Biofuels for climate change mitigation and energy security

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Background

- Swedish climate goal is to reduce national GHG emissions by 50% in 2050
- Sweden also aims to minimize use of oil
- Biomass is an important but limeted resource

Aim

To analyse how an increased biomass production up to **400 PJ/year** (111 TWh/yr) in **Sweden** can be efficiently used to **reduce domestic**

1. Net emission of CO_2
2. Use of oil

Source: Gustavsson, L., Holmberg J.M., Dornburg V., Sathre R., Eggers T., Mahapatra K. and Marland G., 2007. Using biomass for climate change mitigation and oil reduction, *Energy Policy,* 35: 5671-5691.

Indices to compare options

To compare effectiveness in mitigating *climate change*:

* Monetary cost of CO_2 mitigation (€/CO_2 avoided)
* Primary energy cost of CO_2 mitigation (GJ primary energy/CO_2 avoided)
* Biomass cost of CO_2 mitigation (GJ biomass/CO_2 avoided)

To compare effectiveness in reducing *oil dependency*:

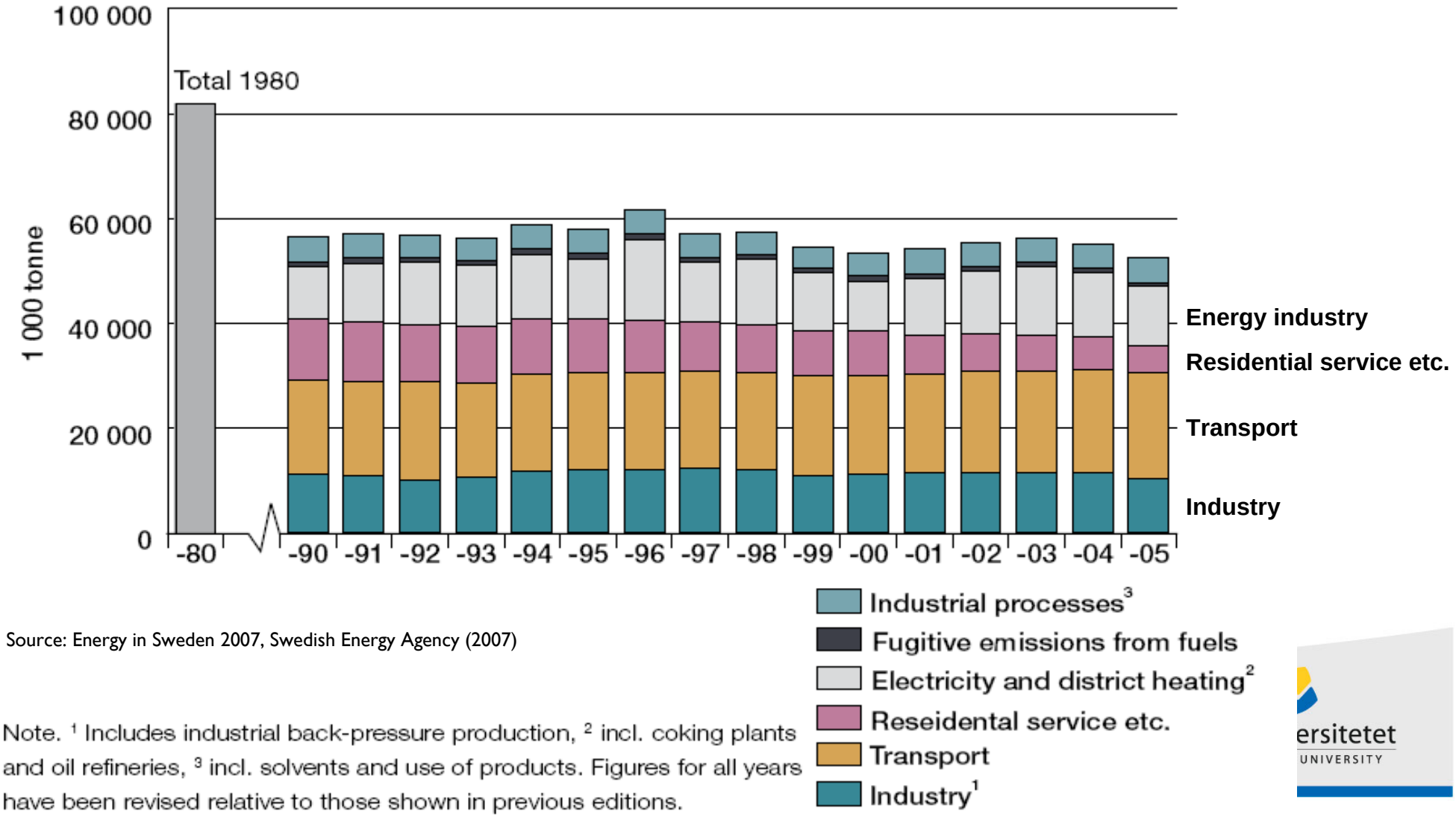
* Monetary cost of reduced oil imports (€/GJ oil reduced)
* Primary energy cost of reduced oil imports (GJ primary energy/GJ oil reduced)
* Biomass cost of reduced oil imports (GJ biomass/GJ oil reduced)

Four scenarios

- Maximize CO_2 emission reduction
- Maximize oil use reduction
- Reduce both CO_2 emission and oil use
- Produce ethanol for transport fuel

- ➢ Based on knowledge about technology performance and fossil fuel use
- ➢ Significant uncertainties

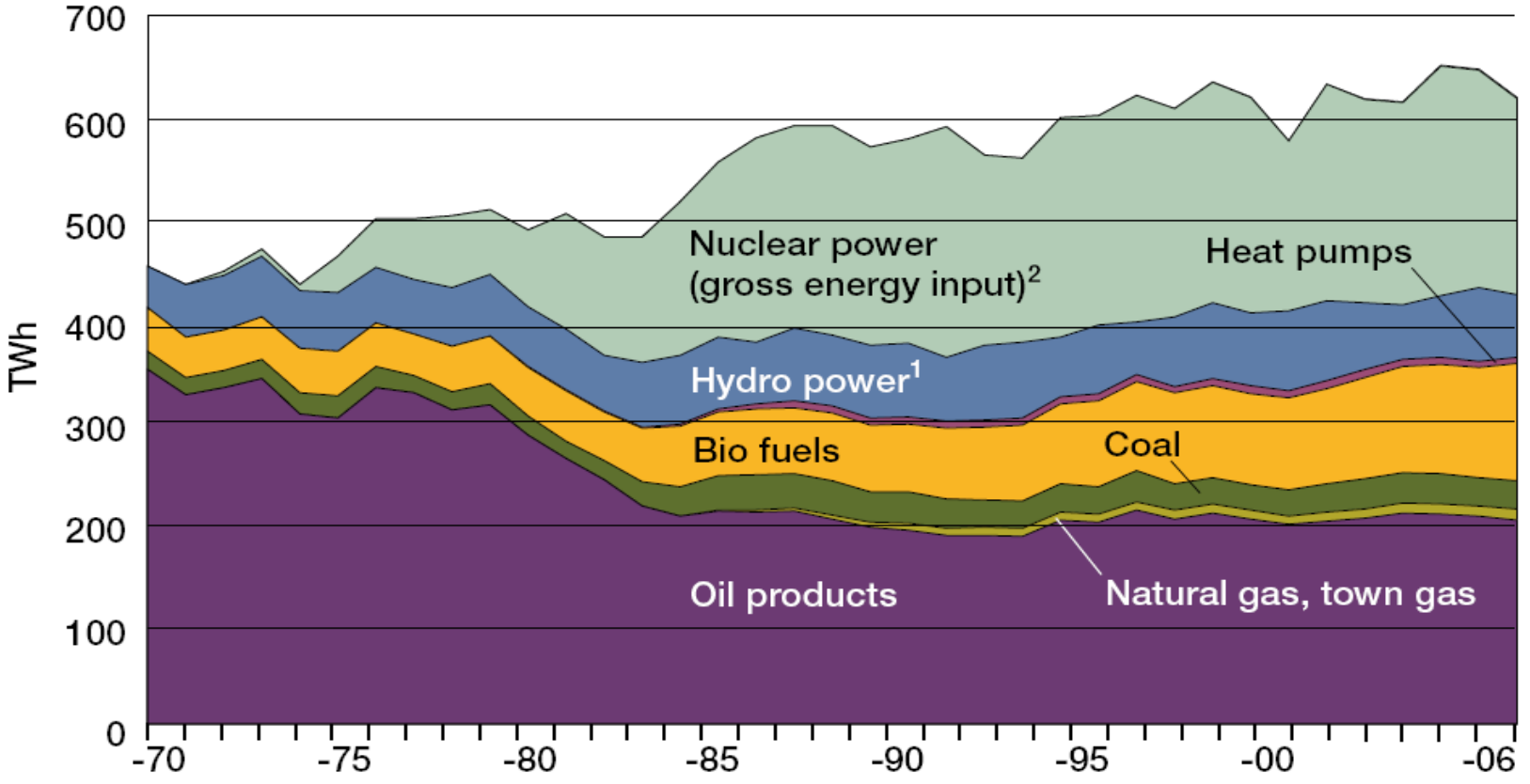
Swedish carbon dioxide (CO_2) emissions



Source: Energy in Sweden 2007, Swedish Energy Agency (2007)

Note. [1] Includes industrial back-pressure production, [2] incl. coking plants and oil refineries, [3] incl. solvents and use of products. Figures for all years have been revised relative to those shown in previous editions.

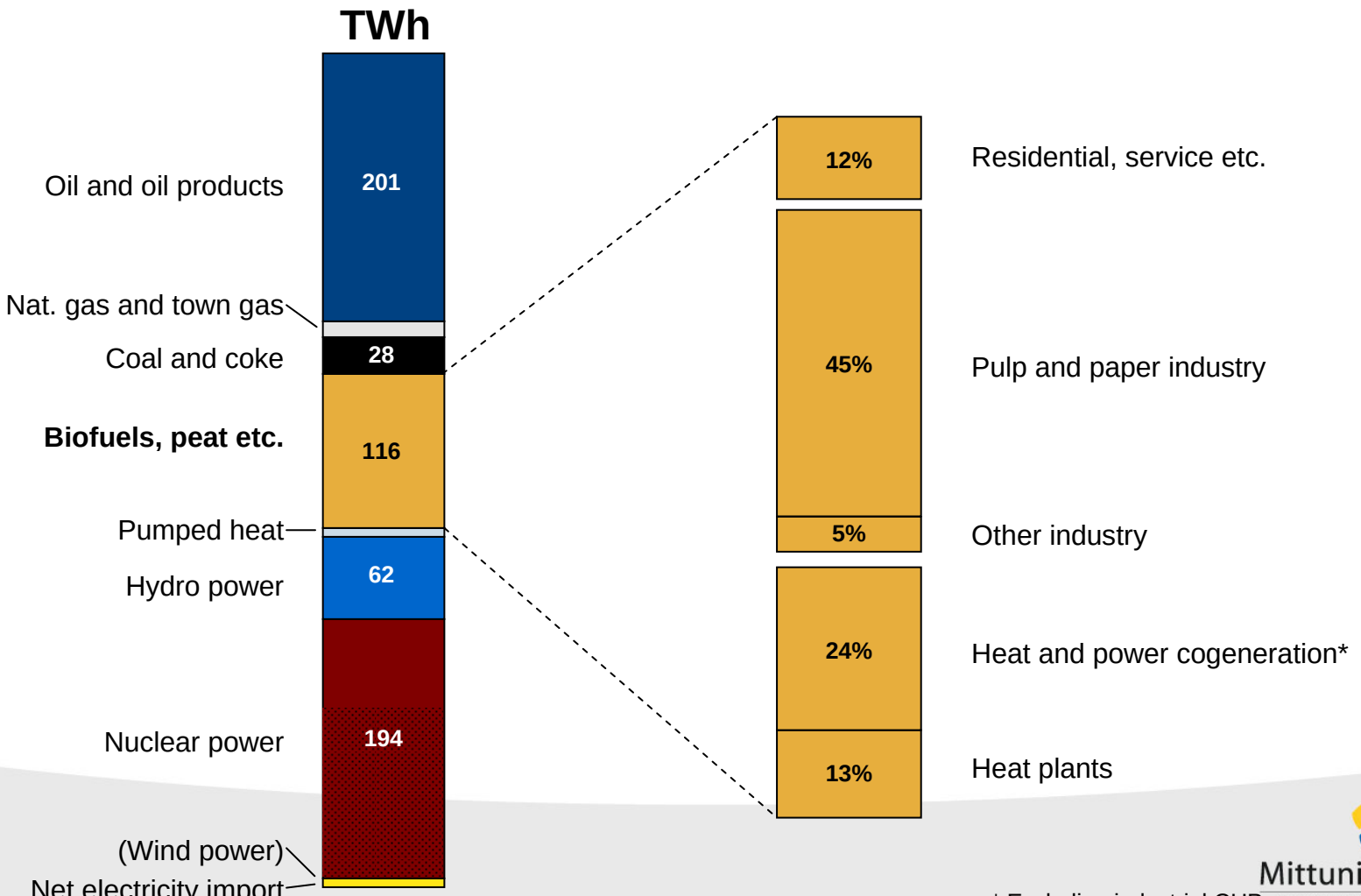
Total energy use in Sweden, 1970-2006, excluding net electricity exports



SOURCE: STATISTICS SWEDEN AND THE SWEDISH ENERGY AGENCY

Note. [1] Including wind power up to and including 1996 . [2] Calculated in accordance with the UN/ECE method for energy supply from nuclear power.

