractive option during many years and the physical potential is large.**
- [Carbon Capture & Storage - *BP* Technology - YouTube]
- **With increasing carbon taxes in all parts of the world, such developments could be expected everywhere.**

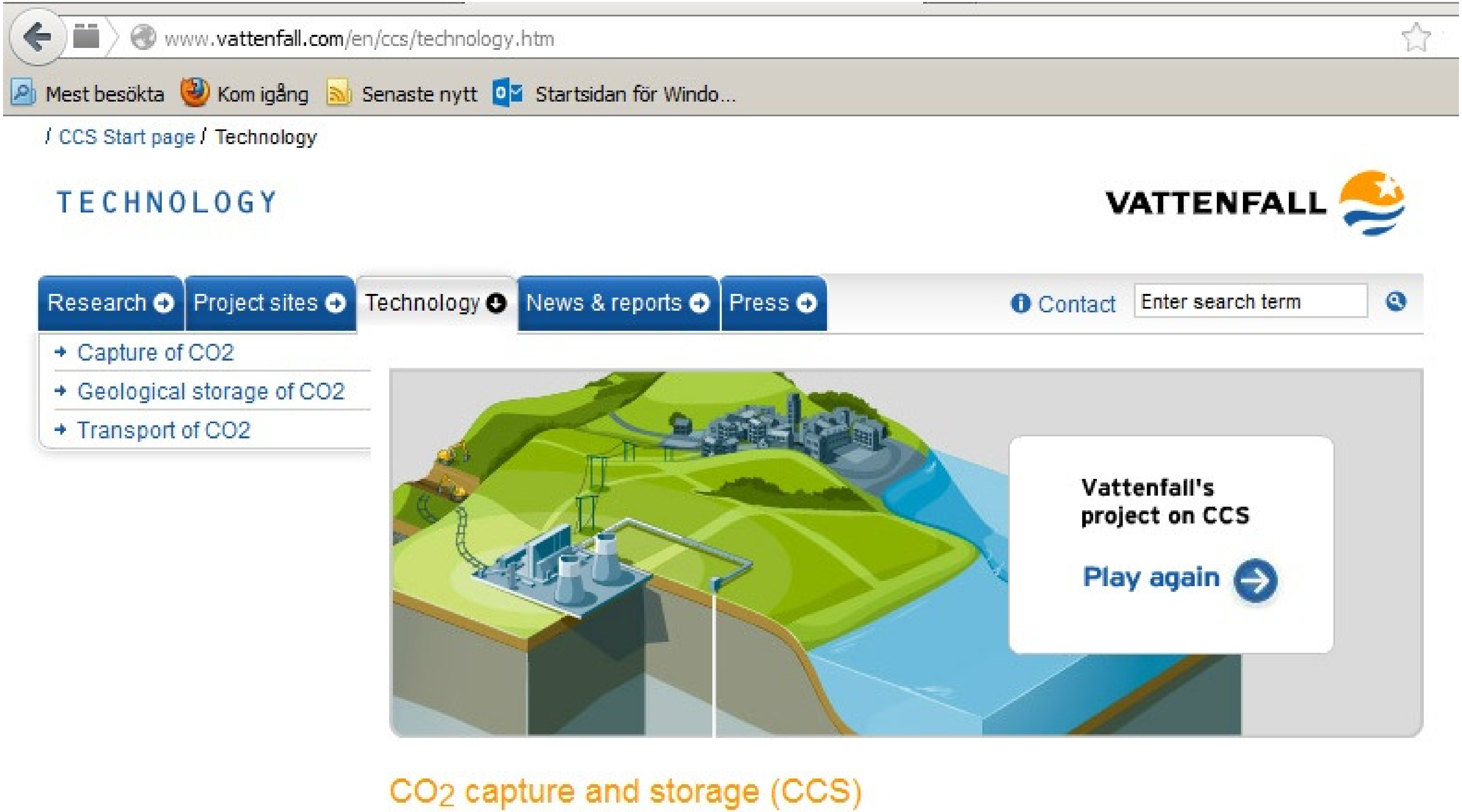
Vattenfall, a Swedish energy company, is also active in Germany and in CCS research.

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.




www.vattenfall.com/en/ccs/technology.htm
Mest besökta
Kom igång
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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)

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.

