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Logistics for 2nd Generation Biofuels

2nd Latin American Congress
Biorefineries, Materials and Energy
May 4th – 6th 2009 , Concepción

Forschungszentrum Karlsruhe in der Helmholtz-Gemeinschaft

Universität Karlsruhe (TH) Forschungsuniversität • gegründet 1825

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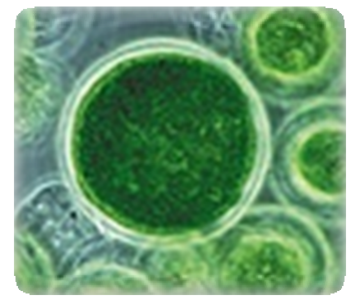
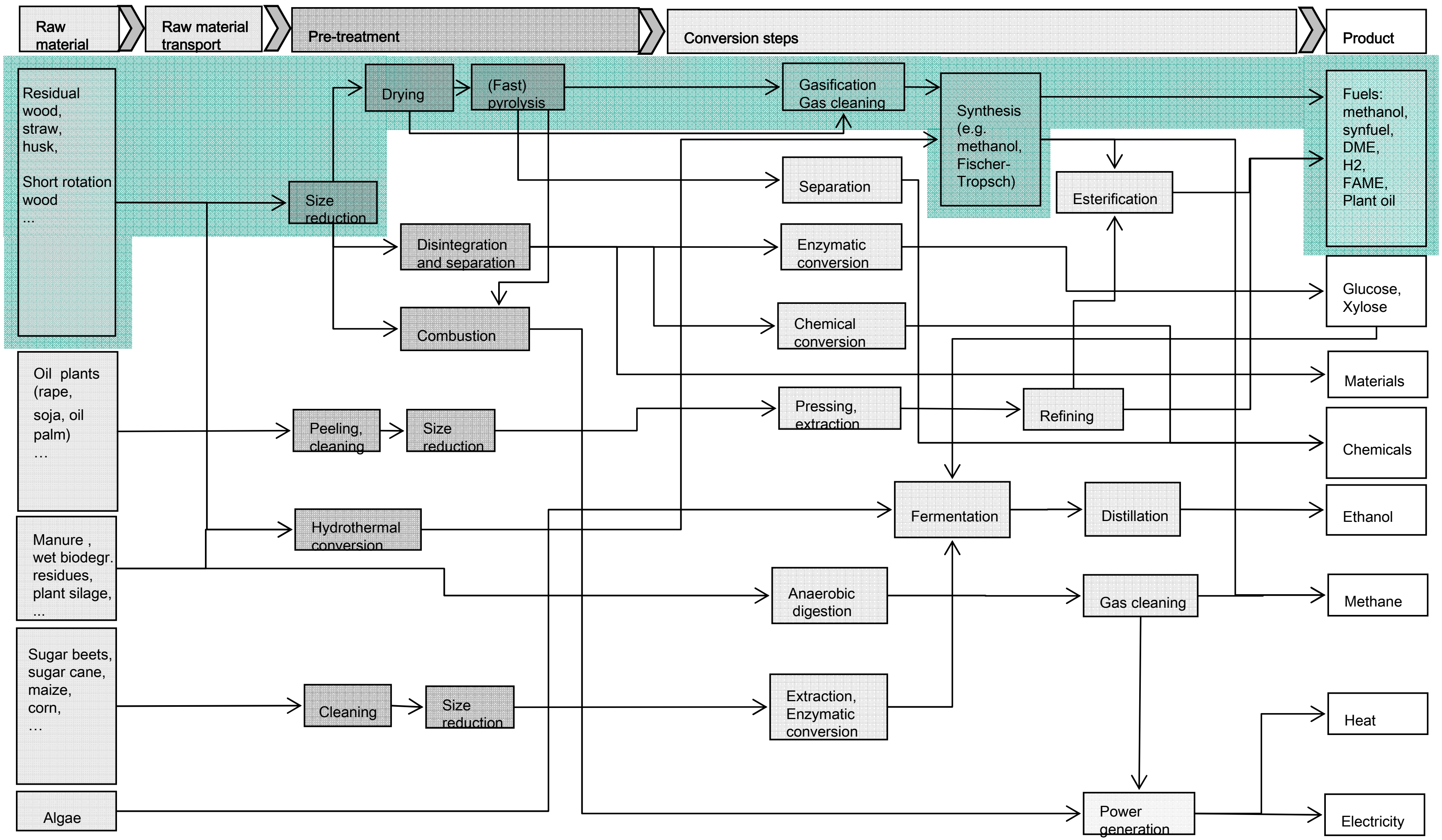


Outline

- The role of logistics in the development of Biomass-to-liquid fuel (BtL) production processes
- Evaluation of logistical scenarios for BtL fuel production
- Methodological approach: Facilitiy location planning to evaluate logistical concepts for BtL production
- Case study Baden-Württemberg: Results of the scenario analyses
- Conclusions

Exemplary biomass utilisation paths



Biomass-to-liquid fuel production

Emerging Technology

Advantages

- No direct competition with food chain
- Use of waste materials (straw, wood residues); whole crops
- Fuel specifications adaptable to specific needs („Designer fuels“)

Determinative factors of the biomass logistics

- **Operating in a natural environment**
  - Spatial distribution
  - Comparable small yield per acreage
  - Principle of sustainability limits the amounts that can be harvested
  - Seasonal supply variability

- **Dealing with wood**
  - Comparable high water content
  - Comparable low density for certain assortments
  - Comparable low market value of mass assortments