Energy supply and use in Sweden 2006 (2)



* Excluding industrial CHP

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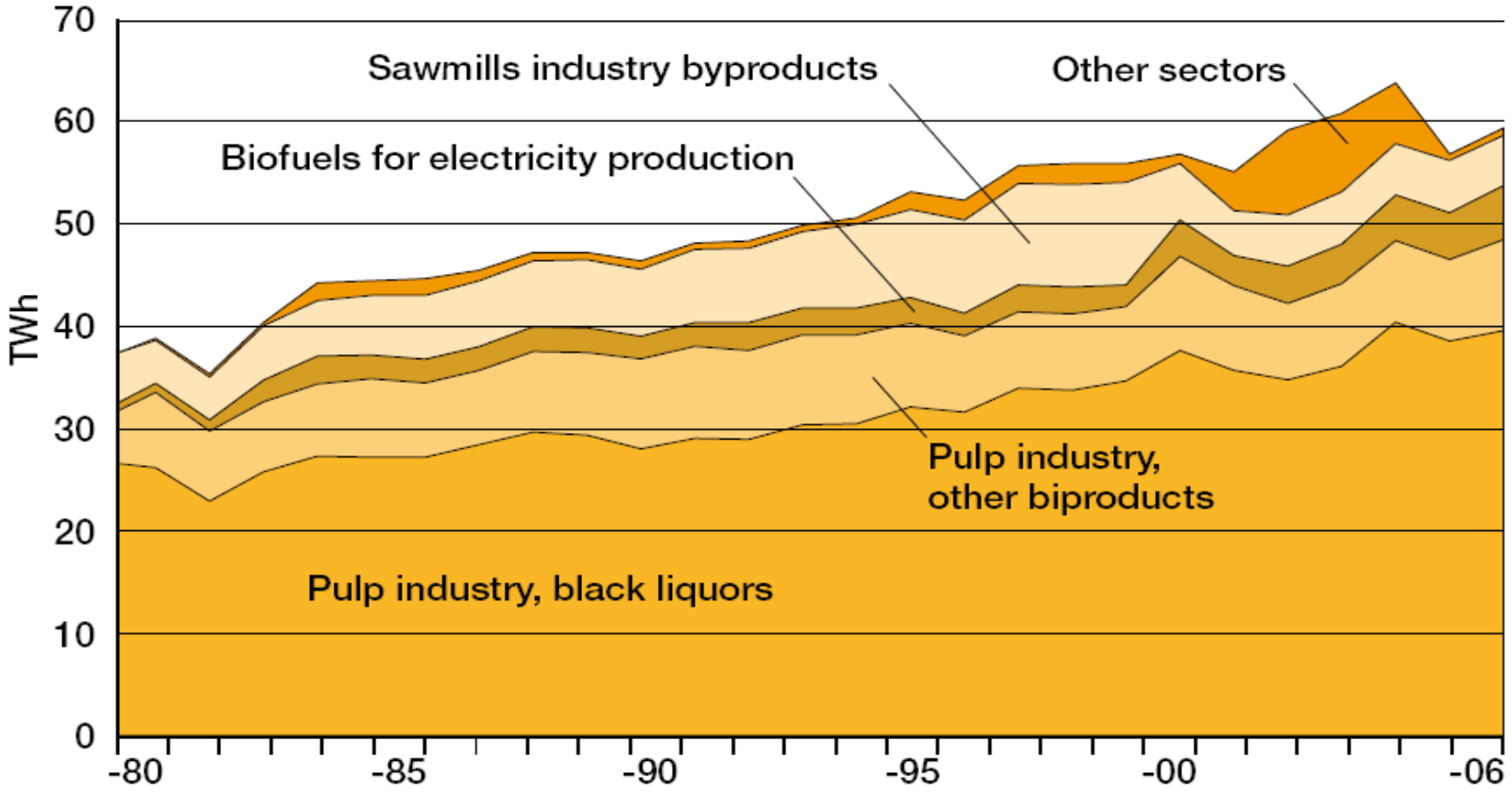
Source: Energy in Sweden 2007, Swedish Energy Agency (2007); Energiförsörjningen fjärde kvartalet 2006, Statistics Sweden (2007)

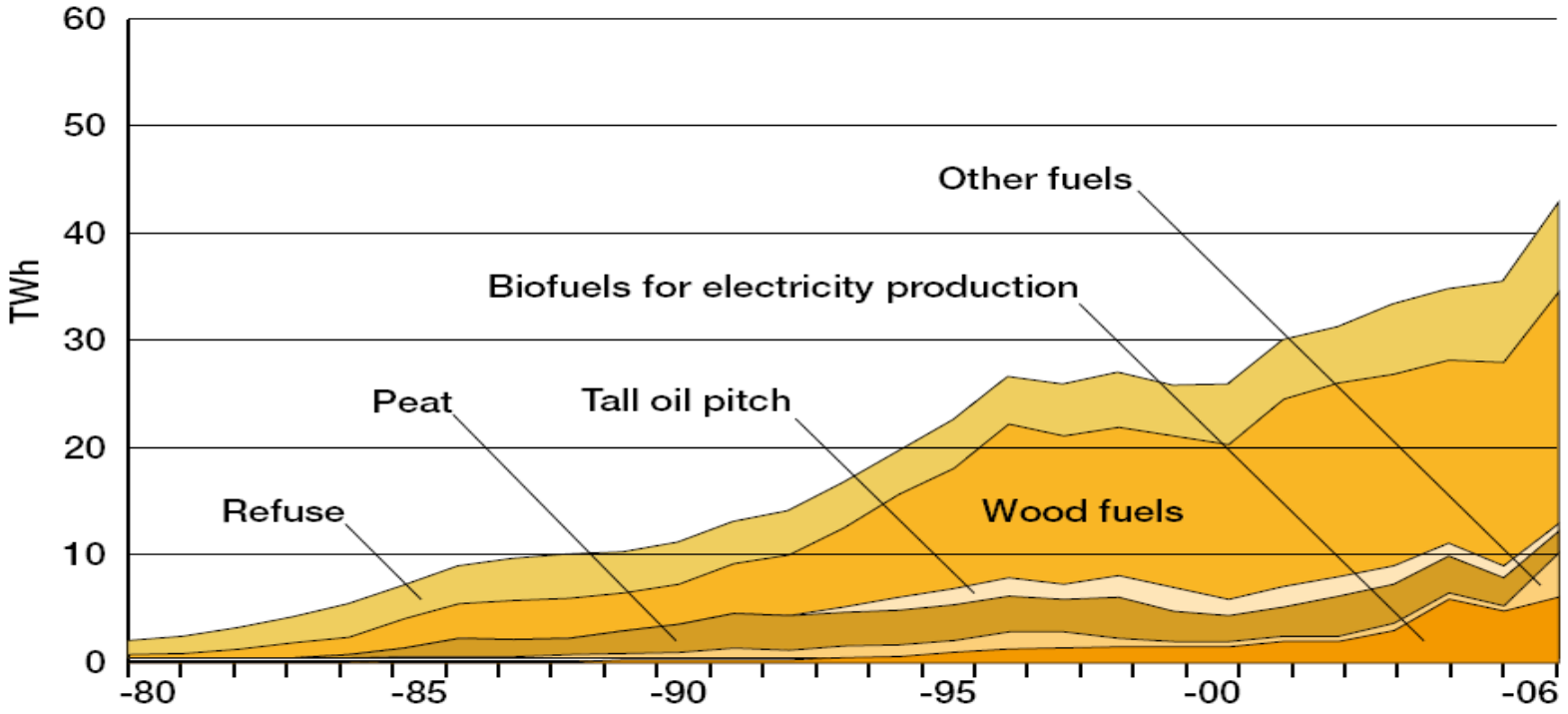
Use of biofules, peat etc. in *industry*, 1980-2006



SOURCE: STATISTICS SWEDEN AND THE SWEDISH ENERGY AGENCY

Note. The preliminary statistics for other sectors have been under-estimated for the last few years. See the text for more details.

Use of biofules, peat etc. in *district heating* plants, 1980-2006



SOURCE: STATISTICS SWEDEN AND THE SWEDISH ENERGY AGENCY

Note. The preliminary statistics for the use of wood fuels have been systematically over-estimated for several years. See the text for more details.

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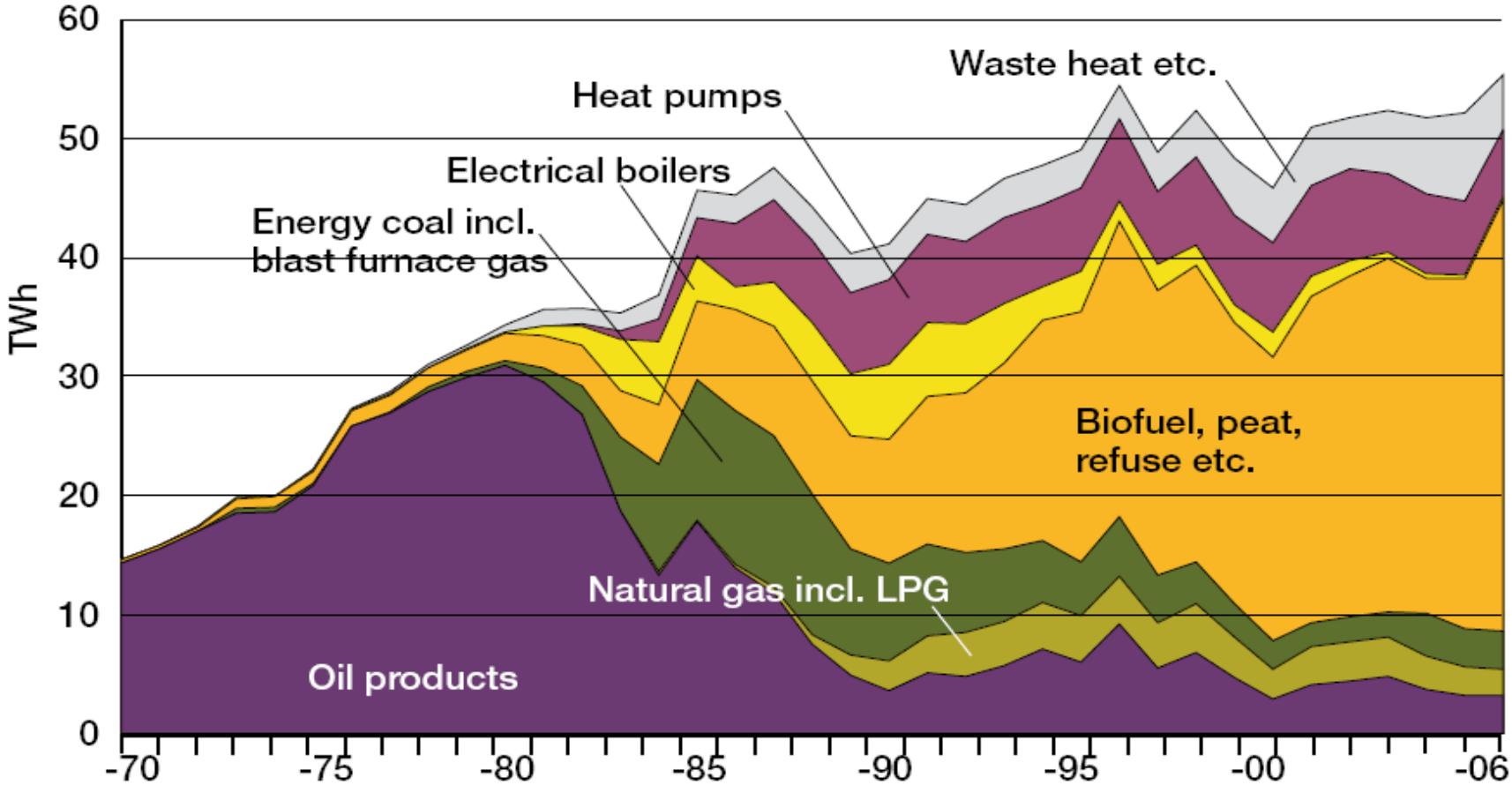
Energy input for *district heating*, 1970-2006



SOURCE: STATISTICS SWEDEN AND THE SWEDISH ENERGY AGENCY

Emission of CO_2 in Sweden - 2004

	Mton	%
Industry	11,4	20,6
Industrial processes etc.	4,7	8,5
Transport	19,9	35,9
Residential and Services etc.	6,0	10,9
Electricity and district heating	12,4	22,5
Fugitive emissions from fuels	0,9	1,6
Total	**53,4 Mton CO_2 = 14,6 Mton C**	

Final use of fossil fuels 2004 in different sectors and for electricity and district heating production

Sector	**Oil**	**(%)**
Industry	19.5	(14)
Transport (diesel, petrol)	82.3*	(59)
Transport (aviation fuels)	10.0	(7)
Residential and Services etc.	21.7	(16)
Electricity production	2.4	(2)
District heating production	3.7	(3)
Total	**139.6 TWh**	
Total	**502.6 PJ**	

*Petrol 47.8; Diesel 34.5

Basic assumptions

- Same reference units (avoid allocation)
- System boundaries: from natural resource to delivered service
- Commercial or potentially commercial technologies from a short-time period perspective
- Current final energy use
- Structural changes (electric heating converted to district heating, heat pumps, pellet boilers)
- Electricity production from an European perspective (marginal electricity coal-fired)