- Lohmander, P., Economic forest production with consideration of the forest and energy industries, E.ON International Bioenergy Conference, Malmo, Sweden, 2008-10-30
  http://www.lohmander.com/eon081030/eon081030.ppt

- Lohmander, P., Optimal dynamic control of the forest resource with changing energy demand functions and valuation of CO2 storage, UE2008.fr, The European Forest-based Sector: Bio-Responses to Address New Climate and Energy Challenges? Nancy, France, November 6-8, 2008
  http://www.lohmander.com/Nancy08/Nancy08.ppt

- Lohmander, P., The Economics of Forest Biomass and a Rational European Carbon Policy, NCSU, North Carolina State University, Pulp and Paper Laboratory, March 22, 2012
  http://www.lohmander.com/PLNCSU120322.ppt
  http://www.lohmander.com/PLNCSU120322.pdf
  http://www.lohmander.com/PLNCSU2012.pdf
  http://www.lohmander.com/PLNCSU2012.doc

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

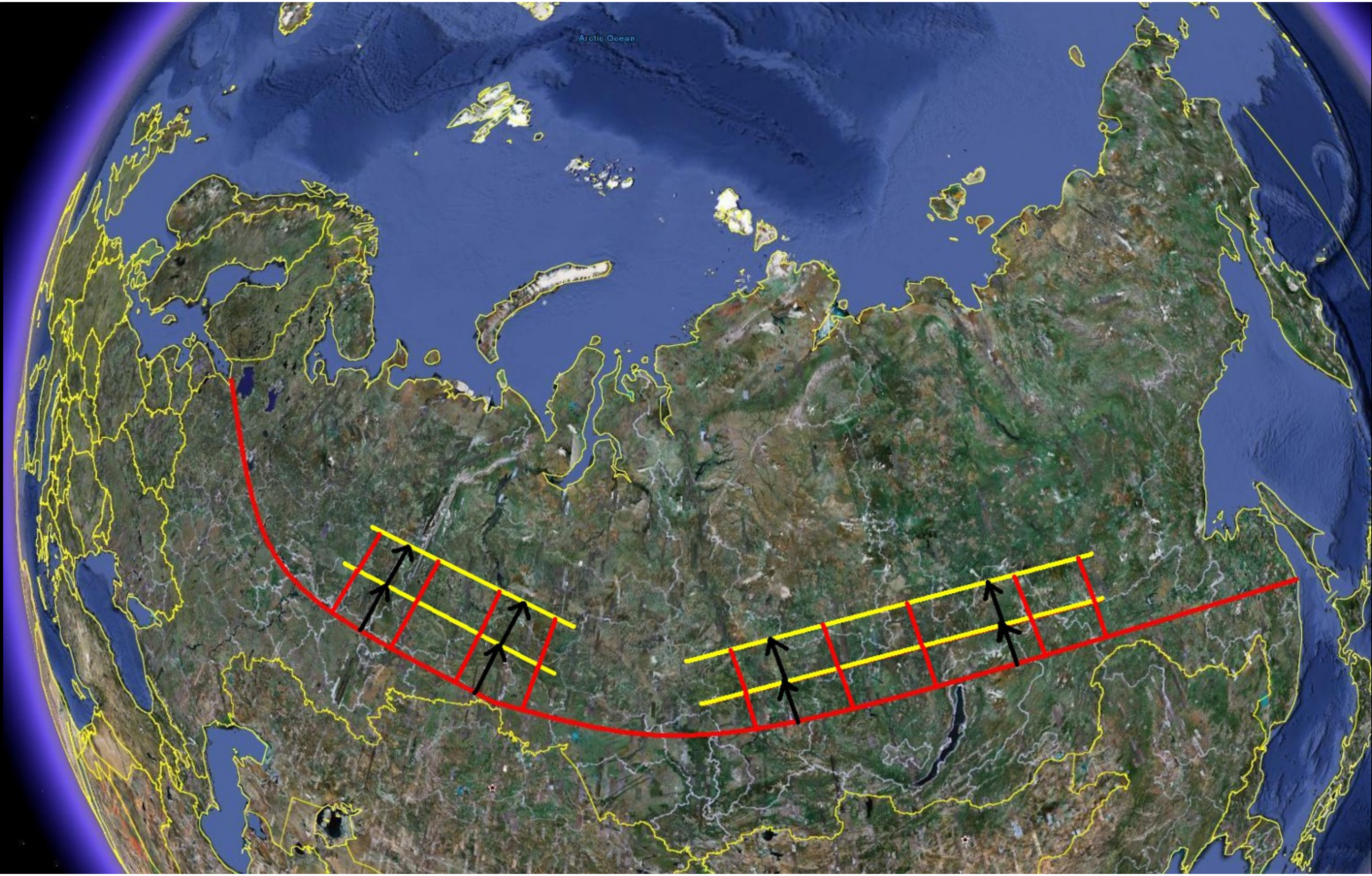
The "2020" targets of EU with respect to renewable energy, can be met, in an economically favorable way, with bioenergy from the forests of Russian Federation.