- **Organisational aspects**
  - Numerous owners
  - Earnings not only objective of the owner
  - Communication essential

(Schweinle/Fröhling 2008)

Process chain of a BtL-concept

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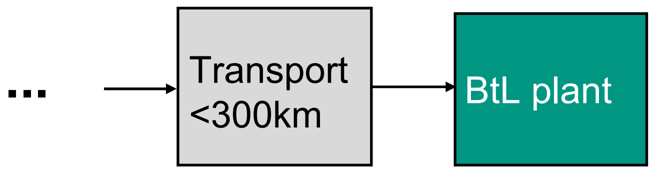
Biomass supply (harvesting) → Transport and preparation → Gasification → Gas cleaning → Synthesis → Product end preparation →

Biomass supply (harvesting)	Transport and preparation	Gasification	Gas cleaning	Synthesis	Product end preparation
Wood (residues)	Transport by tractor (short distance)	Fixed bed reactor	Cyclone	Fischer-Tropsch synthesis	Hydrocracking
Straw	Transport by truck (long distance)	Fluidized bed reactor	Tar cracker	Methanol synthesis	Distillation
Maize	Other means of transport	Entrained flow reactor	Washer	...	...
…	Pyrolysis		Guard beds		
	Drying		...		
	Milling				
	...				

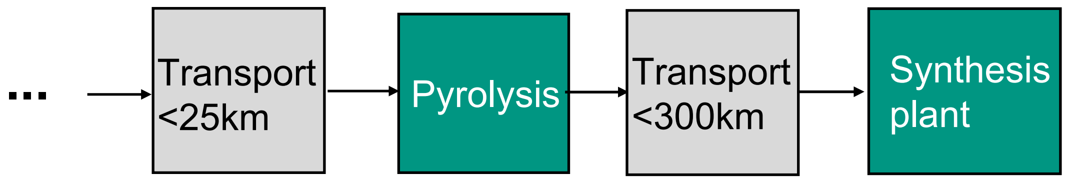
Central and decentral biomass preparation and transport

- *Central biomass preparation & transport:*



  - Smaller specific investment due to scale-up effects
  - Higher transportation load and costs
  - Higher environmental impact of the transport

- *Decentral biomass preparation & transport:*



  - Lower transportation load and costs
  - Lower environmental impact of the transport
  - Higher specific investment due to scale-up effects

Methodological approach

Reference configuration

Preparation → Gasification → Gas cleaning Conditioning → Fischer Tropsch synthesis → Product end preparation → FT-fuel

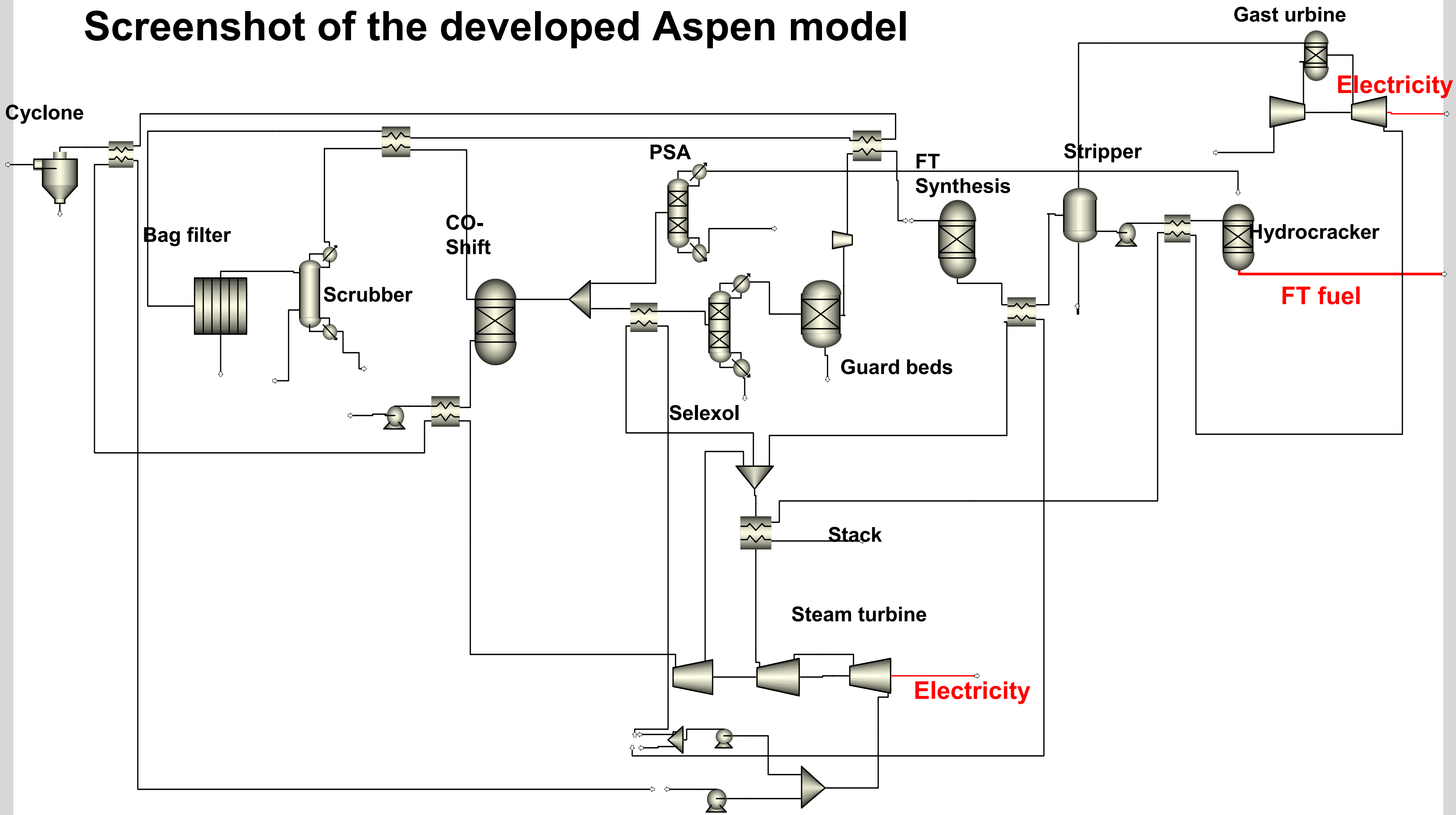
- Preparation: Drying, Pyrolysis
- Gasification: Entrained flow (with O2)
- Gas cleaning / Conditioning: Cyclone, Baghouse filter, Scrubber, Guard beds, CO-conversion
- Fischer Tropsch synthesis: Fixed bed (Co)
- Product end preparation: Separation, Hydrocracking, Distillation