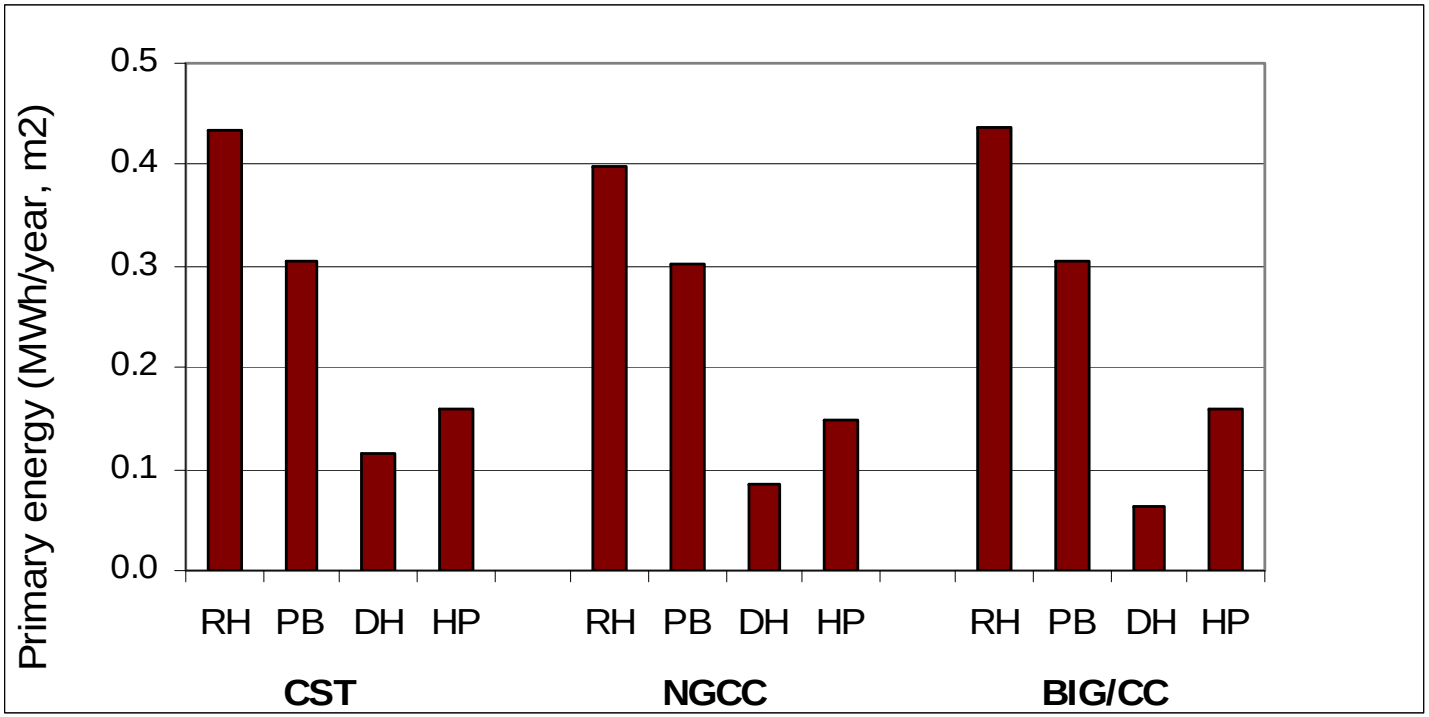
Alternative technologies for biomass utilization

- Electricity and heat production
  - Residential-/premises heating, small- and medium-scale establishments (s1-s12, m1-m8)
  - Industrial process heat (i1-i5)
  - District heating (d1-d4)
  - Electricity production only (e1-e3)
- Liquid transportation fuels (t1-t8)
- Wood building construction (b1)
- Replace coke in iron production (c1)
- Co-production of electricity and refined fuels in pulp mills (p1-p7)

Ref. Nr.	Reference fossil technology	Biomass technology
	Reference fossil technolog	**Biomass technology**
	Small-scale heat	
s1	Small scale oil boiler	Pellet boiler
s2	Small scale gas boiler	Pellet boiler
s3	Electric resistance heating	Pellet boiler
s4	Electric boiler	Pellet boiler
s5	Small scale oil boiler	Heat pump with bio-electricity
s6	Small scale gas boiler	Heat pump with bio-electricity
s7	Electric resistance heating	Heat pump with bio-electricity
s8	Electric boiler	Heat pump with bio-electricity
s9	Small scale oil boiler	DH - BIG/CC CHP
s10	Small scale gas boiler	DH - BIG/CC CHP
s11	Electric resistance heating	DH - BIG/CC CHP
s12	Electric boiler	DH - BIG/CC CHP
	Medium scale heat	
m1	Oil boiler	Medium scale wood boiler
m2	Gas boiler	Medium scale wood boiler
m3	Coal boiler	Medium scale wood boiler
m4	Oil boiler	DH - BIG/CC CHP
m5	Gas boiler	DH - BIG/CC CHP
m6	Coal boiler	DH - BIG/CC CHP
m7	Electric resistance heating	DH - BIG/CC CHP
m8	Electric boiler	DH - BIG/CC CHP
	Industrial heat/steam	
i1	Process heat, oil boiler	Industrial wood boiler
i2	Process heat, gas boiler	Industrial wood boiler
i3	Process heat, coal boiler	Industrial wood boiler
i4	Industrial space heating, oil boiler	Medium scale wood boiler
i5	Industrial space heating, oil boiler	DH - BIG/CC CHP

Ref. Nr.	Reference fossil technology	Biomass technology
	Reference fossil technology	**Biomass technology**
	Electric power only	
e1	Power plant oil	Power - BIG/CC
e2	Power plant gas	Power - BIG/CC
e3	Power plant coal	Power - BIG/CC
	Transport fuels	
t1	Gasoline	Ethanol
t2	Gasoline	Methanol
t3	Diesel	DME
t4	Diesel	FT-Diesel
t5	CNG	Ethanol
t6	CNG	Methanol
t7	CNG	DME
t8	CNG	FT-Diesel
	Building material	
b1	Concrete-frame building [a]	Wood-frame building
b2	Concrete-frame building [b]	Wood-frame building
	Metallurgy	
c1	Metallugy coke [a]	Charcoal
c2	Metallugy coke [b]	Charcoal
	Pulp and paper, BLG	
p1	Coal-based electricity	BLGCC
p2	Gas-based electricity	BLGCC
p3	Diesel [a]	BLGDME
p4	Gasoline [a]	BLGMethanol
p5	Diesel [b]	BLGDME
p6	Gasoline [b]	BLGMethanol

Space heating of detached houses – primary energy use



HP= Heat pump
RH= Resistance heaters
DH= District heating
CHP=Combined heat and power

CST= Coal, steam turbine
BST= Biomass, steam turbine
BIG/CC= Biomass, integrated gasification combined cycle

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Efficient co-generation of energy products in pulp industry

We have compared **potential** production of electricity and motor fuels in pulp mills using

- Conventional recovery boiler (RB) - reference
- Black liquor gasification combined cycle (BLGCC)
- Black liquor gasification for motor fuels (BLGMF)

Source: Holmberg, J.M. and Gustavsson, L., CO_2 and oil use reduction by implementation of black liquor gasification and energy efficiency in pulp and paper industry, *Resources, Conservation and Recycling* (accepted).

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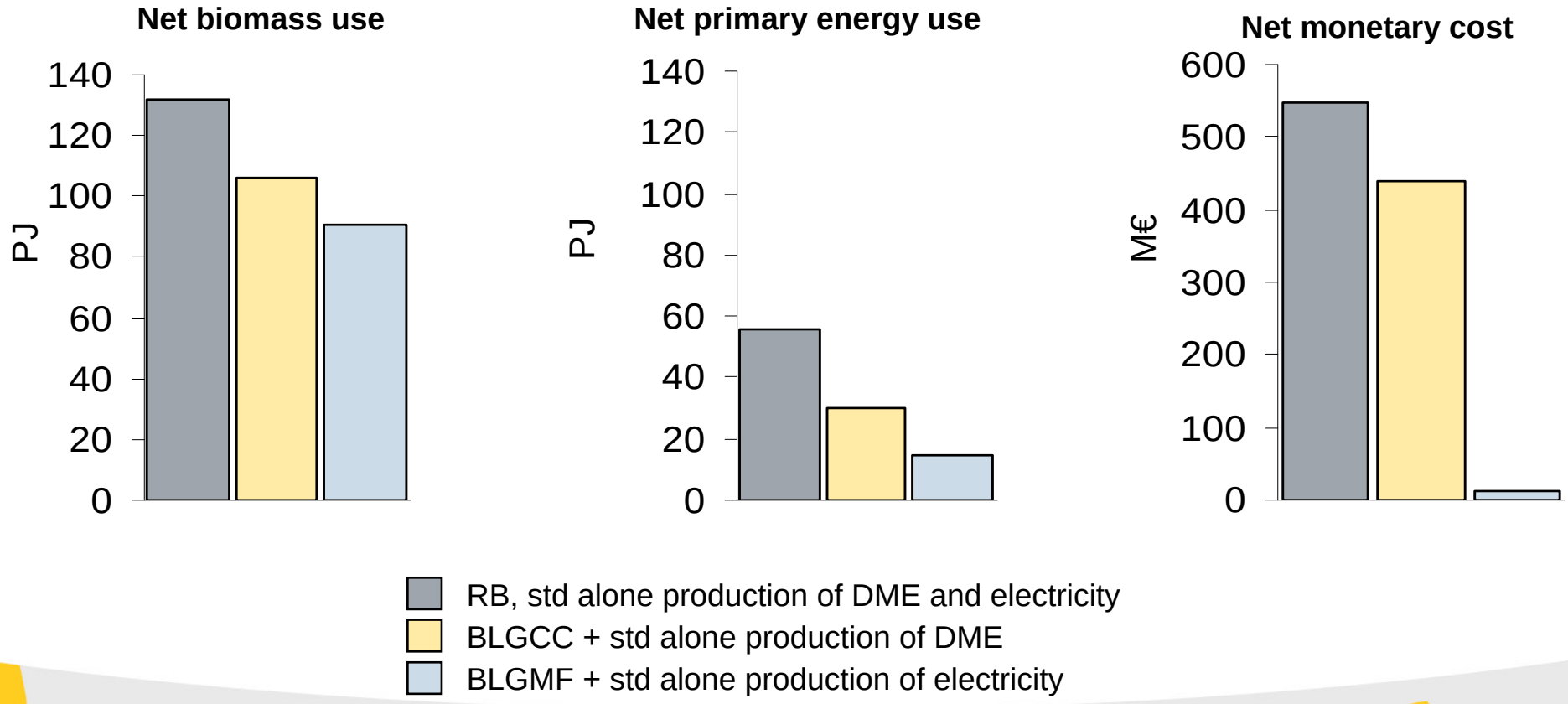
Costs to reduce Swedish CO_2 emissions by 1.6 Mt C and oil use by 64 PJ



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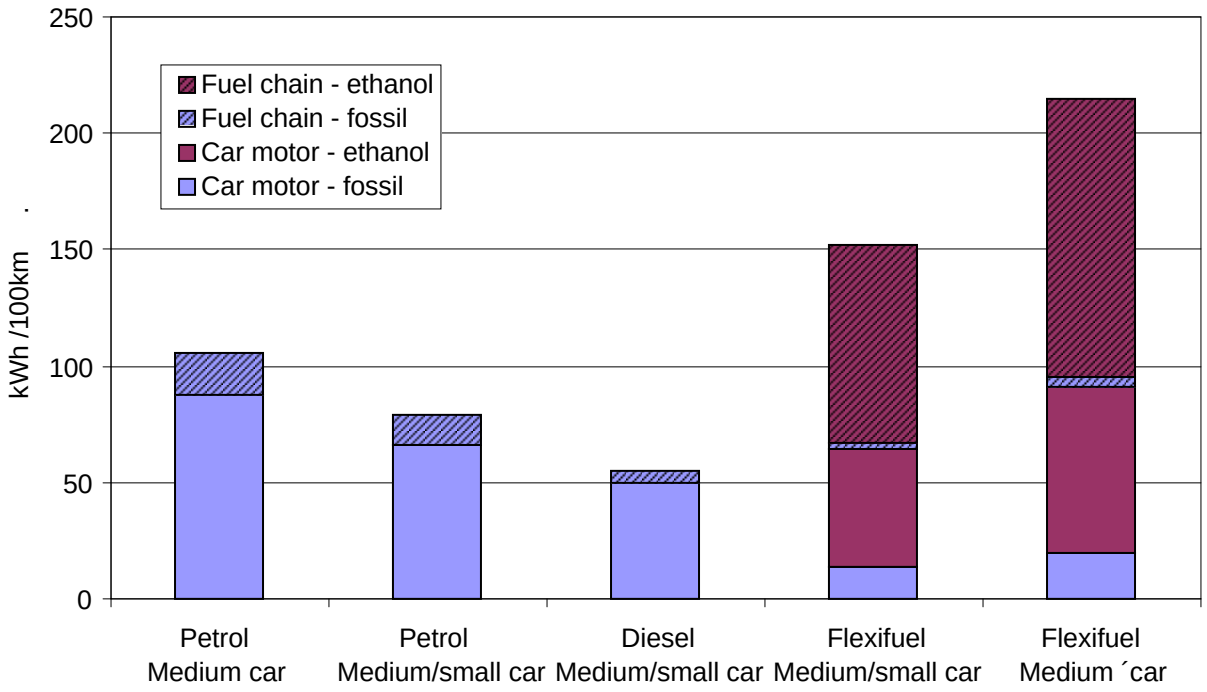
Primary energy use for various types of cars and transportation fuels