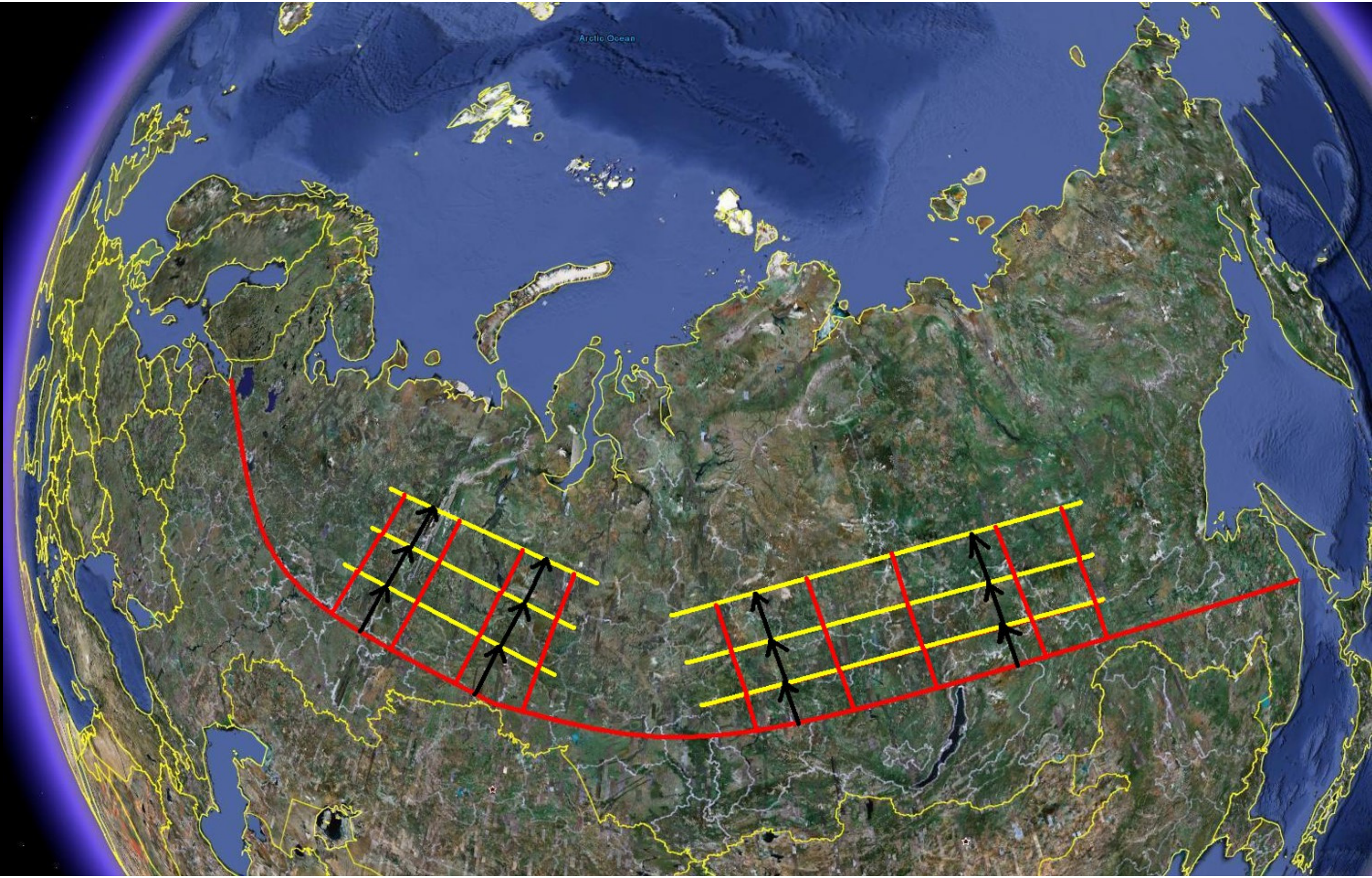
Lohmander, P., Methodology for optimization of coordinated forestry, bioenergy and infrastructure investments with focus on Russian Federation, Moscow State Forestry University Forest Bulletin, ISSN 1727-3749, No 84, Issue 1, 2012
http://www.lohmander.com/PLMosc12.pdf
http://www.lohmander.com/PLRU201202.doc
http://www.Lohmander.com/PLRU2010.pdf
http://www.lesaevrasii.ru/wp-content/uploads/oficialnye-dokumenty/sbornik_le_2010.pdf