Approach

Determination of a reference configuration → Modelling of material and energy flows (e.g.: Material flow analysis, process simulation) → Estimation of material and energy flows for different scenarios → Estimation of investments and production costs / Estimation of environmental impacts → **Location and logistics planning** → **Scenario and sensitivity analyses**

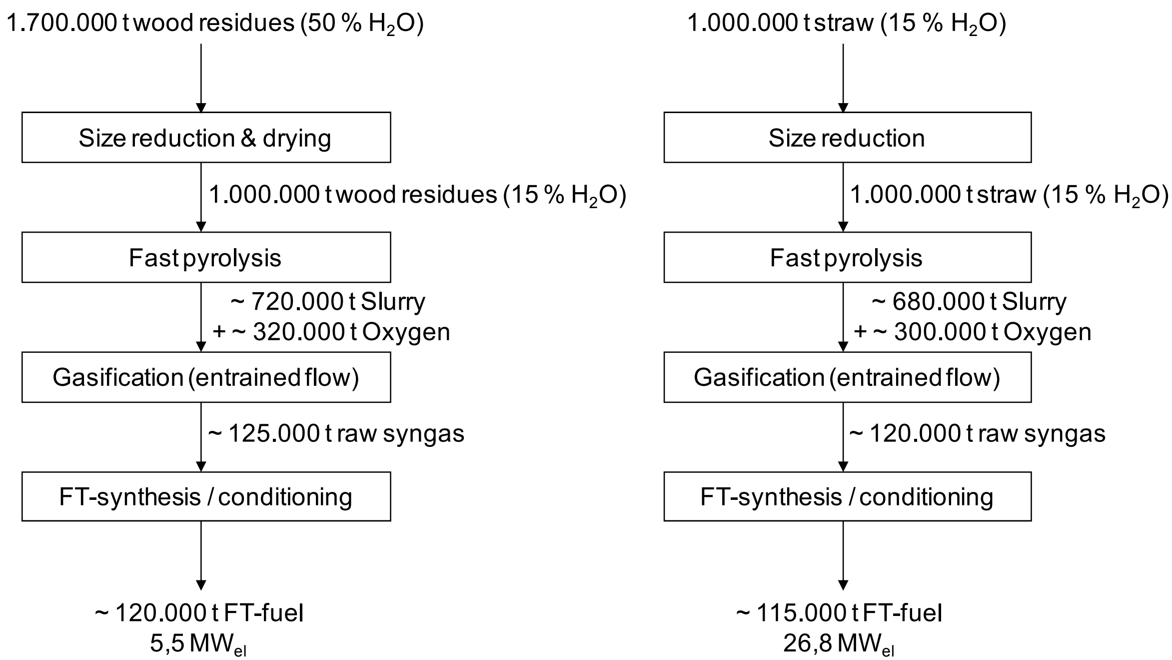
Modelling of material and energy flows

Screenshot of the developed Aspen model



Estimation of material and energy flows

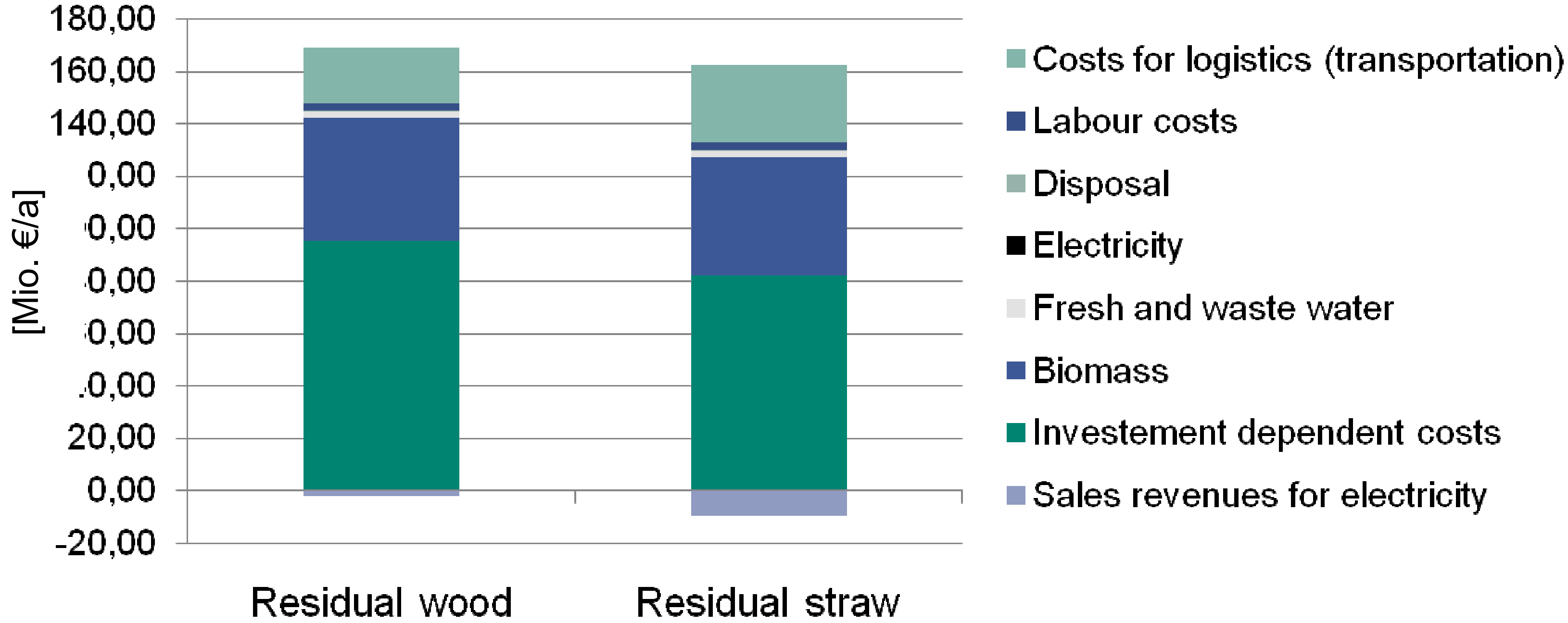