Source: Konsumentverket, Vägverket, Naturvårdsverket, 2006

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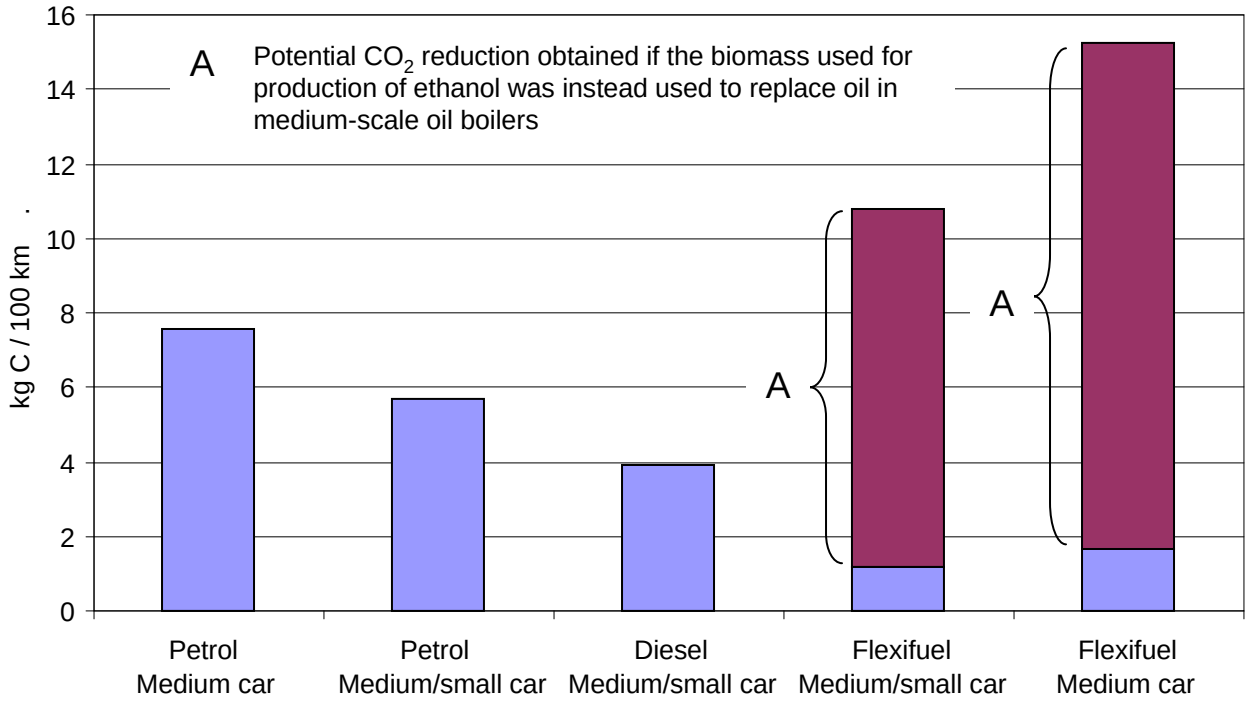
Fuel-cycle CO_2 emission for various types of cars and transportation fuels



Source: Konsumentverket, Vägverket, Naturvårdsverket, 2006

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Sector potential fossil fuel reduction

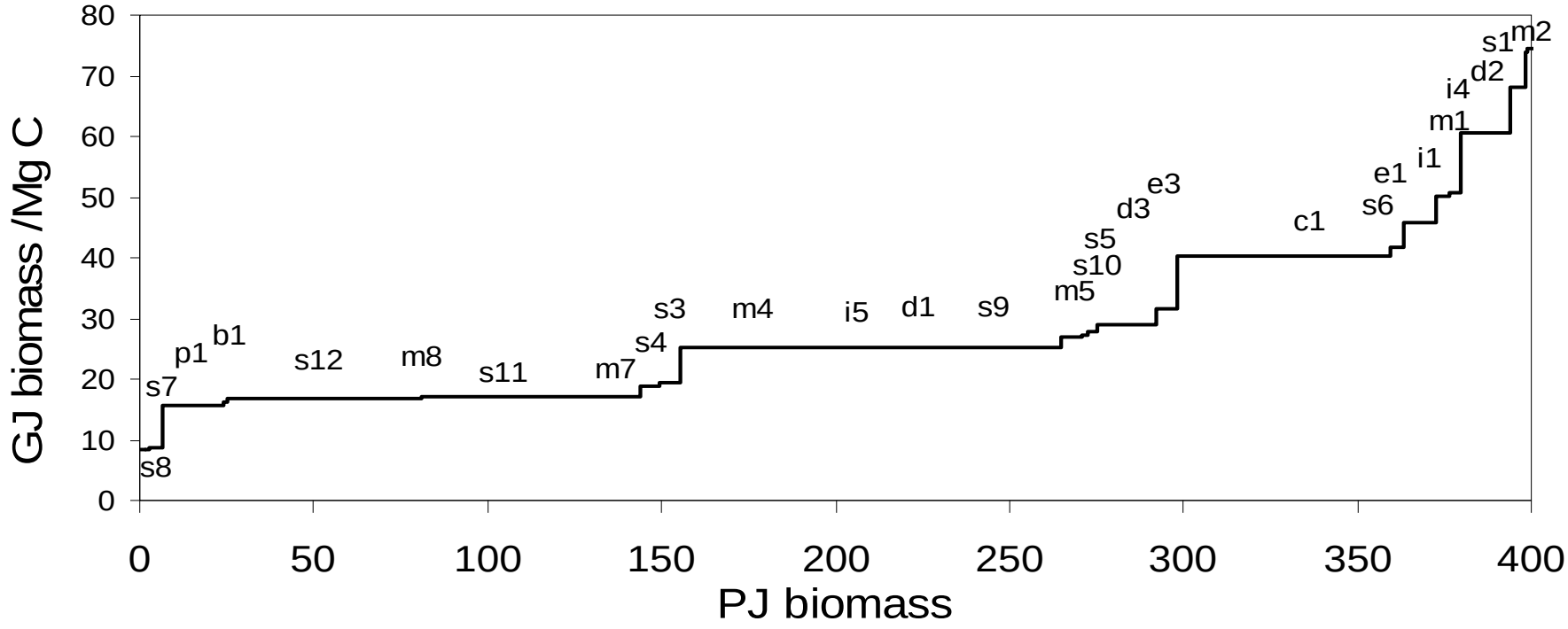
Table 6.1: Current levels of fossil use in Sweden, and potentials to replace with biomass intensive technologies.

Fossil use	Current level of use/activity	Potential replacement [a]
Small scale heating in densely populated areas [1,2,3]		
Oil boiler	20.4 PJ oil	PB: 100%, HP: 10%, DH: 95%
Gas boiler	0.7 PJ natural gas	PB: 95%, HP: 10%, DH: 95%
Electric boiler	19.0 PJ electricity	PB: 95%, HP: 10%, DH: 95%
Resistance heaters	18.0 PJ electricity	PB: 95%, HP: 10%, DH: 95%
Small scale heating in sparsely populated areas [1,2,3]		
Oil boiler	8.4 PJ oil	PB: 100%, HP: 50%, DH: 0%
Electric boiler	7.8 PJ electricity	PB: 95%, HP: 50%, DH: 0%
Resistance heaters	9.7 PJ electricity	PB: 95%, HP: 50%, DH: 0%
Medium scale heating [1,2]		
Oil boiler	20.5 PJ oil	PB: 100%, DH: 80%
Gas boiler	3.7 PJ natural gas	PB: 95%, DH: 80%
Electric boiler	4.7 PJ electricity	PB: 95%, DH: 80%
Resistance heaters	9.3 PJ electricity	PB: 95%, DH: 80%
Industrial oil use [1,4,5]	54 PJ oil	Process heat, biomass boiler: 20% Space heat: PB 30%, DH 25%
District heating [6]	11.9 PJ oil	BIG/CC CHP: 20% Wood powder burner: 65%
Electricity production [6]		
Oil power plant	8.7 PJ oil	BIG/CC: 50%
Coal power plant	6.4 PJ coal	BIG/CC: 100%
Transport [7]		
Gasoline	180 PJ gasoline	Methanol: 95%
Diesel	138 PJ diesel [b]	DME: 100%
Building construction [8]	20,000 apartments, concrete frame	Wood frame: 75%
Metallurgy [9]	41.6 PJ coke	Charcoal: 100%
Pulp and paper		
Black liquor [10]	138 GJ black liquor	BLG: 75%
Lime kilns [4]	6 PJ oil	Biomass fuel: 75%

a) PB: Pellet boiler; HP: Heat pump; DH: District heating. For some categories, several possible biomass technologies are considered and they may have different potentials to replace the current use. In the case of oil boilers, for example, pellet boilers have the potential to replace 100% of oil boilers but district heating systems have the potential to replace only 80% of oil boilers. The implementation of one technology will limit the potential for others.
b) Including 28.3 PJ delivered to other sectors than transport.
References: 1) Statistics Sweden, 2004a; 2) Statistics Sweden, 2004b; 3) K-Konsult, 2001; 4) Wiberg, 2001; 5) SEPA, 2006a; 6) Statistics Sweden, 2005b; 7) Statistics Sweden, 2005a; 8) Boverket, 2006; 9) Statistics Sweden, 2006b; 10) Statistics Sweden, 2004c

Climate change mitigation scenario

Biomass cost to reduce carbon emission (GJ biomass / Mg C)



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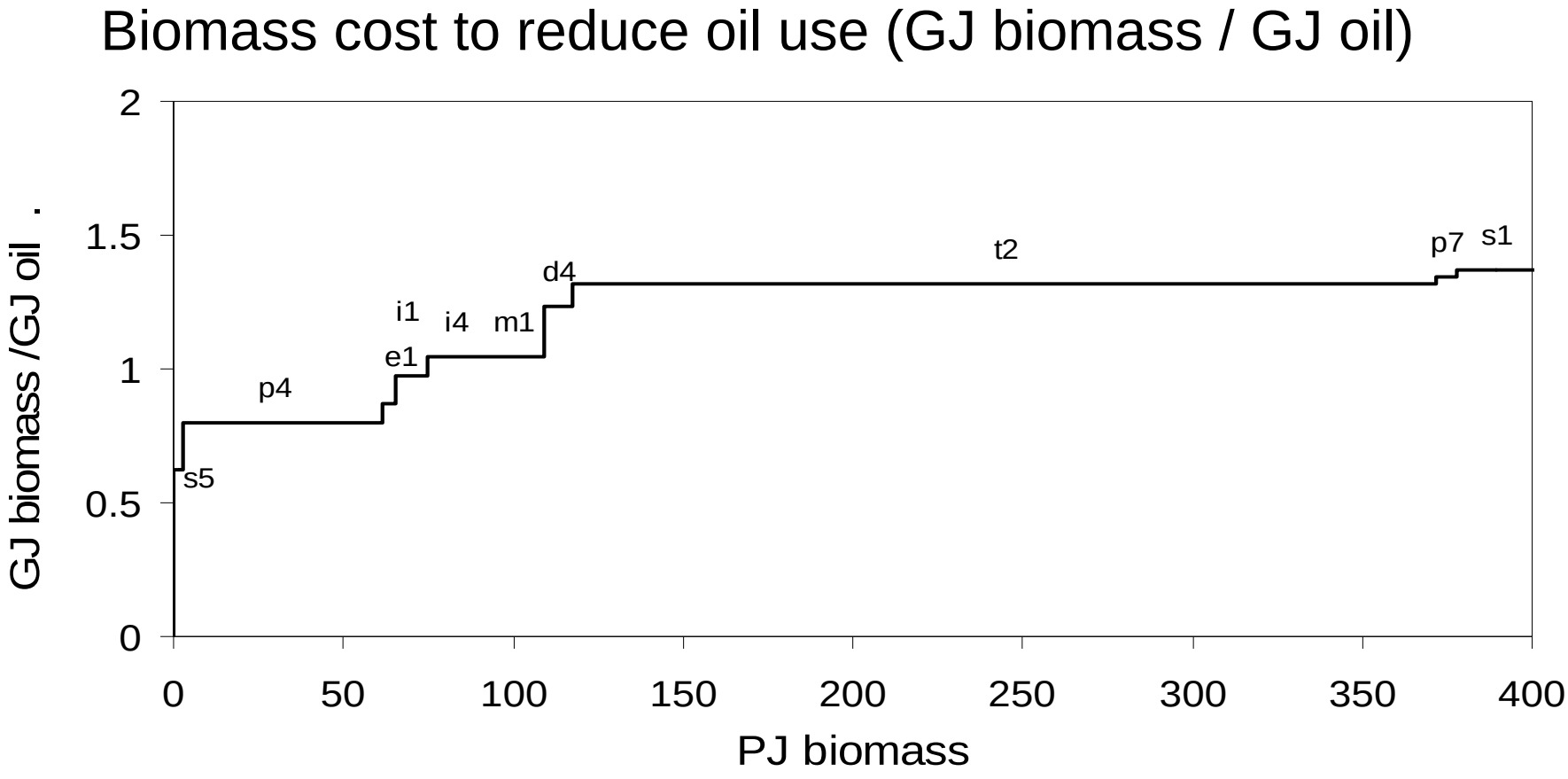
Oil reduction scenario



