Investments into forest biorefineries under different price and policy structures

Hanna-Liisa Kangas, Lintunen, J.,
Pohjola, J., Hetemäki, L. & Uusivuori, J.

NOTE: PRELIMINARY RESULTS, DO NOT CITE.

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TERMS

- **Biorefinery:** a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass
- **Forest biorefinery:** biorefinery in the forest sector, e.g. pulp and paper integrated biorefinery
- **Biofuel:** Liquid fuel, produced from renewable energy source, in this case from forest biomass (i.e. wood fiber or black liquor)
- **NOTE:** In the model, we use the term biorefinery to denote the biofuel production part of an integrated pulp and paper mill

MOTIVATION (1)

- **Need for alternative, renewable transportation fuels**
  - Oil - scarcity and CO_2 emissions
  - EU - 10 % of overall petrol and diesel consumption should be covered by sustainable biofuels by 2020

    → Biorefineries offer one important solution for increasing biofuel production

- **The research on biorefineries has been technology driven,** none of the previous studies link
  - the pulp and paper markets with
  - the investment possibilities for different biorefinery technologies

MOTIVATION (2)

- Biorefinery is especially interesting in the forest sector:

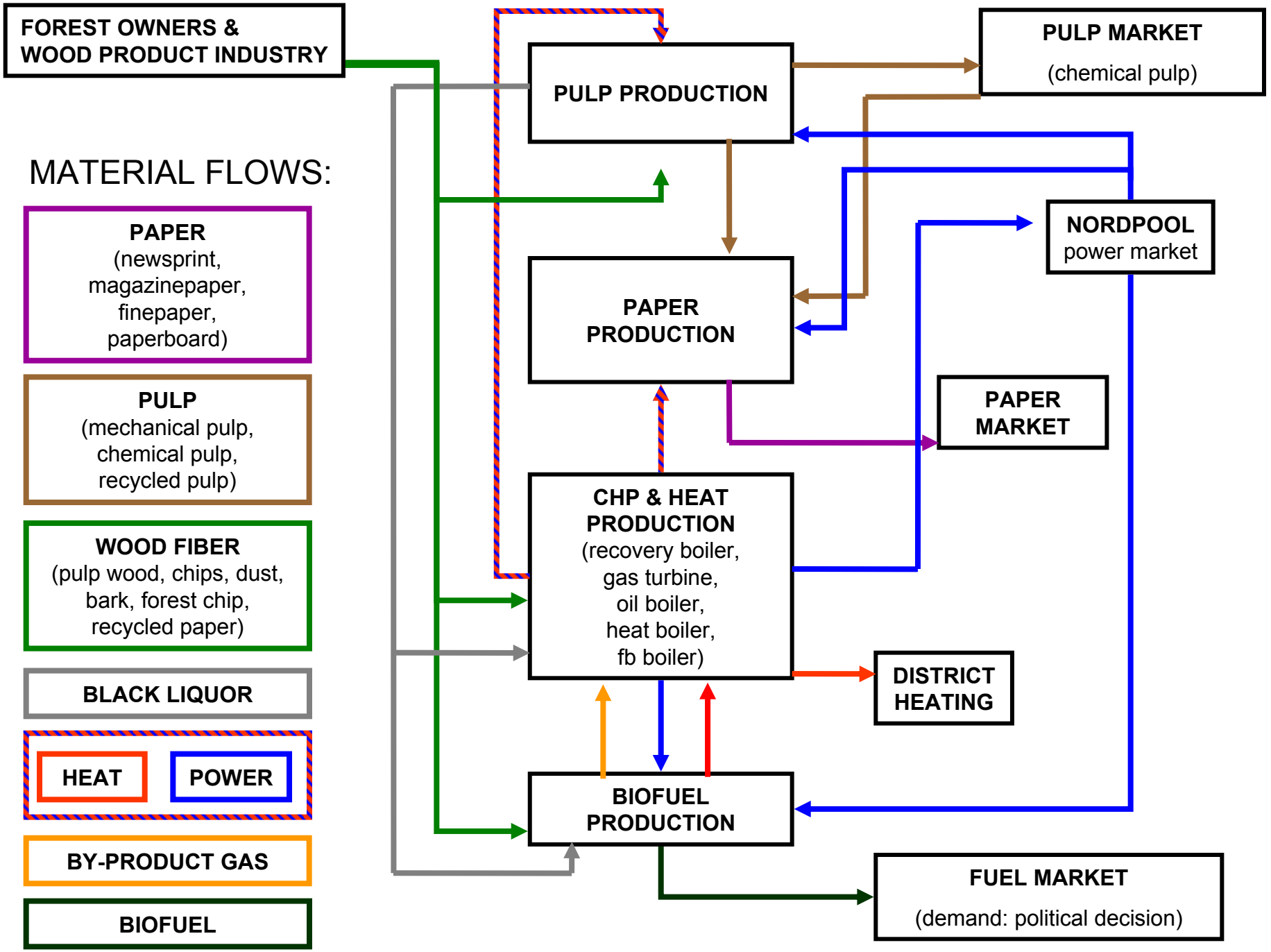
1) Structural reforms of the sector
   - demand decreasing in the developed countries
   - new investments to South-America, Asia
2) P&P mills already have some of the required infrastructure
   - Wood processing and transportation, black liquor by-production
3) Forest biomass does not compete with food or animal feed markets (if agricultural land is not converted to forest land)
4) Forest biomass has generally better GHG/energy ratio than agricultural biomass
5) Other advantages: year around availability, easy storing