- **Material and energy flow modelling using process simulation**
- **Results: Input and output flows and characteristic dimensions of aggregates**



Main material and energy flows for wood residues and straw

Estimation of investments and production costs
Techno-economic assessment

Cost estimation for an industrial scale BtL plant in Germany

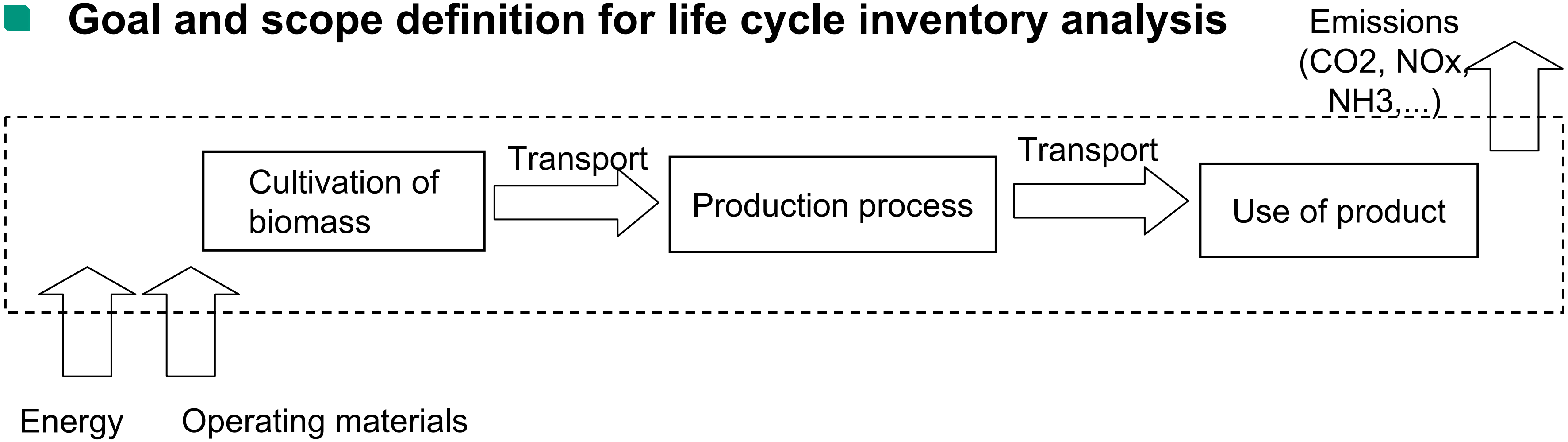


Sources : Rentz , Kerdoncuff, Froehling , and Calaminus (2006); Kerdoncuff (2008)

	Residual wood	Residual straw
Overall costs per year [Mio. €/a]	166,87	152,62
Total production of FT-fuels [t]	120.000,00	114.000,00
Production costs [€/l FT fuel]	1,06	1,02