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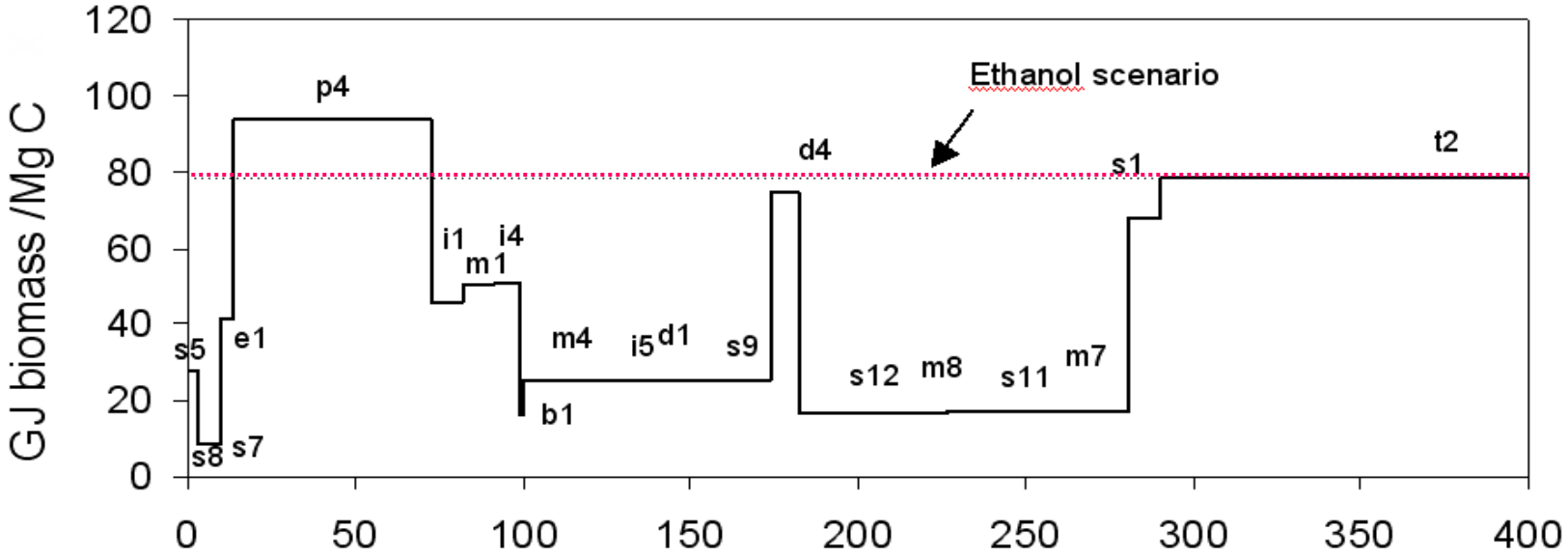
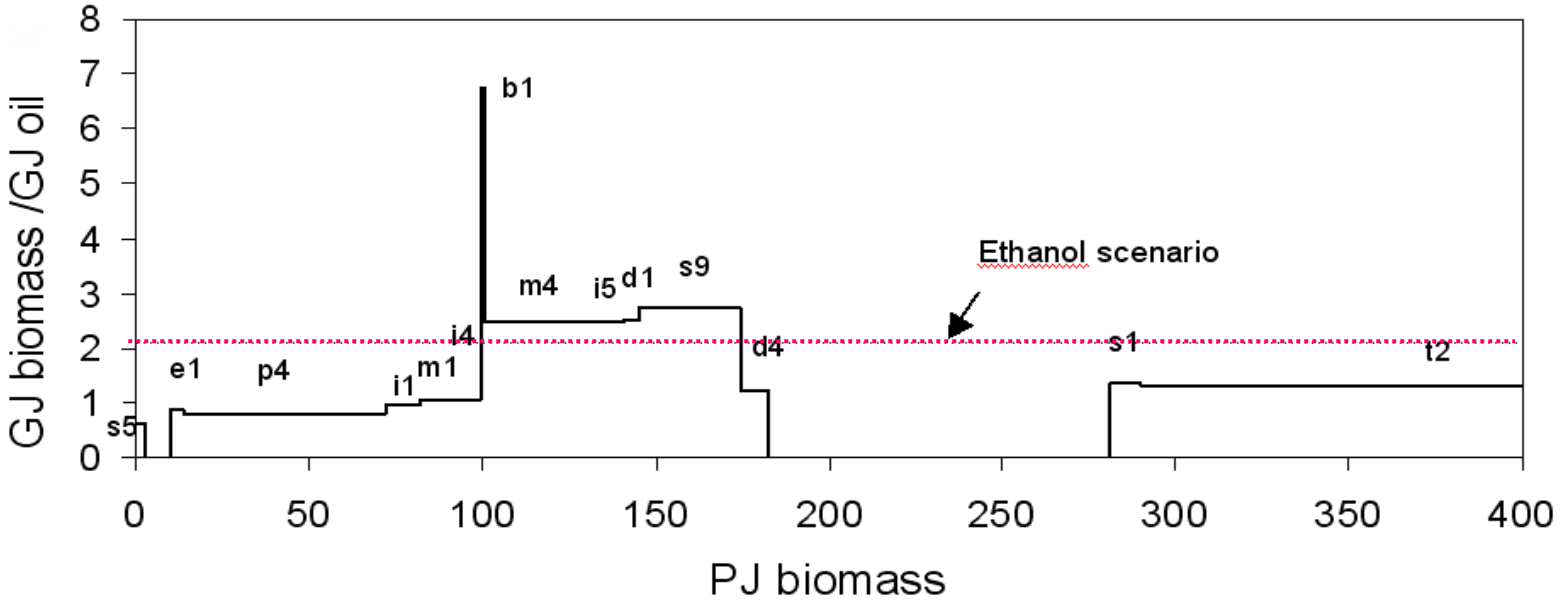
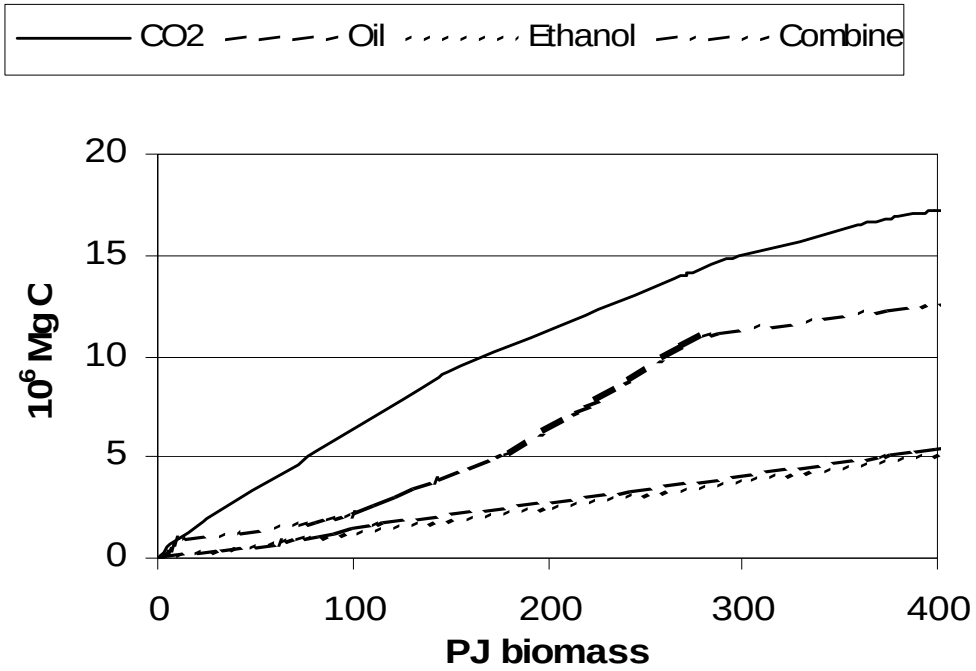
Combined scenario



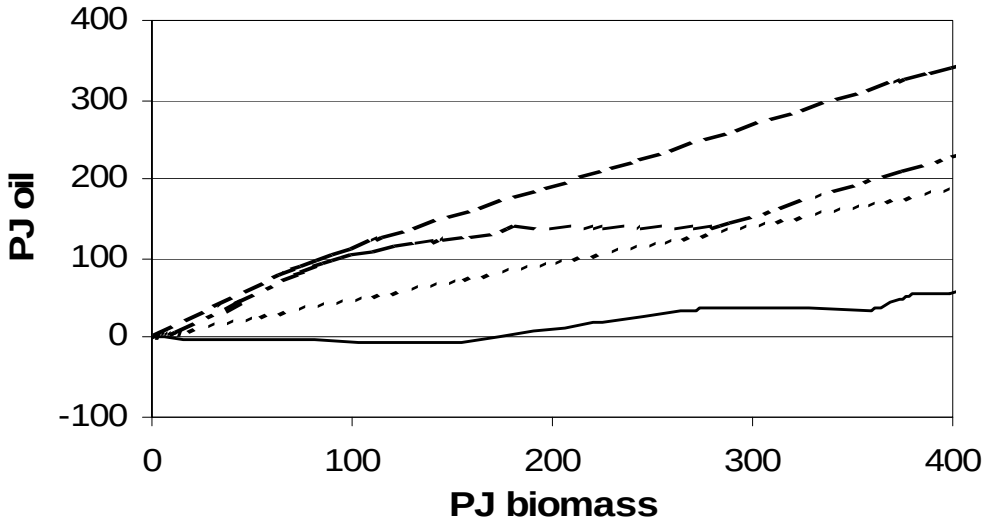


Cumulative results (up to 400 PJ biomass)

CO_2 emission reduction



Oil use reduction



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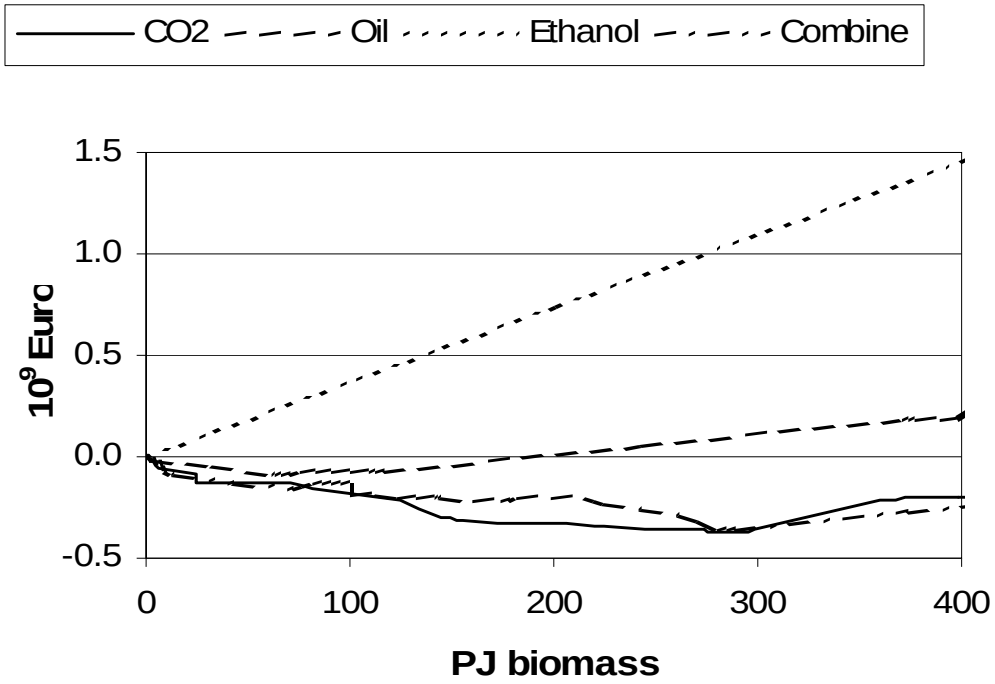
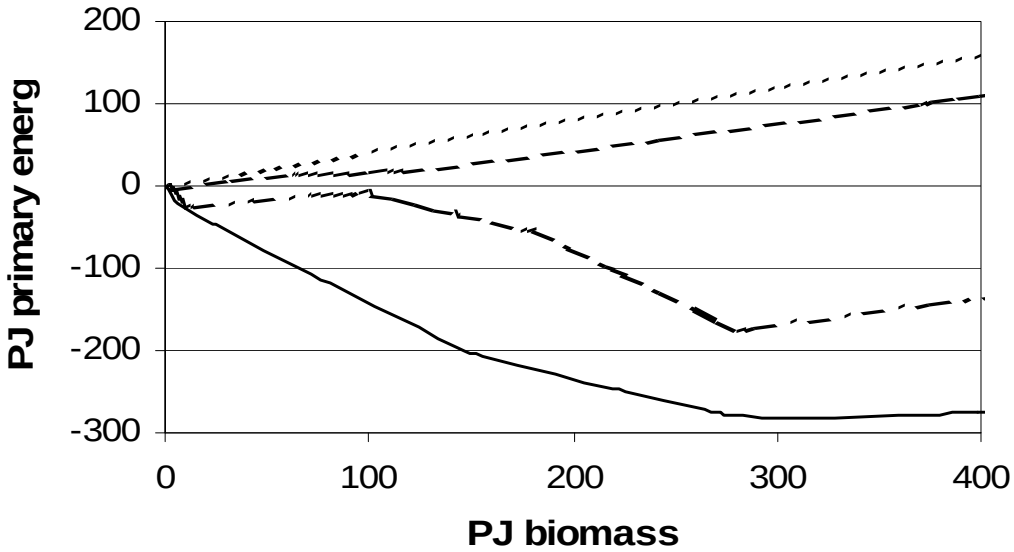
Cumulative costs