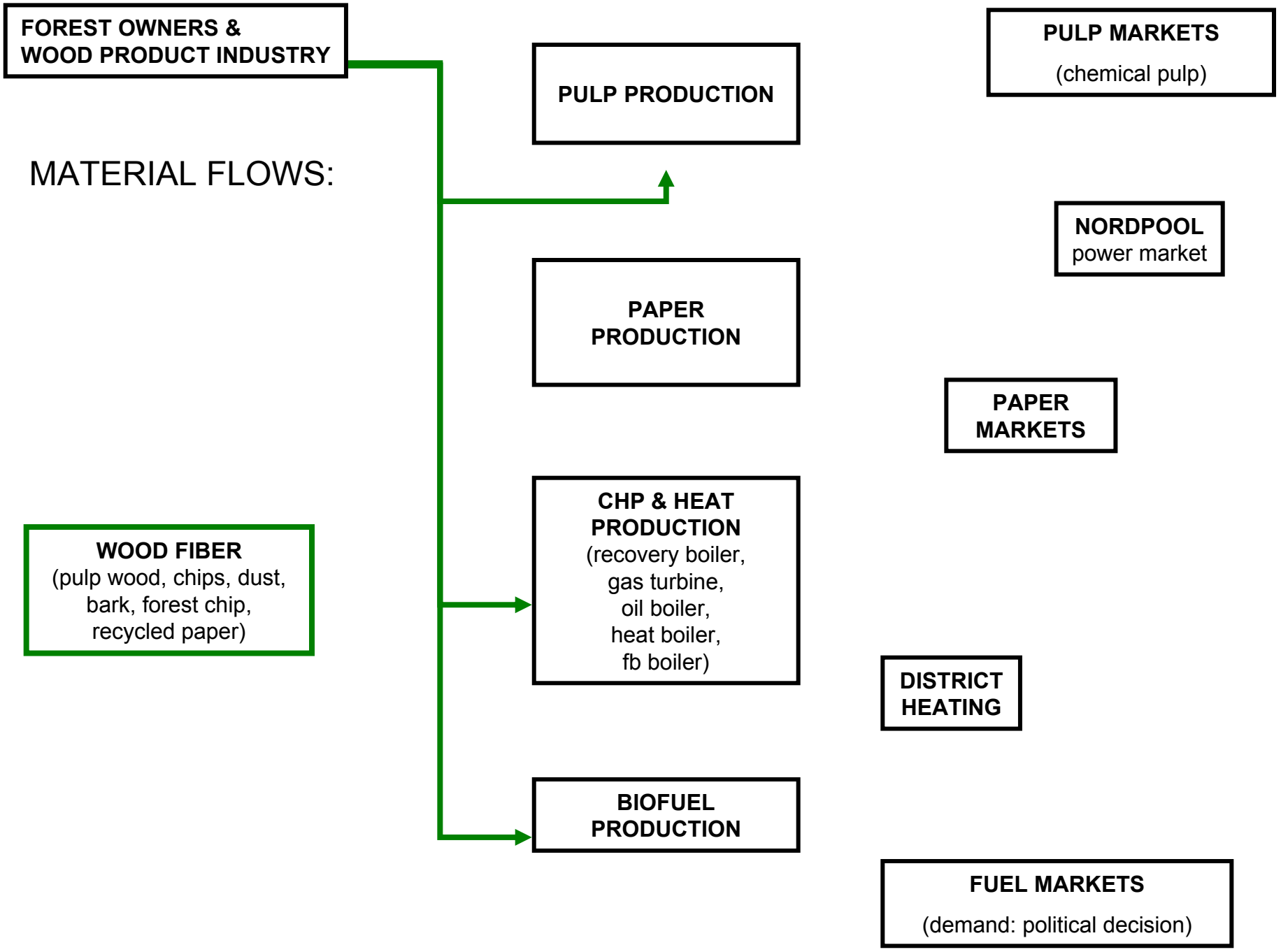
THE OBJECTIVE

- At what fuel price and subsidy levels are forest biorefineries profitable?
- Input choice (wood vs. black liquor) in biofuel production?
- How do different policy measures change the prices, policy costs and input choices?

→ Pulp and paper market model with biorefinery investment possibility

→ Data represent the Finnish pulp and paper sector


FOREST OWNERS & WOOD PRODUCT INDUSTRY
PULP PRODUCTION
PULP MARKET
(chemical pulp)
MATERIAL FLOWS:
PAPER
(newsprint, magazinepaper, finepaper, paperboard)
PULP
(mechanical pulp, chemical pulp, recycled pulp)
WOOD FIBER
(pulp wood, chips, dust, bark, forest chip, recycled paper)
BLACK LIQUOR
HEAT
POWER
BY-PRODUCT GAS
BIOFUEL
PAPER PRODUCTION
NORDPOOL
power market
PAPER MARKET
CHP & HEAT PRODUCTION
(recovery boiler, gas turbine, oil boiler, heat boiler, fb boiler)
DISTRICT HEATING
BIOFUEL PRODUCTION
FUEL MARKET
(demand: political decision)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FOREST OWNERS & WOOD PRODUCT INDUSTRY