Estimation of environmental impacts

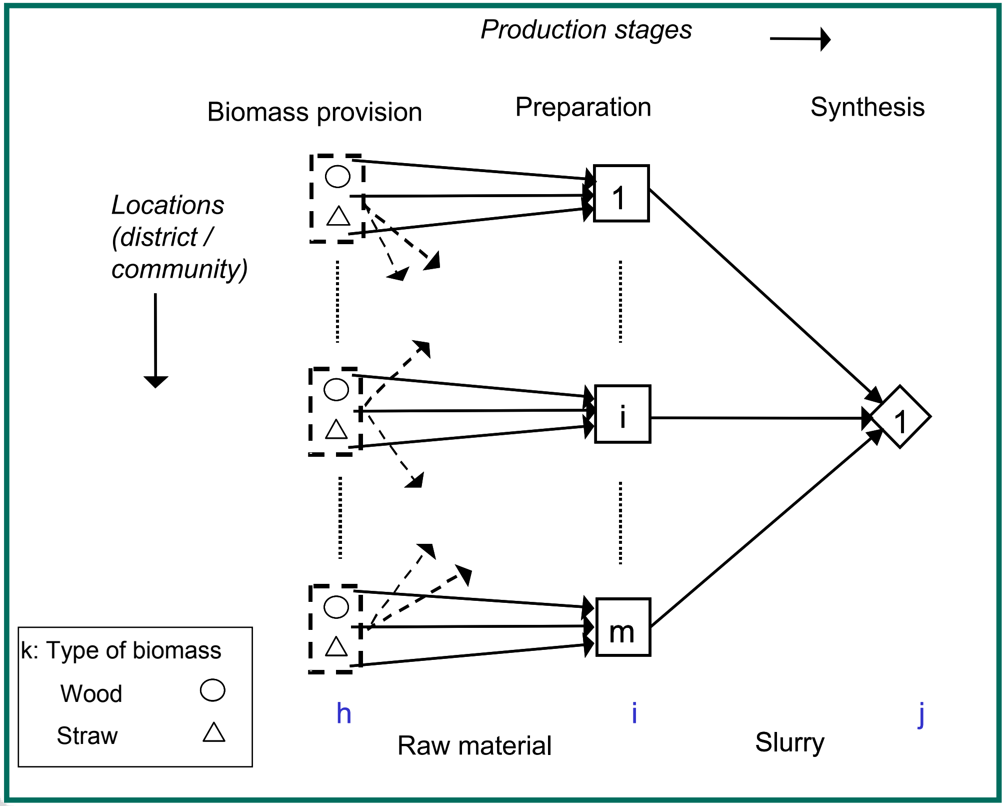
- **Methodology for life cycle assessment (LCA) according to the european standard DIN EN ISO 14040 and 14044**
- **Goal and scope definition for life cycle inventory analysis**



- **Selection of adequate impact categories, e.g.**
  - **Climate change**
  - **Eutrophication**
  - **Acidification**
- **Life cycle impact assessment (allocation of material and energy flows to the corresponding impact categories and conversion to indicator values, e.g. CO_2 equivalents)**

Location and logistics planning

- **Problem structure:** 2-staged capacitated **Facility-Location-Problem (FLP)**
- **Objective:** Minimisation of the decision relevant costs along the process chain between the biomass production areas and the Fischer-Tropsch (FT) Synthesis Plant



Constraints:
- 1 location for the FT unit
- Limited availability of biomass in each location (district / community)
- Limited capacity of the preparation units
- Transport distances between the districts and communities
- ...

A facility location planning model for BtL-concepts (1)

Minimisation of the decision relevant costs of the production chain from the biomass supply to the synthesis

MIN

$$\sum_{h\in H}\sum_{i\in I}\sum_{k\in K} p_{hk}\cdot x_{hik}^{bm}$$

biomass supply (purchasing)

$$+\sum_{h\in H}\sum_{i\in I}\sum_{k\in K} c_{hik}^{bm,truck}\cdot x_{hik}^{bm}$$

short distance transport biomass (truck), supplier to preparation

$$+\sum_{i\in I} f_i^{prep}\cdot z_i^{prep}$$

investment biomass preparation units

$$+\sum_{h\in H}\sum_{i\in I}\sum_{k\in K} c_{ik}^{var,prep}\cdot x_{hik}^{bm}$$

operation of biomass preparation units

$$+\sum_{i\in I}\sum_{j\in J} c_{ij}^{slur,truck}\cdot x_{ij}^{slur}$$

long distance transport slurry (truck), preparation to synthesis

Symbols (excerpt):

Sets:

$h \in H$	possible biomass supplier
$i \in I$	possible preparation unit
$j \in J$	possible synthesis unit
$k \in K$	type of biomass

Parameters:

$c_{hik}^{bm,truck}$	transport costs (truck) for biomass [€/t*km]
$c_{ik}^{var,prep}$	variable costs for preparation [€/t]
$c_{ij}^{slur,truck}$	transport costs (truck) for slurry [€/t*km]
f_i^{prep}	investment dependent fix costs [€]
p	price [€/t]

Variables:

x_{hik}^{bm}	transported biomass [t]
x_{ij}^{slur}	transported slurry [t]

$$z_i^{prep} = \begin{cases} 1\text{: unit is built} \\ 0\text{: unit is not built} \end{cases}$$

A facility location planning model for BtL-concepts (2)

Subject to (excerpt):

$\sum_{i \in I} x_{hik}^{bm} \leq \overline{x}_{hk}$	$\forall h,k$	limited availability of biomass of type *k*
$y_{ik}^{prep} = \sum_{h \in H} \alpha_{hk} \cdot x_{hik}^{bm} \cdot \beta_k$	$\forall i,k$	production of slurry from biomass *k* at location *i*
$y_i^{prep} = \sum_{k \in K} y_{ik}^{prep}$	$\forall i$	total mass of slurry produced at location *i*
$y_{ik}^{prep} \geq \underline{y}_k^{prep} \cdot z_i^{prep}$	$\forall i,k$	lower capacity limit in the preparation unit
$y_{ik}^{prep} \leq \overline{y}_k^{prep} \cdot z_i^{prep}$	$\forall i,k$	upper capacity limit in the preparation unit
$y_i^{prep} = \sum_{j \in J} x_{ij}^{slur}$	$\forall i$	mass balance preparation
$\sum_{i \in I} z_i^{prep} \leq M^{prep}$		limitation of the max. number of preparation units