Monetary cost



Primary energy cost



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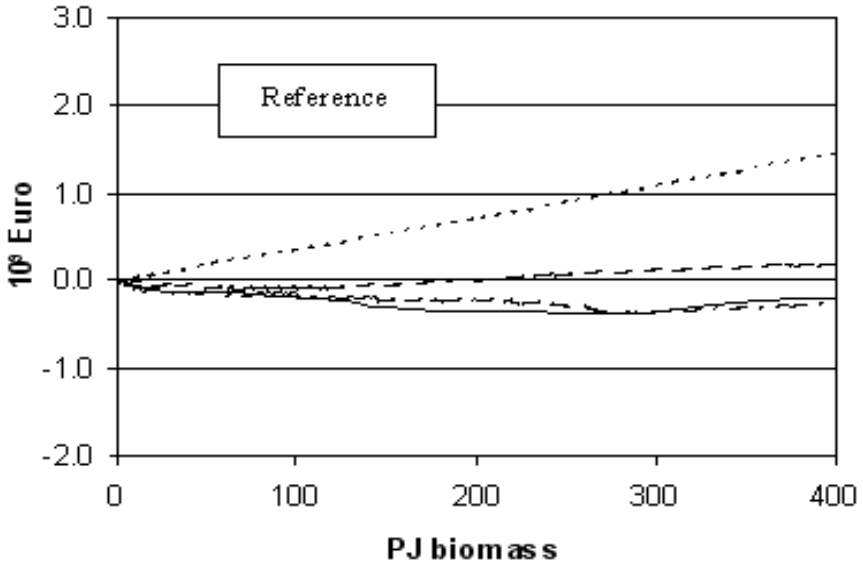
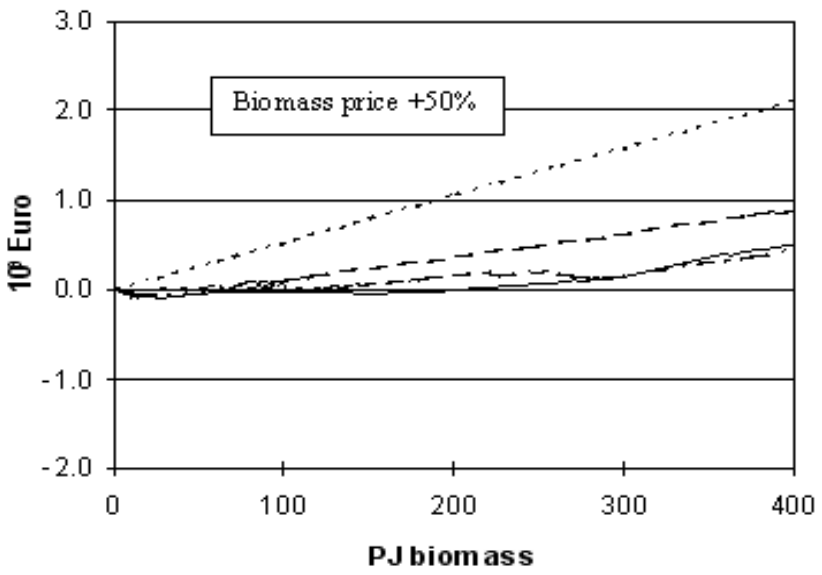
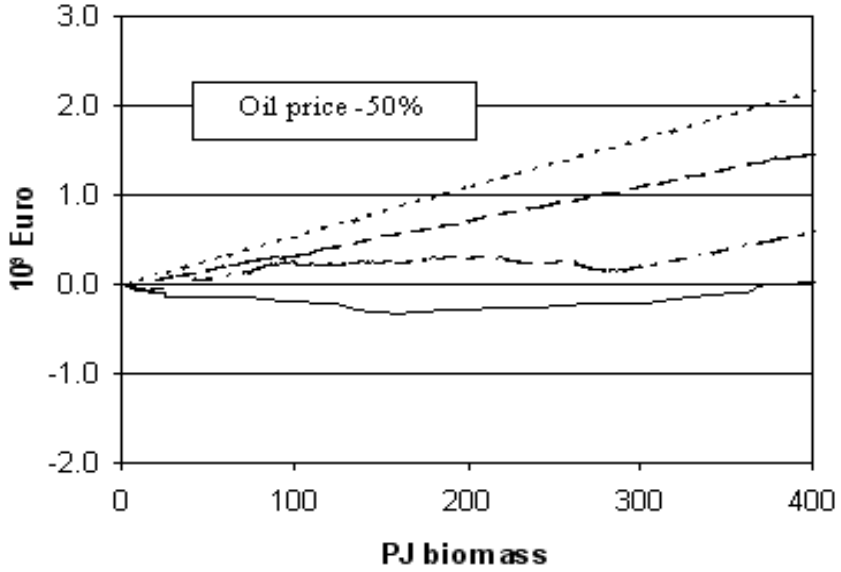
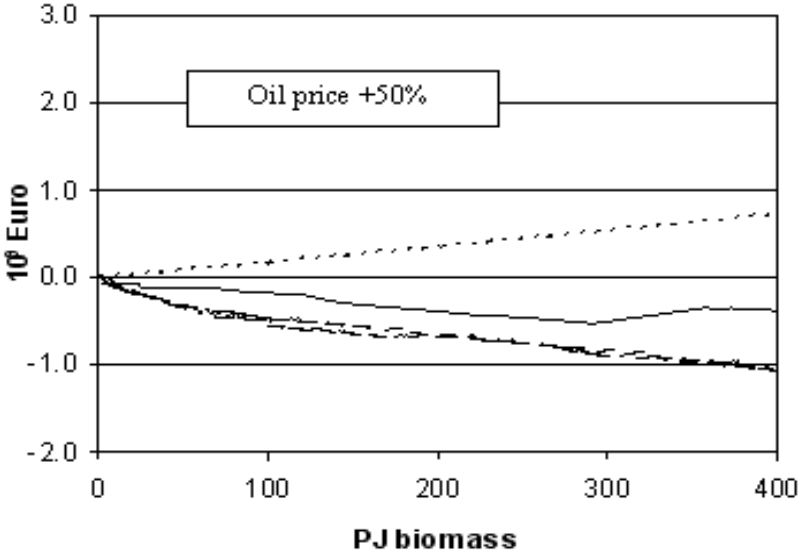
Sensitivity to fuel prices









Important how biomass is used – it is possible to strongly reduce both CO_2 emisson and oil use

- Maximum CO_2-reduction is 17.4 TgC/year
  - Oil use reduced by 60 PJ/year
  - Monetary cost is 130 milion €/year
- Maximum oil reduction is 350 PJ/year
  - CO_2-emission reduced by 5.5 TgC/year
  - Monetary cost is 330 milion €/år
- **A combined strategy reduces**
  - **CO_2-emission by 12.5 TgC/year (72% of max)**
  - **Oil use by 230 PJ/year (67% of max)**
  - **Monetary saving is 45 milion €/year**
- Ethanol-scenario gives lowest CO_2-reduction, intermediate oil reduction, and high monetary cost

Conclusions/Discussion

- Search for long-term and robust solutions in the context of sustainable development (but analyses are complex)
- Biofuels for electricity and heat production
- Develop/commercialize gasification technology for electricity and heat production
- Black-liquor gasification for production of transportation fuels
- A long-term strategy for the heating sector:
  - Expand district heating system
  - Built district heating facilities for combined electricity and heat production with high electricity exchange
  - Use heat pumps outside district heating areas if appropriate heat sources exist – otherwise pellet boilers
- Build wooden houses

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		System I	System II
A	**Input**	1 MWh biomass	1 MWh biomass
	Fuel produced	0.30 MWh ethanol, 0.42 MWh lignin	0.65 MWh methanol
	Fuel displaced	0.35 MWh petrol, 0.42 MWh coal	0.75 MWh petrol
	CO2 emission displaced	62 kgC	53 kgC
B	**Input**	1 MWh biomass	0.89 MWh biomass
	Fuel produced	0.30 MWh ethanol, 0.42 MWh lignin	0.30 MWh methanol, 0.42 MWh biomass
	Fuel displaced	0.35 MWh petrol, 0.42 MWh coal	0.35 MWh petrol, 0.42 MWh coal
	CO2 emission displaced	62 kgC	62 kgC

Production costs and conversion efficiency

Biofuel	Production cost (€/GJ)	Conversion efficiency (HHV)
Methanol	12	58,9% (-4% el)
Ethanol	22	34,9% (4,1% el)
FT diesel	18	42,1% (3,2% el)

(Source: Hamenlick, dissertation from Utrecht, Netherlands, 2004)

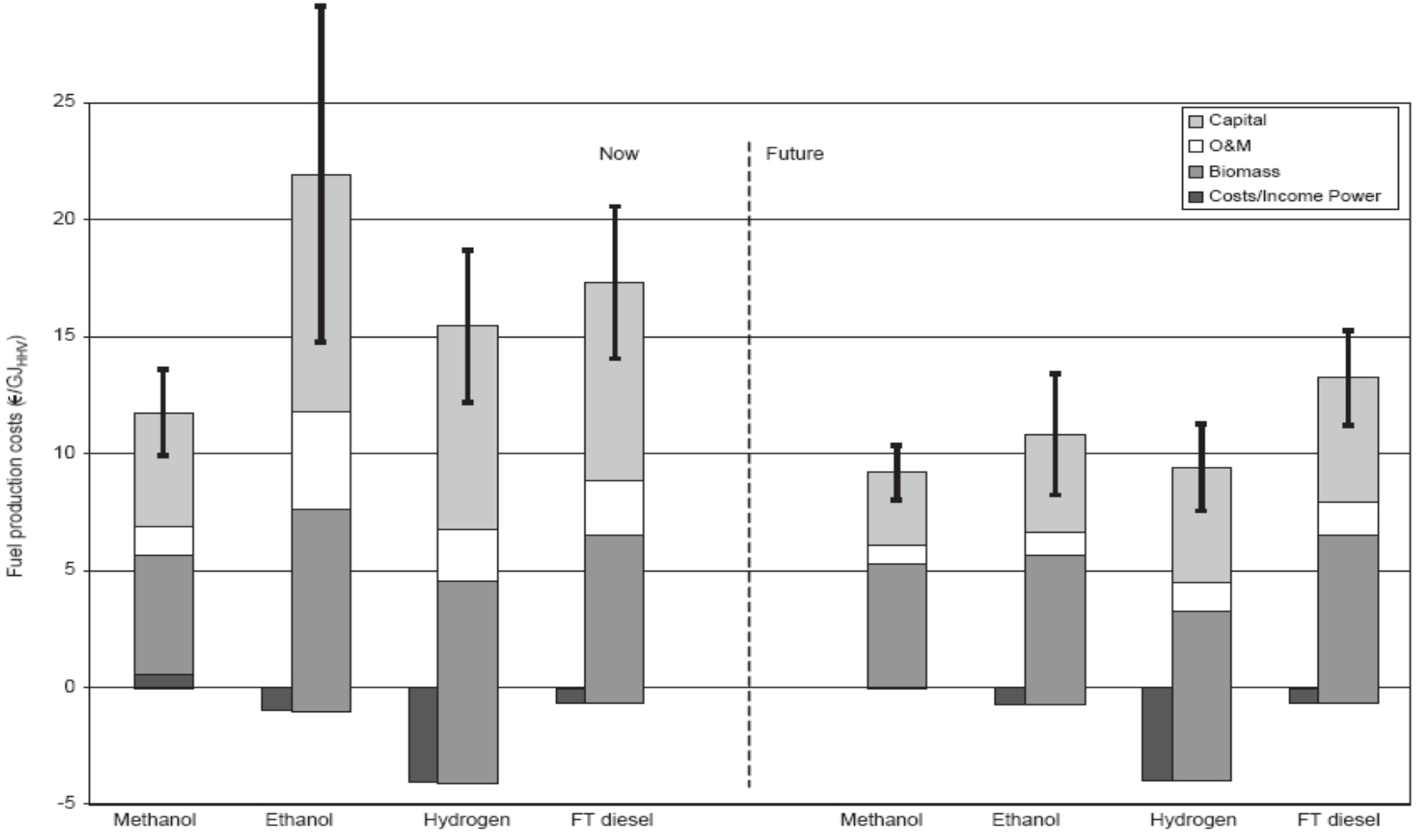
Efficiencies of biofuel production now and in future

	Now		Future	
	Fuel (HHV)	Electricity (HHV)	Fuel (HHV)	Electricity (HHV)
Methanol	58.9 %	-4.0 %	57.0 %	-0.1 %
Ethanol	34.9 %	4.1 %	47.3 %	4.0 %
FT Diesel	42.1 %	3.2 %	42.1 %	3.2 %

Source: Hamelinck and Faaij (in press)

Production costs of methanol, ethanol, hydrogen and FT diesel from biomass now and in the future

(Feedstock costs 3 Euro/GJ_{HHV})



Source: Hamelinck and Faaij (in press)