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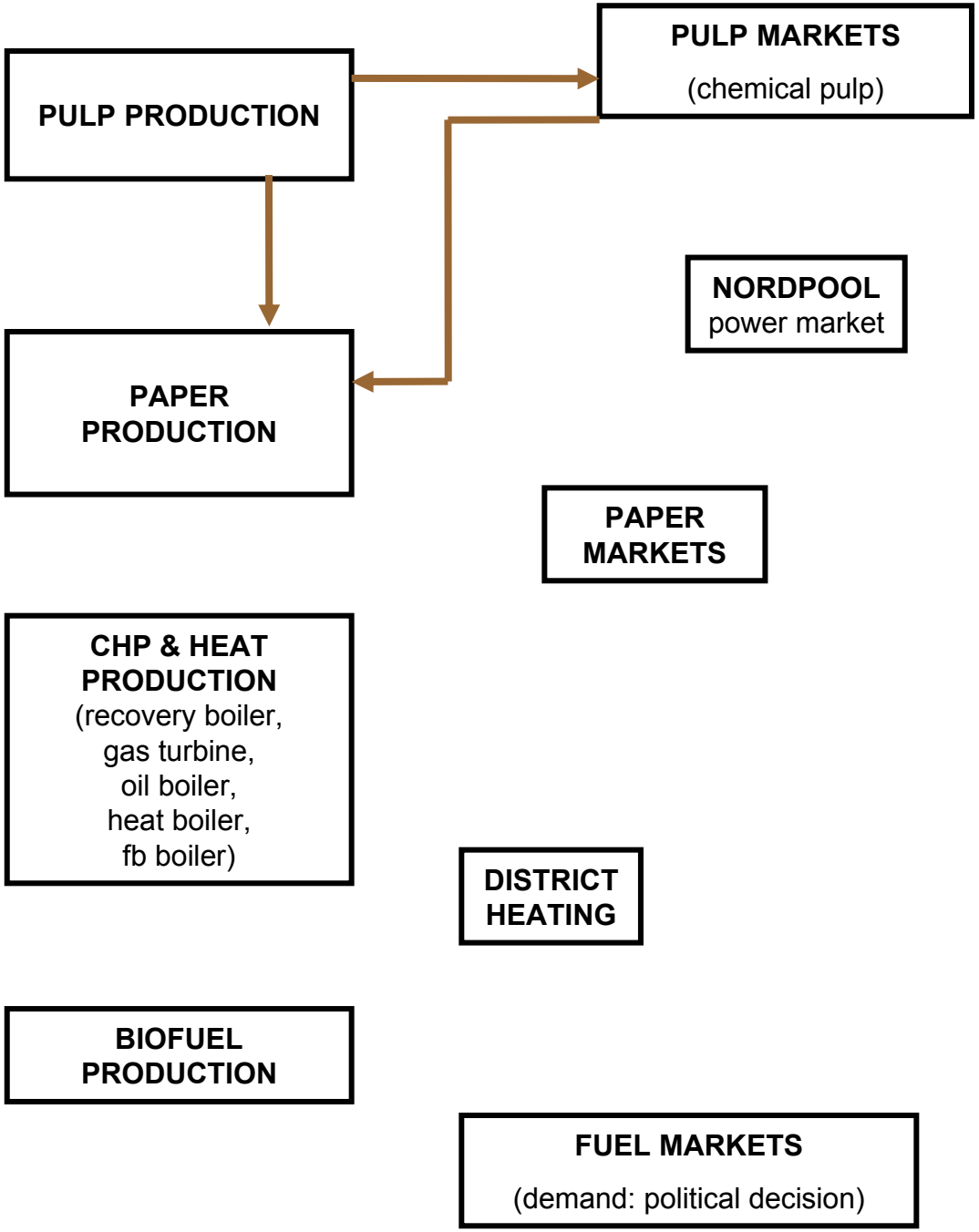