Symbols (excerpt):

Sets:

$h \in H$	possible biomass supplier
$i \in I$	possible preparation unit
$j \in J$	possible synthesis unit
$k \in K$	type of biomass

Parameters:

α_{hk}	share of water
β_k	production coefficient
M^{prep}	maximum number of preparation units
$\overline{x}_{hk}$	maximum available amount of biomass [t]
$\underline{y}_k^{prep}$	lower capacity limit in preparation unit [t]
$\overline{y}_k^{prep}$	upper capacity limit in preparation unit [t]

Variables:

x_{hik}^{bm}	transported biomass [t]
x_{ij}^{slur}	transported slurry [t]
y_i^{prep}, y_{ik}^{prep}	slurry production preparation unit

$$z_i^{prep} = \begin{cases} 1: \text{unit is built} \\ 0: \text{unit is not built} \end{cases}$$

A facility location planning model for BtL-concepts (3)

• • •

$y_j^{syn} = \sum_{i \in I} x_{ij}^{slur}$	$\forall j$	mass of slurry, used in synthesis unit *j*
$y_j^{syn} \geq \underline{y}_j^{syn} \cdot z_j^{syn}$	$\forall j$	lower capacity limit of the synthesis unit
$y_j^{syn} \leq \overline{y}_j^{syn} \cdot z_j^{syn}$	$\forall j$	upper capacity limit of the synthesis unit
$\sum_{j \in J} y_j^{syn} = y^{syn,capacity}$		mass balance synthesis
$\sum_{j \in J} z_j^{syn} \leq M^{syn}$		limitation of the maximum number of synthesis units
$x_{hik}^{bm}, x_{ij}^{slur}, y_i^{prep}, y_i^{syn} \geq 0$	$\forall h, i, j, k$	nonnegativity of the decision variables
$z_i^{prep}, z_j^{syn} \in \{0,1\}$	$\forall i, j$	definition of the binary variables

Symbols: (excerpt)

Sets:

$h \in H$	possible biomass supplier
$i \in I$	possible preparation unit
$j \in J$	possible synthesis unit
$k \in K$	type of biomass

Parameters:

M^{syn}	maximum number of synthesis units
$\underline{y}_j^{syn}$	lower capacity limit in synthesis unit [t]
$\overline{y}_j^{syn}$	upper capacity limit in synthesis unit [t]
$y^{syn,capacity}$	total fuel production [t]

Variables:

x_{hik}^{bm}	transported biomass [t]
x_{ij}^{slur}	transported slurry [t]
y_i^{prep}	produced slurry [t]
y_j^{syn}	produced fuel [t]

$$z_i^{prep}, z_j^{syn} = \begin{cases} 1\text{: unit is built} \\ 0\text{: unit is not built} \end{cases}$$

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Case study Baden-Württemberg:
Data basis (excerpt)

- Results of
  - the mass and energy flow balancing and
- - the economic and ecological assessment of the reference process chain for
  - Wood residues $1.7*10^6$ t (50 % H_2O)
  - Straw $1.0*10^6$ t (15 % H_2O)
- Distance matrix (87 locations for biomass collection)

		1	2	3	4	5	...
1	Albstadt	0	152	190	96	84	
2	Auenwald		0	148	247	146	
3	Baden-Baden			0	285	42	
4	Bad Wurzach				0	268	
5	Baiersbronn					0	
...							0

- Quantity of biomass in each community

	Wood residues (t wet)	Straw (t wet)
Albstadt	48,243	10,831
Auenwald	41,873	7,481
Baden-Baden	48,763	3,416
Bad Wurzach	32,053	6,532
Baiersbronn	67,093	7,910
..	...	...

Case study Baden-Württemberg:
Scenario and sensitivity analyses

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- **Considered scenarios**

Biomass	Wood residues	Straw
Concept	Central biomass preparation	Decentral biomass preparation with 2, 10, 20 locations for the preparation units

- **Sensitivity analyses for following parameters**
  - Cost of biomass production
  - Cost of biomass transport

Exemplary results:
Scenarios “wood residues”

Results scenario „central biomass preparation “

Location of biomass	Location of the synthesis	Quantity of wood tranported (wet t)	Distance (km)
Albstadt	Schramberg	48.243	63
Baden-Baden		48.763	112
Baiersbronn		67.093	42
Balingen		45.773	48
Balgheim		48.243	42
Buchenbach		41.678	67
Donaueschingen		60.203	38
...		...	

Total costs of the production chain: 165 • 10^6 Euro

Transport: 11.4 • 10^7 t • km

Results for the scenario „decentral biomass preparation (10 locations)“:

- Synthesis plant in Epfendorf
- 10 pyrolysis plants in: cf. Table
- Total costs of the production chain: 185 • 10^6 €
- Transport: 6.6 • 10^7 t • km

Number	Biomass preparation location
1	Gondelsheim
2	Baiersbronn
3	Ebhausen
4	Rottenburg am Neckar
5	Hausach
6	Albstadt
7	Unterkirnach
8	Tuttlingen
9	Ühlingen
10	Epfendorf

Exemplary results:
Scenarios “straw”

Results scenario „central biomass preparation“

Location of biomass	Location of the synthesis	Quantity of wood tranported (wet t)	Distance (km)
Albstadt	Berglen	10.820	136
Auenwald		7.473	86
Bad Wurzach		6.525	194
Balingen		7.152	118
Balgheim		10.820	147
Binau		17.638	85
Birkenfeld		4.420	87
...		...	