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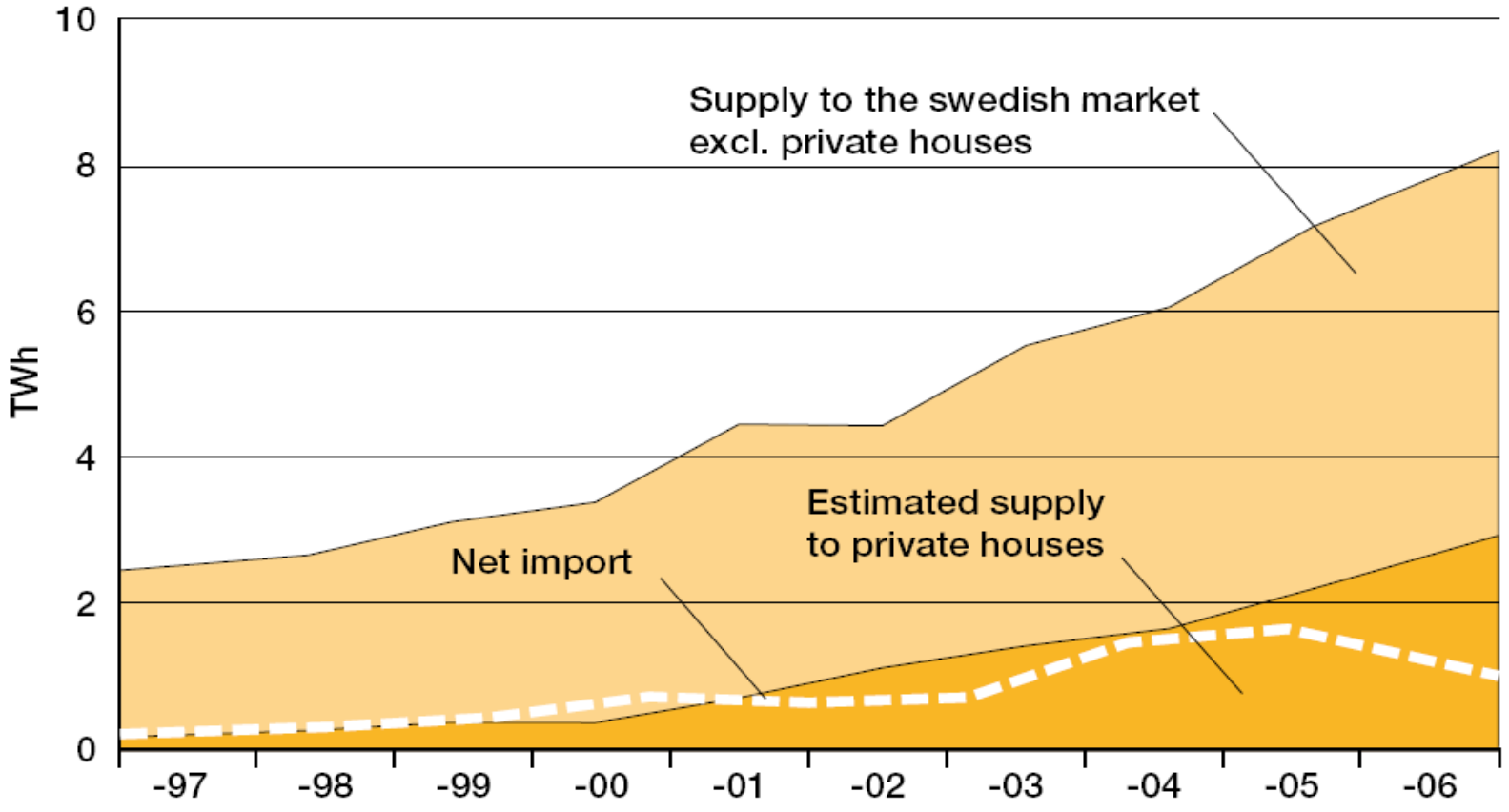
Conclusions

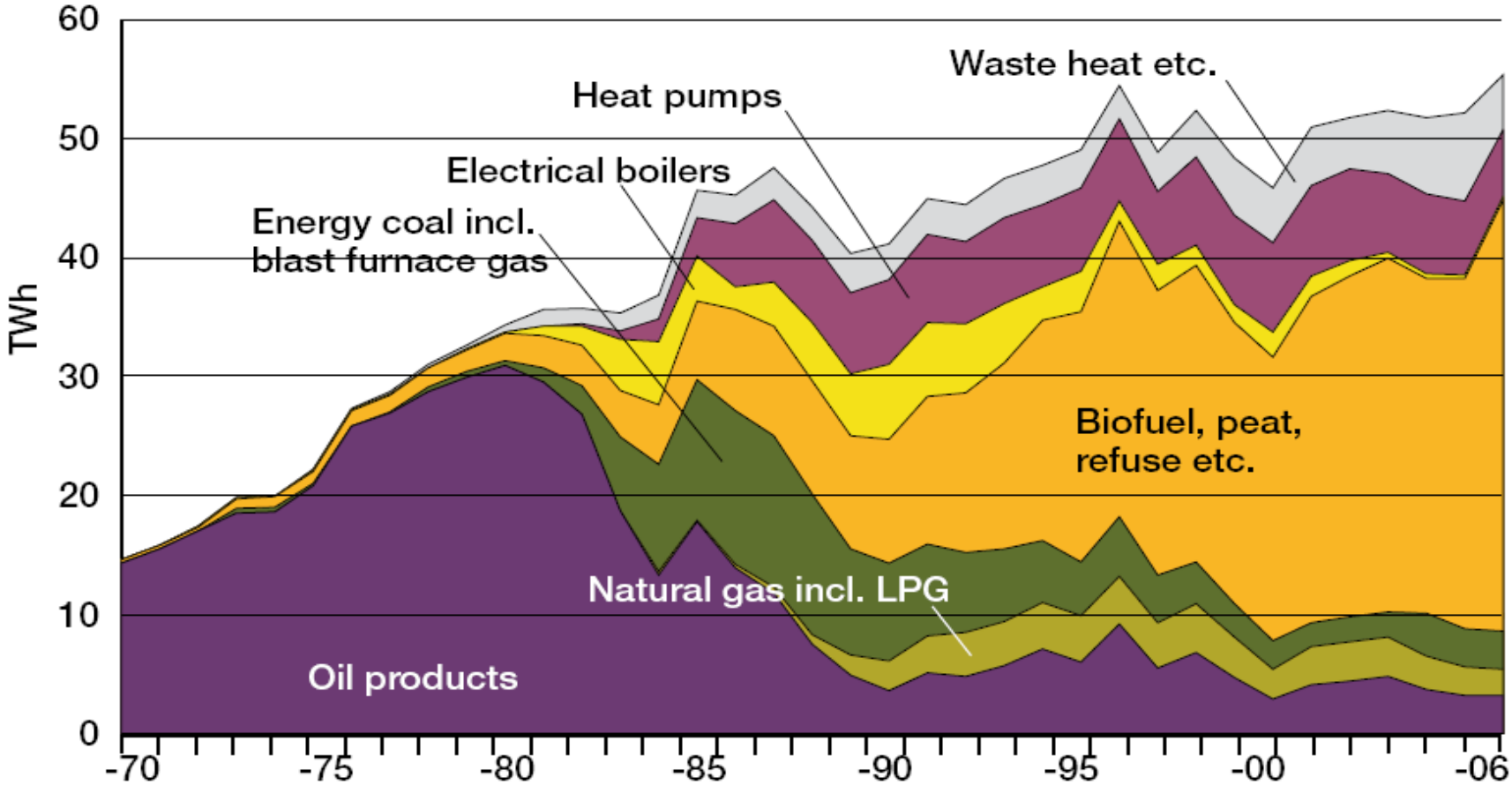
- Using 400 PJ/yr of additional biomass can achieve different goals if used in different ways
- Maximum CO_2 emission reduction is 17 TgC/yr (also reduces oil use by 60 PJ/yr) at a negative monetary cost of –200 million €/yr
- Maximum oil use reduction is 340 PJ/yr (also reduces CO_2 emission by 5.5 TgC/yr) at a positive monetary cost of 200 million €/yr
- Combined scenario reduces CO_2 emission by 12.5 TgC/yr (73% of max) and reduces oil use by 230 PJ/yr (68% of max) at a negative monetary cost of –250 million €/yr
- Ethanol scenario gives lowest CO_2 reduction, medium oil use reduction, and highest monetary cost

Deliveries of pellets to the Swedish market, 1997-2006



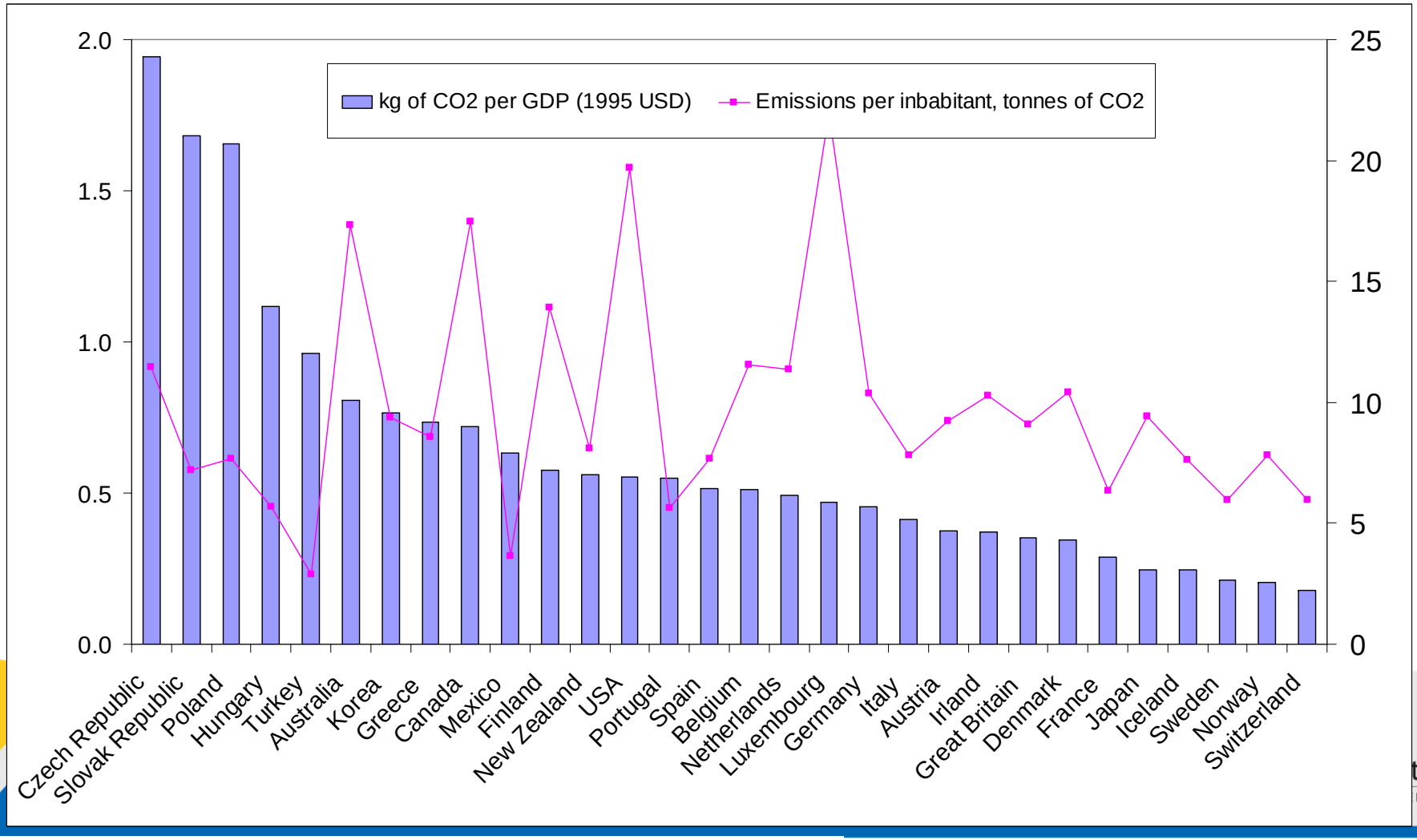
SOURCE: NATIONAL ASSOCIATION OF PELLETS INDUSTRIES (PIR)

Energy input for *district heating*, 1970-2006



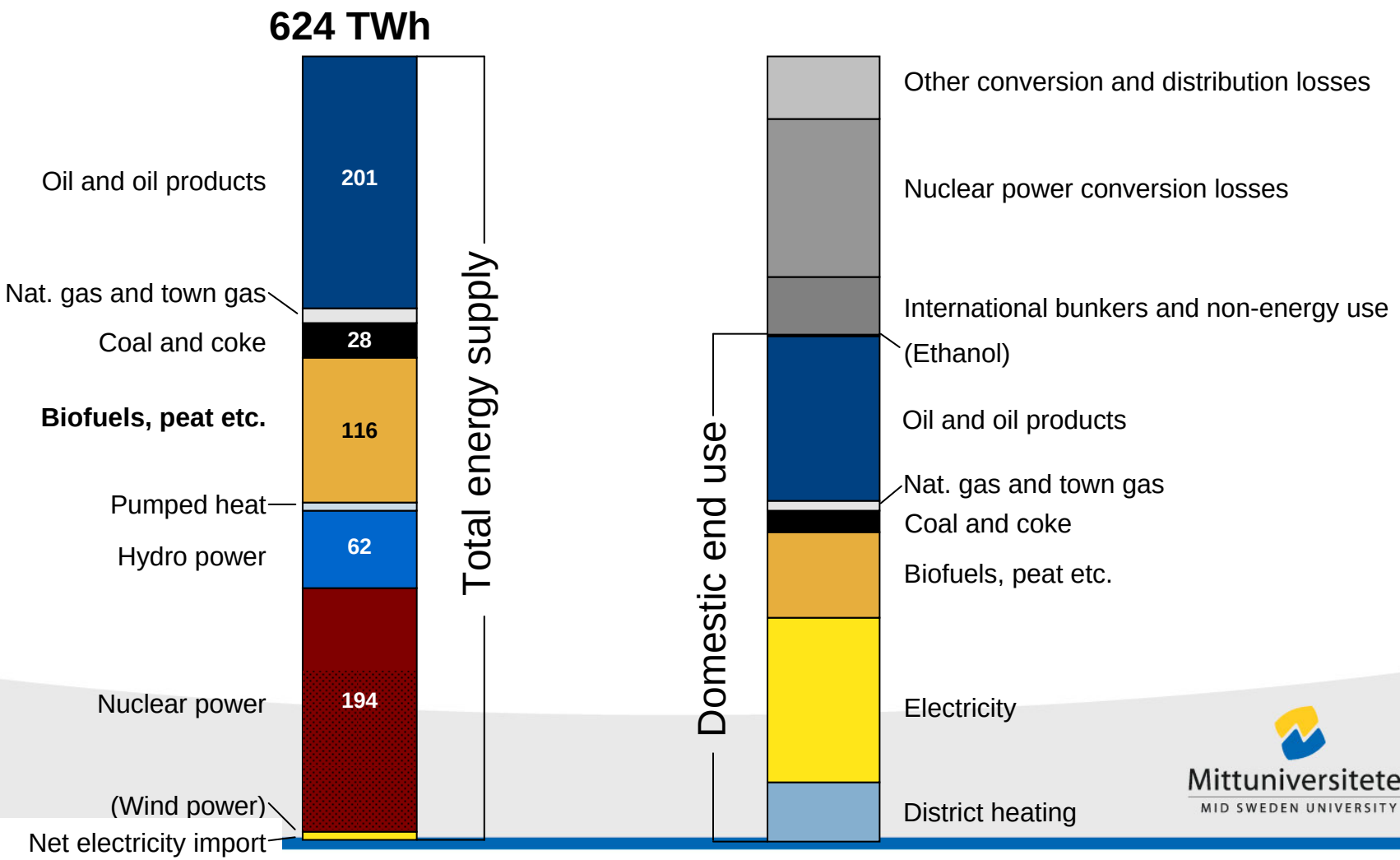
SOURCE: STATISTICS SWEDEN AND THE SWEDISH ENERGY AGENCY

Emissions of carbon dioxide per inhabitant and per GDP in EU and OECD countries, 2003