PULP
(mechanical pulp,
chemical pulp,
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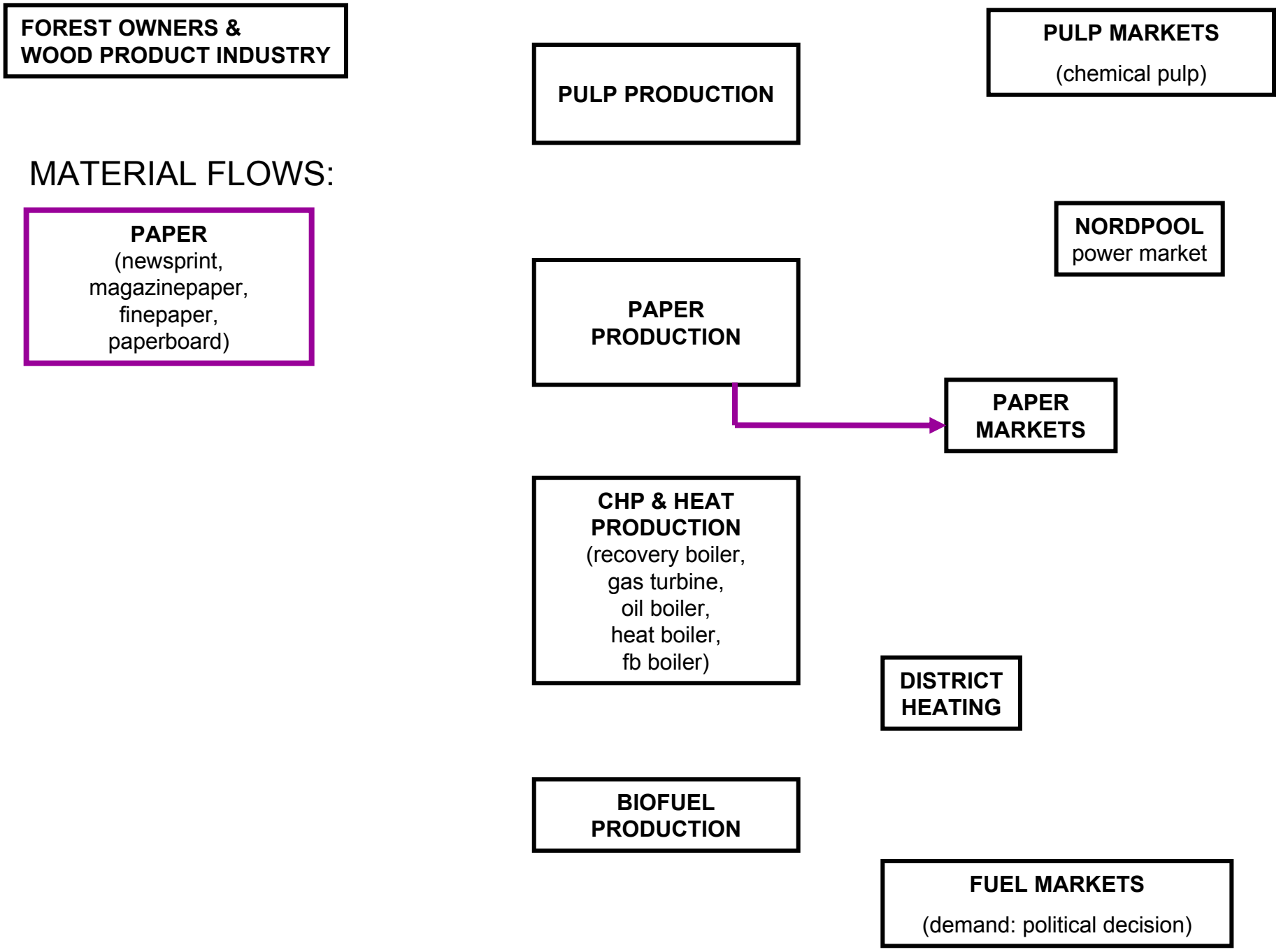
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