Total costs of the production chain:157 • 10^6 Euro

Transport: 9.4 • 10^7 t • km

Results for the scenario „decentral biomass preparation (10 locations)“:

- Synthesis plant in Murr
- 10 pyrolysis plants in: cf. Table
- Total costs of the production chain: 156 • 10^6 €
- Transport: 8 • 10^7 t • km

Number	Biomass preparation location
1	Lauda-Königshofen
2	Neuenstadt am Kocher
3	Gerabronn
4	Gondelsheim
5	Schwäbisch Gmünd
6	Rottenburg am Neckar
7	Dornstadt
8	Ehingen
9	Veringenstadt
10	Murr

Exemplary results:
Scenarios "mixed raw material" central biomass preparation –supply
(7 preparation units for wood residues and 3 preparation units for straw)

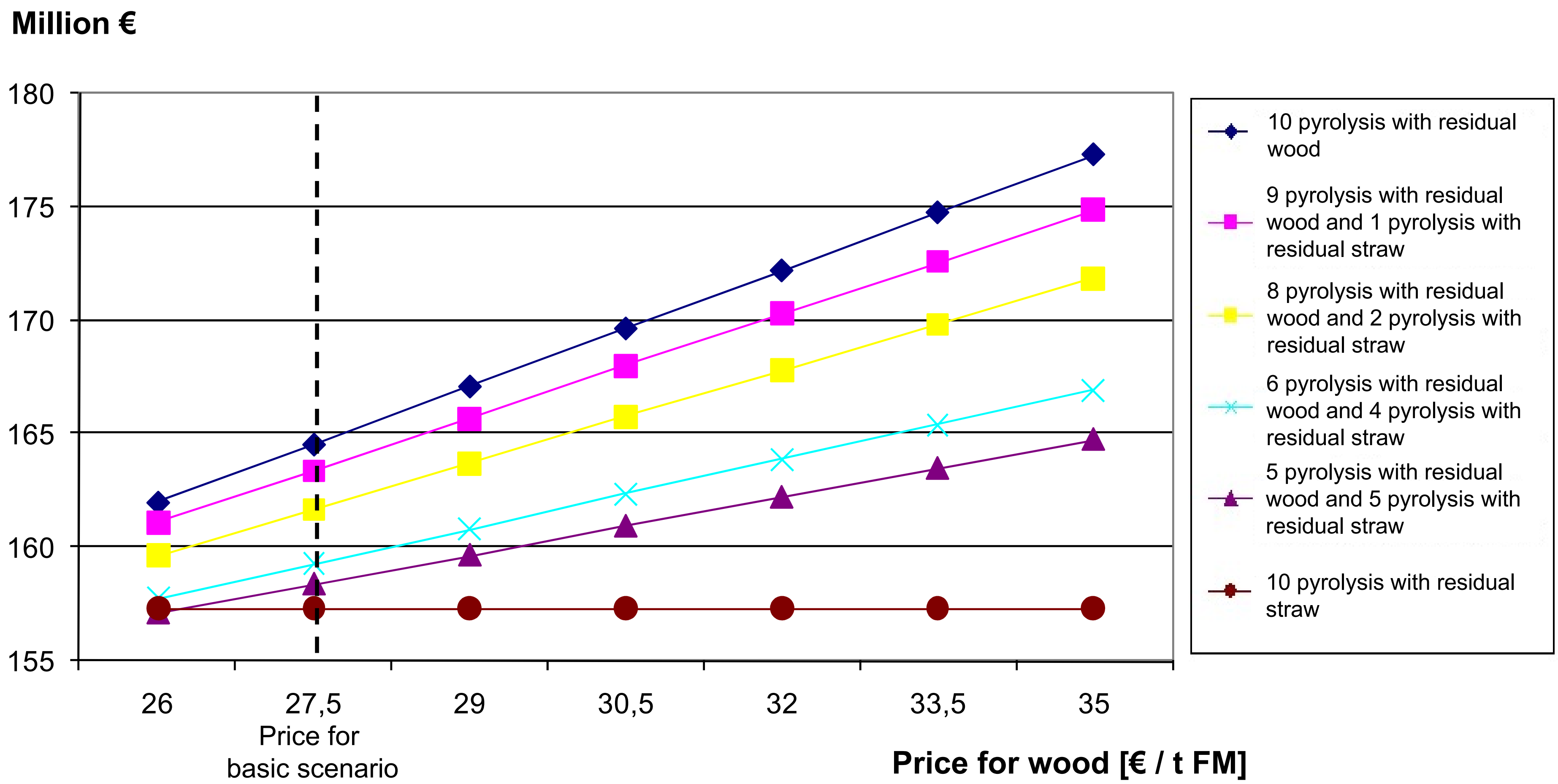
Results for the scenario „central biomass preparation – mix wood residues and straw" (1.360.000 wet t wood residues, 200.000 t straw)

Location of biomass	Location of the synthesis	Quantity of wood transported (wet t)	Quantity of straw transported (wet t)	Distance (km)
Albstadt	Epfendorf	48,243	10,820	48
Baiersbronn		67,093	7,902	48
Balingen		45,773	7,152	33
Balgheim		48,243	10,820	29
Buchenbach		0	2,908	97
Denkendorf		0	6,796	92
Donaueschingen		60,203	11,819	43
...		...	...	...