Source: Energiläget 2006, Swedish Energy Agency (2006)

Energy supply and use in Sweden 2006 (1)



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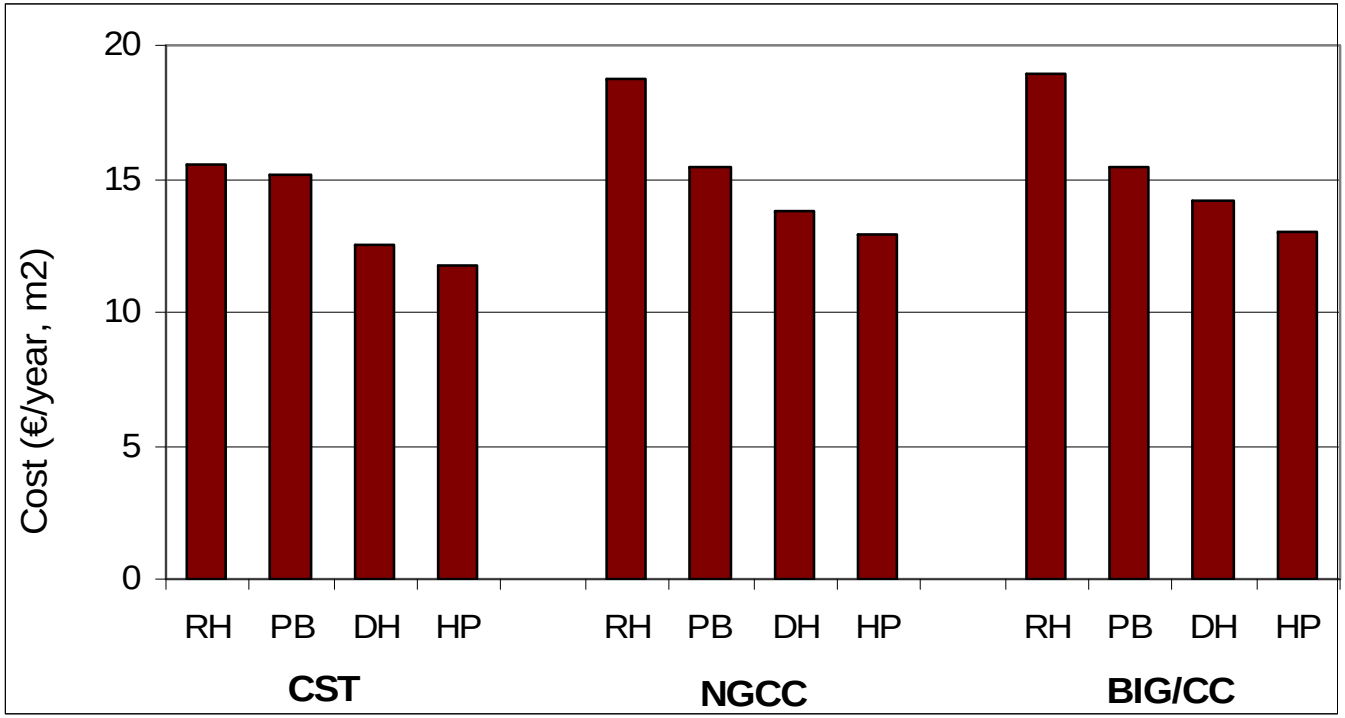
Energy in Sweden 2007, Swedish Energy Agency (2007)

Space heating of detached houses – national economic costs



HP= Heat pump
RH= Resistance heaters
DH= District heating
CHP=Combined heat and power

CST= Coal, steam turbine
BST= Biomass, steam turbine
BIG/CC= Biomass, integrated gasification combined cycle

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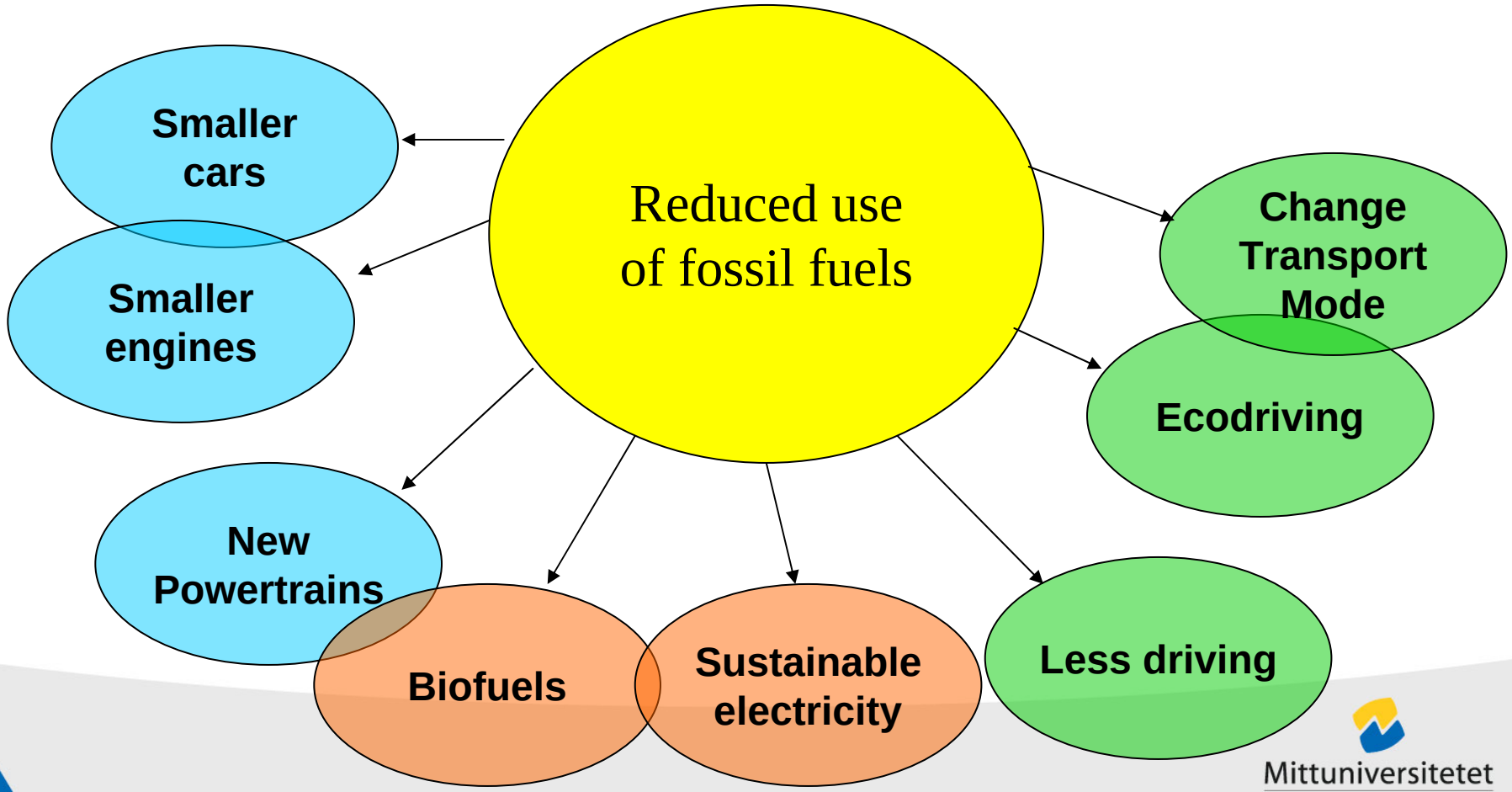
Biofuels is a part of the solution for transportation



O. Hådell. SYNBIOS Conference presentation, maj 2005, Stockholm

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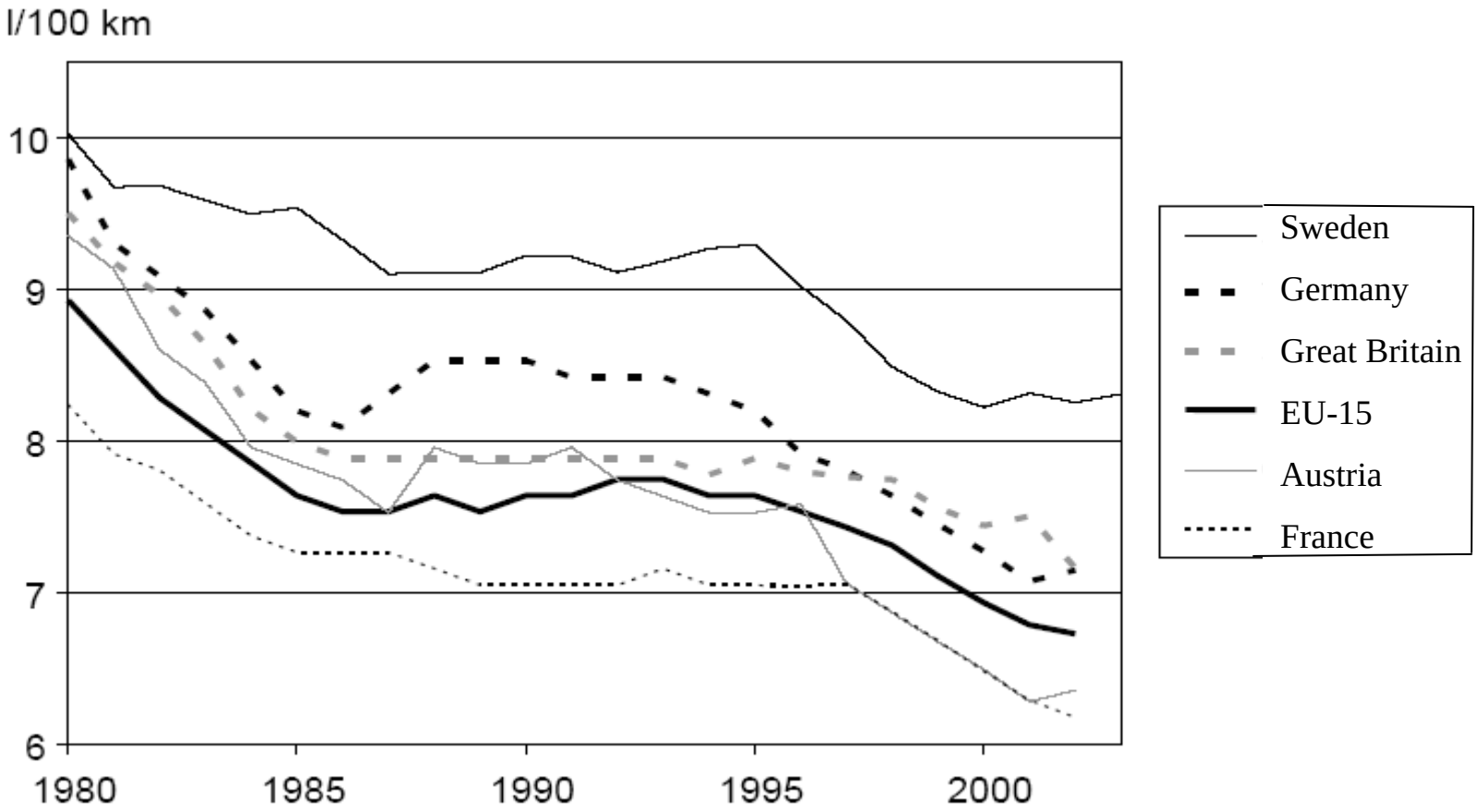
Fuel efficiency of new cars



Source: Klimatstrategi för vägtransporter, Vägverket 2004:102

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Final use of fossil fuels 2004 in different sectors and for electricity and district heating production

Sector	Oil	(%)	Coal	Natural gas
Industry	19.5	(14)	17.3	4.4
Transport (diesel, petrol)	82.3*	(59)	-	0.2
Transport (aviation fuels)	10.0	(7)		
Residential and Services etc.	21.7	(16)	-	1.9
Electricity production	2.4	(2)	4.1	0.9
District heating production	3.7	(3)	3.6	2.8
Total	**139.6**		**25**	**10.2**

*Petrol 47.8; Diesel 34.5

Total supplied **TWh**	206	30	10
Total supplied **PJ**	**742**	**108**	**36**

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