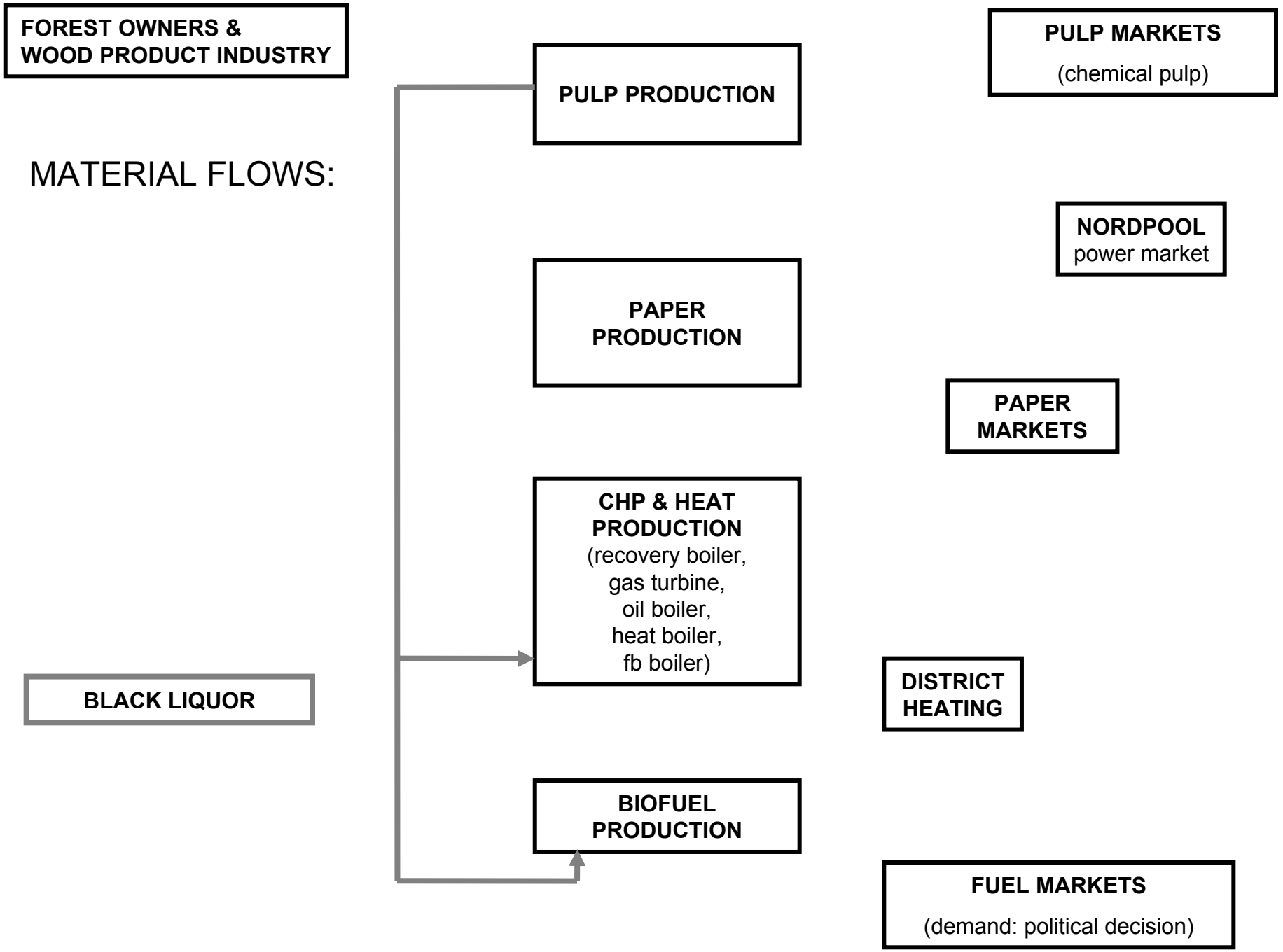
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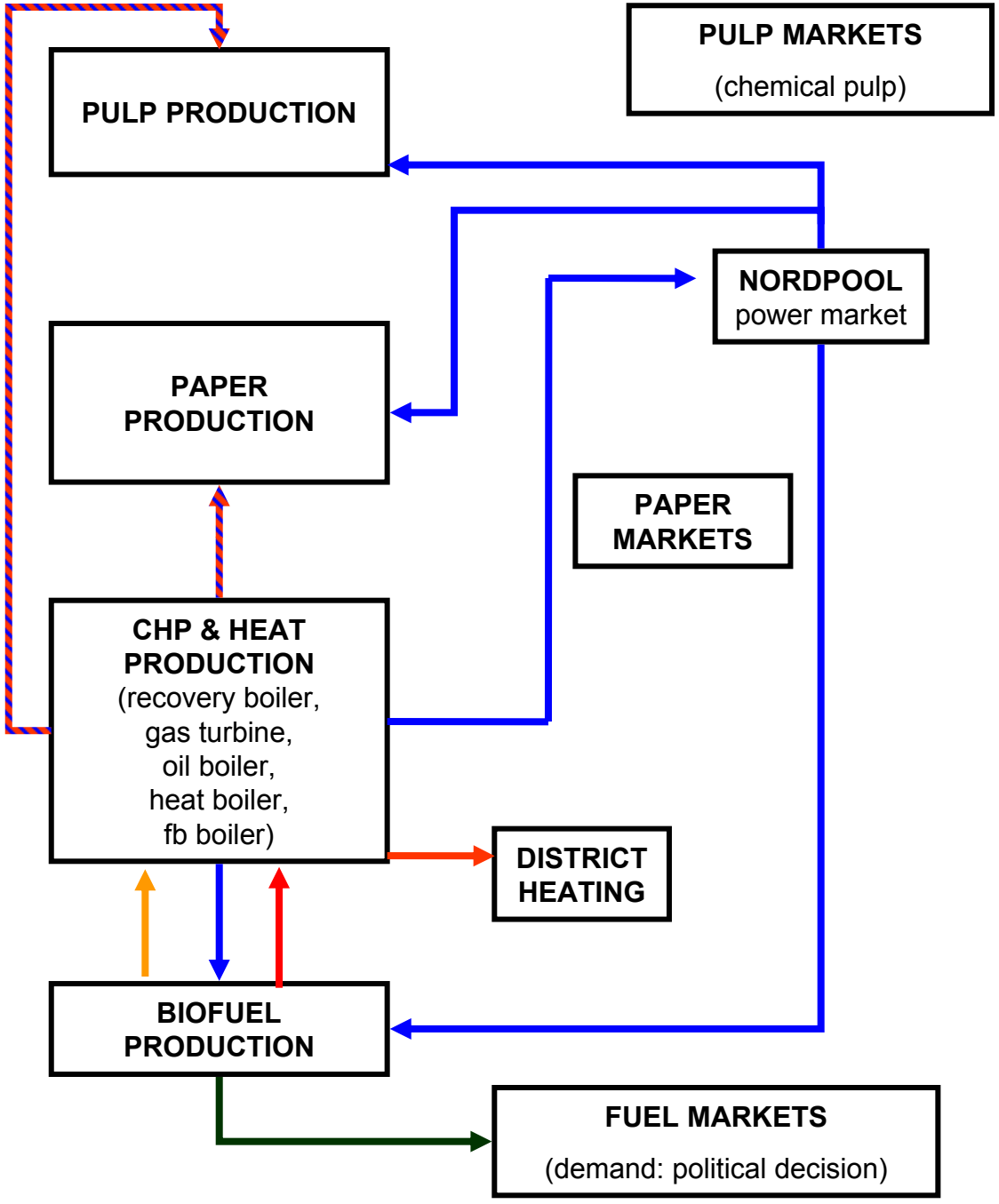
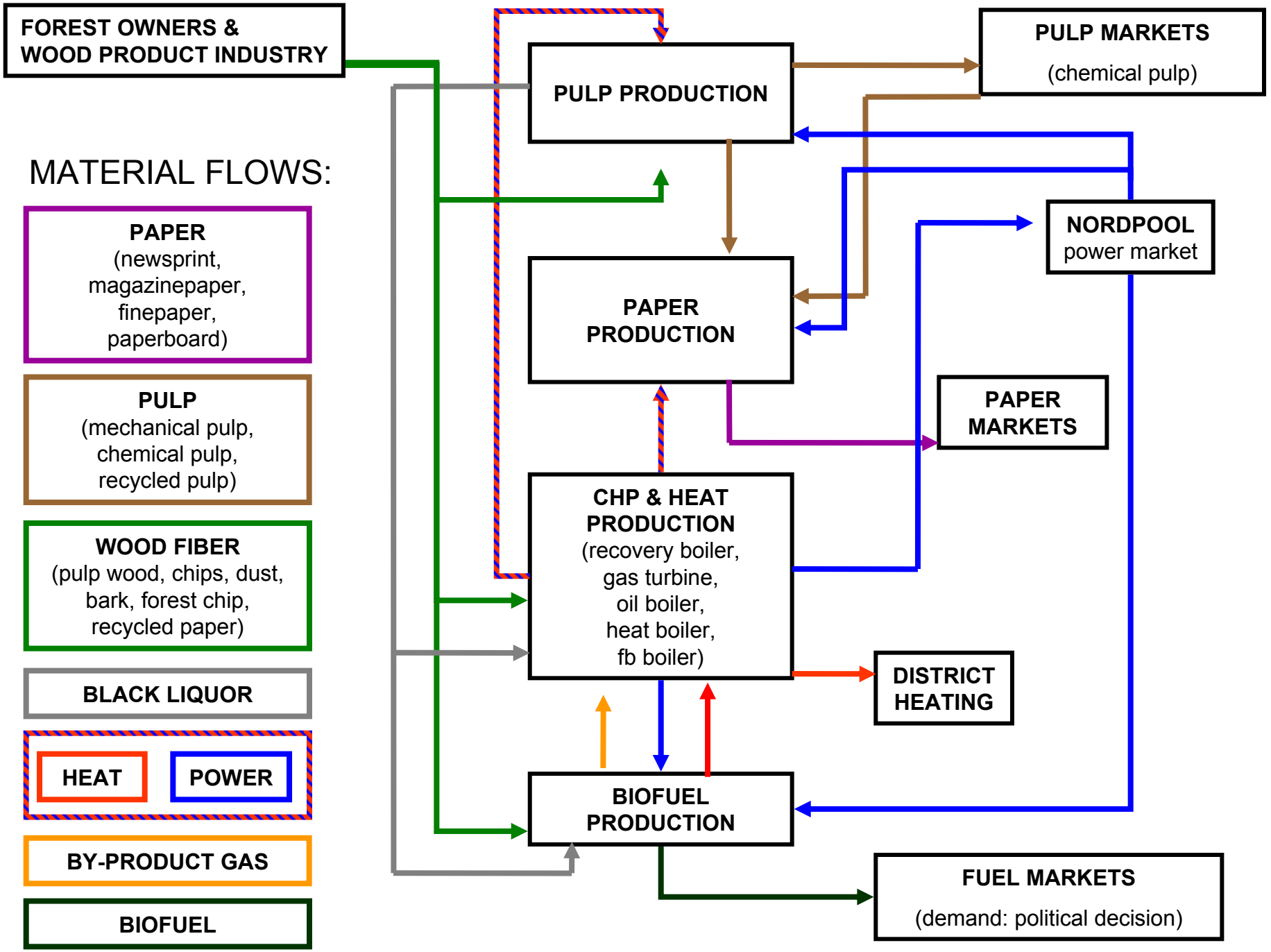