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

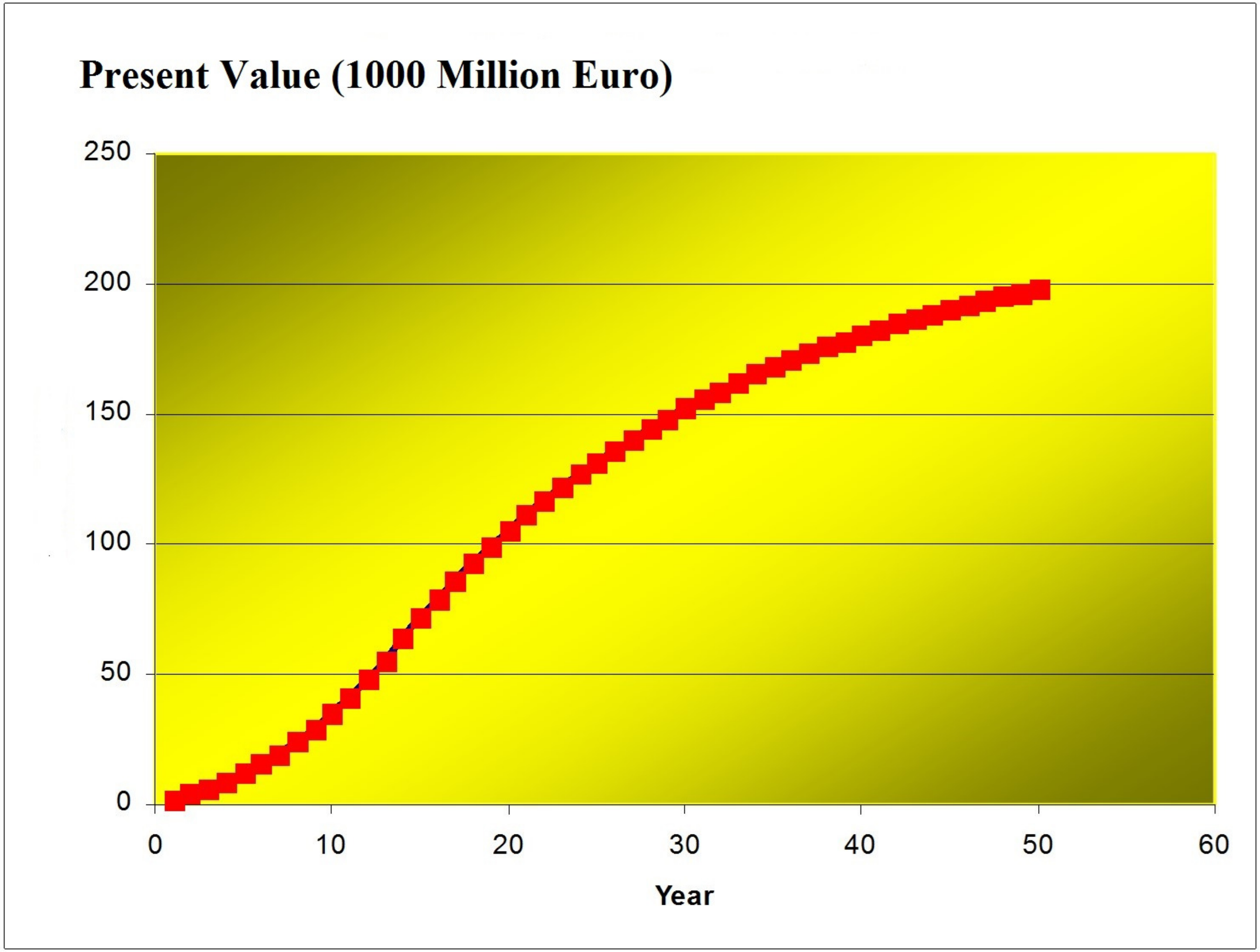

Arctic Ocean
Lohmander, P., Methodology for optimization of coordinated forestry, bioenergy and infrastructure investments with focus on Russian Federation,
Moscow State Forestry University Forest Bulletin,
ISSN 1727-3749, No 84, Issue 1, 2012


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

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

With expanded bioenergy based on forest resources, we may simultaneously and sustainably reduce global warming, improve economic results, international relations and environmental conditions

Professor Dr Peter Lohmander

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BIT's 4th Annual World Congress of Bioenergy

Theme: Roadmap Toward 2020

September 21-23

Qingdao International Convention Center, Qingdao, China

With expanded bioenergy based on forest resources, we may simultaneously and sustainably reduce global warming, improve economic results, international relations and environmental conditions

Professor Dr. Peter Lohmander, SLU, Sweden, http://www.Lohmander.com
Peter@Lohmander.com

- 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 and CO2 uptake can increase.
- In Norway and UK, CCS has been applied and a commercially attractive option during many years and the physical potential is large. 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 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.

[References](http://www.lohmander.com/Information/Ref.htm)
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

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:

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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