Total costs of the production chain: 160 • 10^6 Euro

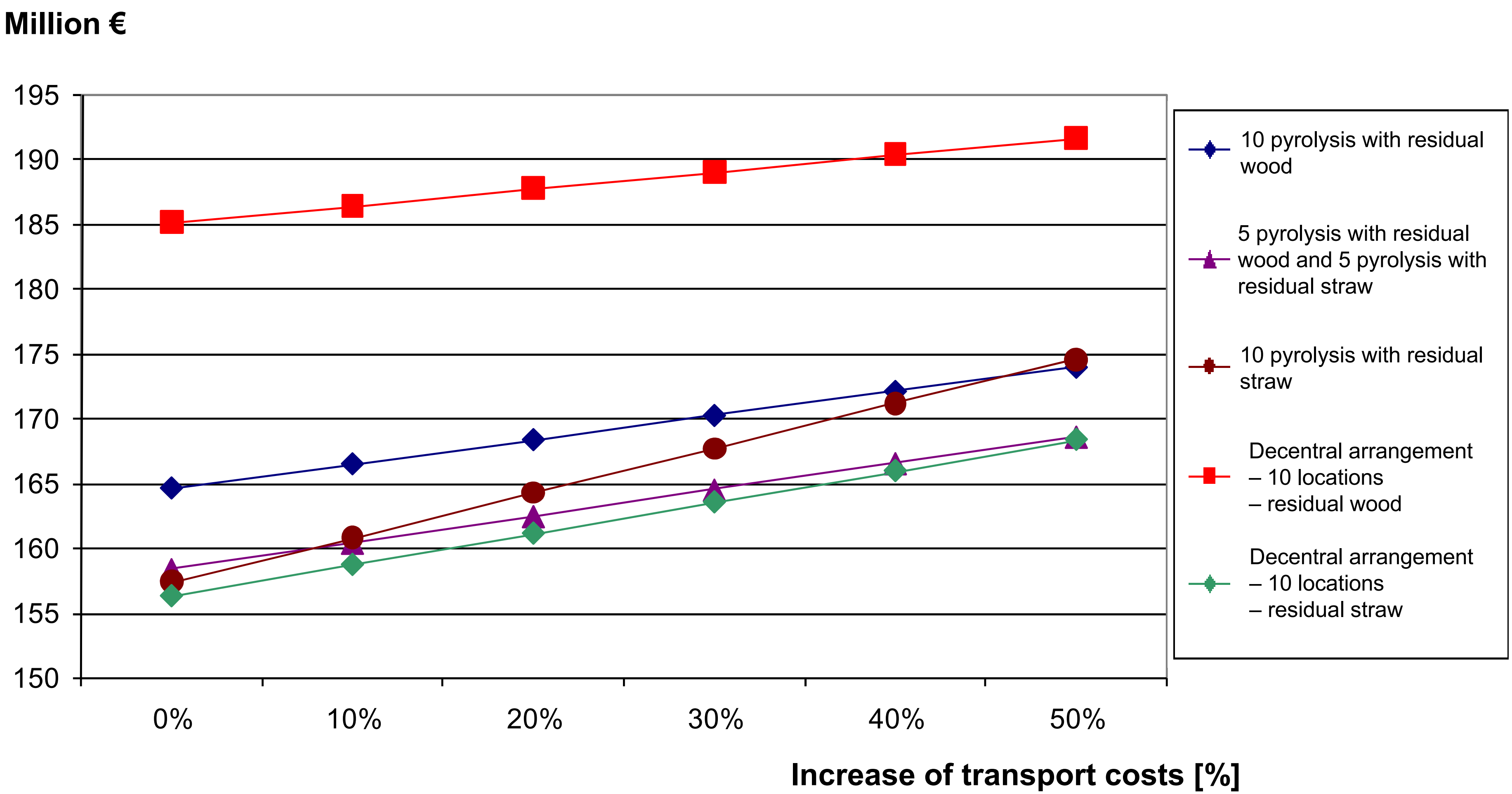
Transport: 7.8 • 10^7 t • km

Sensitivity analyses – Costs of biomass supply



→ stability of the solution for parameter changes

Sensitivity analyses – Costs of biomass transportation



→ stability of the solution for parameter changes

Conclusions

- The contribution shows the influence of the choice of biomass and the logistical configuration on the results of an economic assessment
- For the state of Baden-Württemberg
  - A decentral concept with straw as raw material appears to be favorable from an economic point of view
  - A decentral concept with wood residues as feedstock has the minimum transport load in the compared scenarios
- Sensitivity analyses show stability of solutions for parameter changes
- Biomass costs make up approx. 30 % of the total cost per annum

Outlook

- Chile has large biomass potentials
  - 15.6 million ha of forest
    (13.4 million ha native forests, 2.2 million ha plantations)
  - 3.88 million tons (DM) of residual straw
- Questions of biomass supply, logistics and costs need to be answered
- BtL concepts might be an attractive option for Chile, but a detailed assessment is necessary
- The presented approach is transferable to Chile to assess a realization under Chilean conditions
- BtL should not be the only investigated option, a comparison with further utilization pathways (e.g. SNG, biorefineries) should be carried out
- Adaptation of the Model considering multiple utilization pathways may help to develop regional biomass utilization concepts

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Thank you for your attention!

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