HEAT **POWER**

BY-PRODUCT GAS

BIOFUEL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THE MODEL (1): Producer‘s problem

- Leontief production function for paper, pulp and biofuel production:

- Paper

$$y^m = \min\left\{\frac{x_g^m}{a_g^m}, \frac{x_j^m}{a_j^m}, \ldots, \frac{x_l^m}{a_l^m}\right\}$$

- Pulp

$$y^g = \sum_{w \in WT} y_w^g = \sum_{w \in WT} \min\left\{\alpha_w^g z_w^g, \frac{x_{jw}^g}{a_{jw}^g}, \ldots, \frac{x_{lw}^g}{a_{lw}^g}\right\}$$

- Biofuel

$$y^{bf} = \sum_{b \in GI} \min\left\{\alpha_b^{bf} z_b^{bf}, \frac{x_{j,b}^{bf}}{a_{j,b}^b}, \ldots, \frac{x_{l,b}^{bf}}{a_{l,b}^{bf}}\right\}$$

(The production of biofuel yields gas as a by-product: $x_d = \gamma_d y^{bf}$)

THE MODEL (2): Producer‘s problem

- **CHP production**
  - linear function of energy transformation in combustion
  - constant output efficiency η_j given any fuel *f* input mix

$$R^{chp} = \sum_{s \in BT} R_s^{chp} = \sum_{s \in BT} \left(\sum_{j \in J} p_j \eta_{j,s} \sum_{f \in F_s} x_{f,s} - \sum_{f \in F_s} c_{f,s}(x_s) - \sum_{f \in F_s} p^{ec} \varepsilon_f x_{f,s} \right)$$

where $s \in BT$ are CHP boiler types.

- **Wood input costs**
  - The convex wood fiber input costs:

$$\sum_{w \in WT} c^w \left(z_w^B \right) = \sum_{w \in WT} p_w z_w^B + \frac{2}{3} \sum_{w \in WT} t_w z_w^{B^{\frac{3}{2}}}$$

where t_w is a unit transport cost that increases as a square root of wood use

THE MODEL (3): Investment costs

- Biorefinery investments
  - Specific technologies for gasification of black liquor and wood fibers, i.e. separate capacities
  - The average costs of a biorefinery investment decrease as the size of an investment increases

$$C_{inv,b}^{bf} = \left[c_{inv,b}^{bf} + h_{inv,b}^{bf} \exp\left(-\frac{I_b^{bf}}{\chi_{\min,b}^{bf}} \right) \right] I_b^{bf}$$

THE MODEL (4): Investment cost data

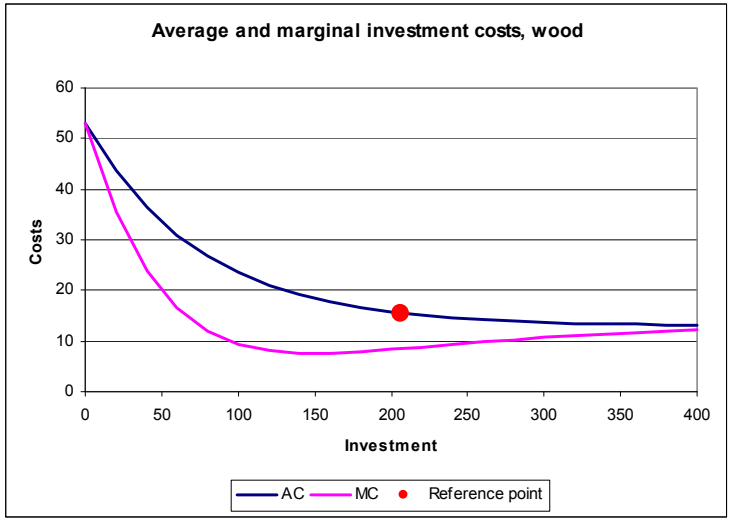
Parameters of the cost function	**Unit investment cost**	**Convex cost parameter**	**Peak of the convex costs**
Parameter	$c_{inv,b}^{bf}$	$h_{inv,b}^{bf}$	$\chi_{\min,b}^{bf}$
Wood	12.95	40	75
Black liquor	10.51	35	60

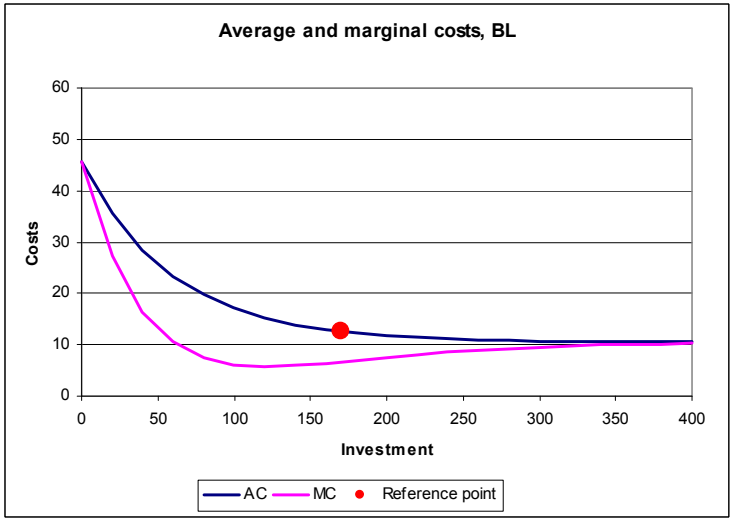
(Larson et al. 2006, McKeough, Kurkela 2008, own calculations)

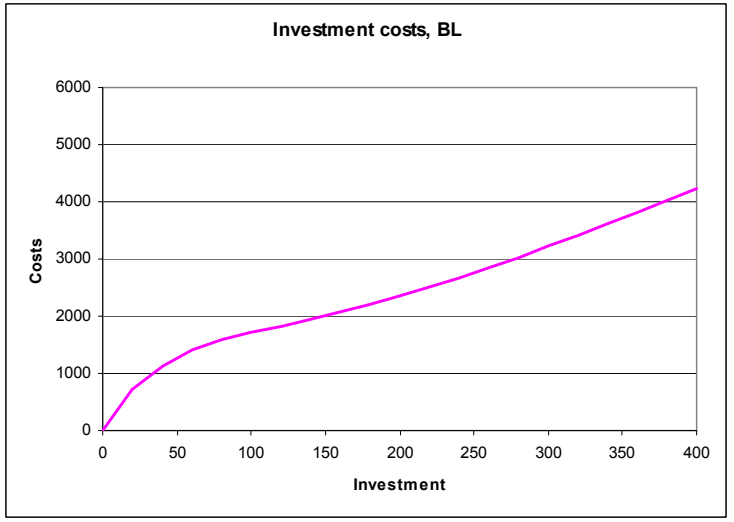
Data for the parameter calculations	**Average investment costs in reference size**	**Inte-rest rate**	**Operation years**	**Exchange rate**	**Overnight installed capacity costs**	**Reference size of mill**
Unit	*€/MW*	*1*	*a*	*€//USD*	*USD 1000*	*MW*
Wood fiber	15.48	0.10	20	0.8	296 736	206.6
Black liquor	12.58	0.10	20	0.8	200 076	170.0

(Larson et al. 2006, McKeough, Kurkela 2008)

THE MODEL (5): Investment cost functions







THE MODEL (6)

- Profit maximization with:
  - Feasibility constraints for wood, pulp, black liquor and heat
  - Capacity constraints for paper, pulp, biofuel and CHP productions

- Endogenously from the model:
  - Supply of pulp, paper, biofuel and heat
  - Demand of wood
  - Demand of pulp $D^g = d_g^0 \left(\frac{p_g}{p_g^0} \right)^{-\varepsilon_g} + \sum_k x_{gk}^s$

- Demand/supply curves (constant elasticity):
  - Demand of paper and heat
  - Supply of wood

NUMERICAL APPLICATION (1)

- 3, 6 or 9 TWh per year target for biofuel production
  - about 5, 10 or 15 % of the total transport fuel consumption in Finland (EU target 2020 10%, Finnish target 2020 7 TWh)
  - we analyze the levels of fuel price and policy instruments (subsidies) that are needed to reach these targets
- Modelled as a mixed complementarity problem using PATH solver in GAMS modeling system.
- The setting is based on real plant level data from pulp and paper industry and the energy market in Finland in 2008

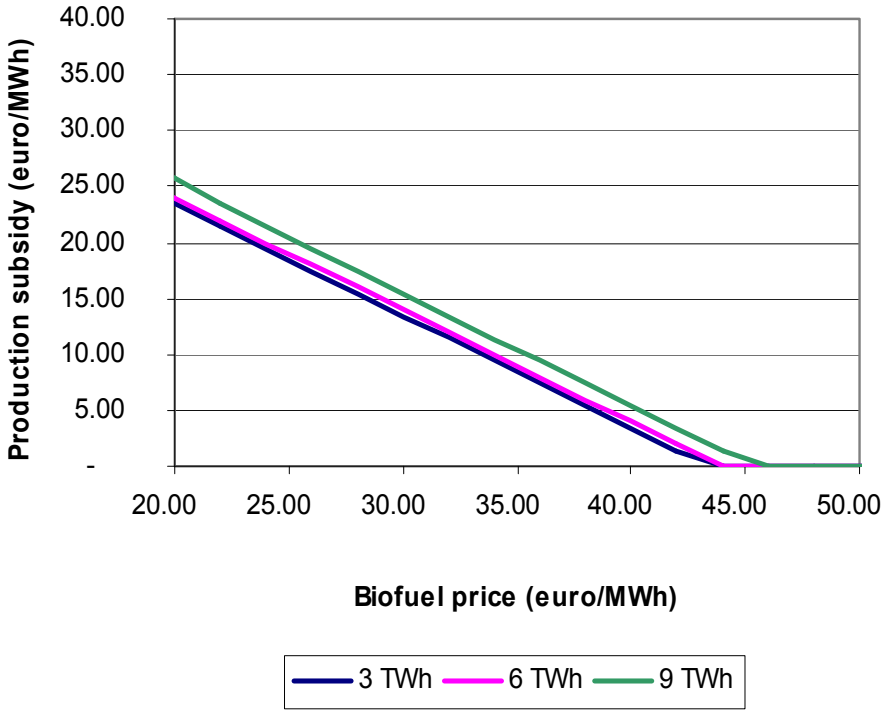
NUMERICAL APPLICATION (2): Subsidies

1) Production subsidy
   - price premium on top of the biofuel price for all the biofuel units produced (by wood or black liquor)

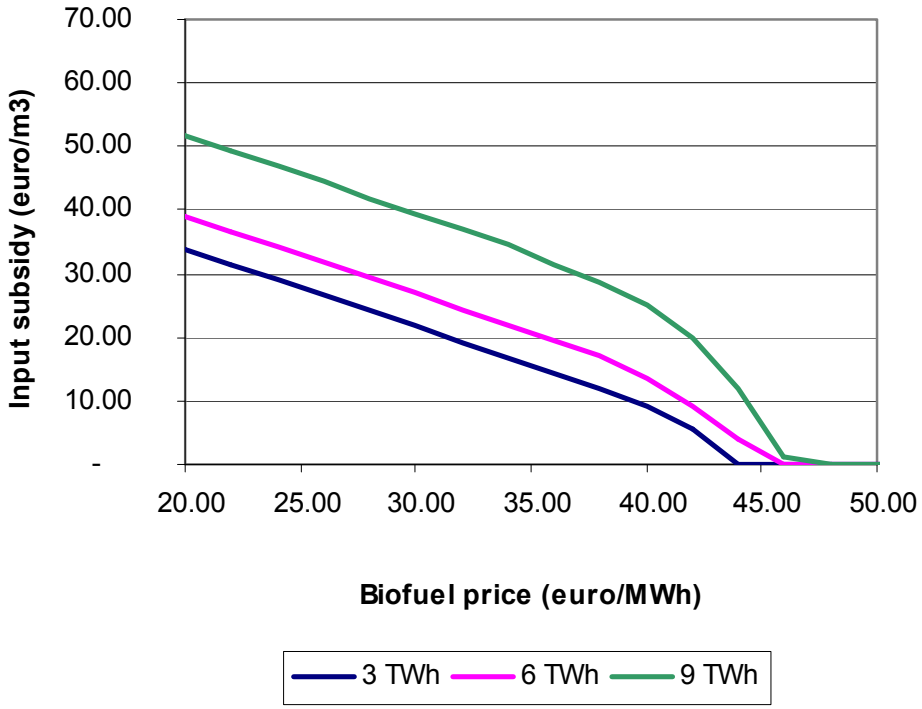
2) Input subsidy (for forest residues)
   - received for each unit of a wood fiber type used in biofuel production (in our analysis only for forest residue)

RESULTS (1): Policy instrument values

- Production subsidy:

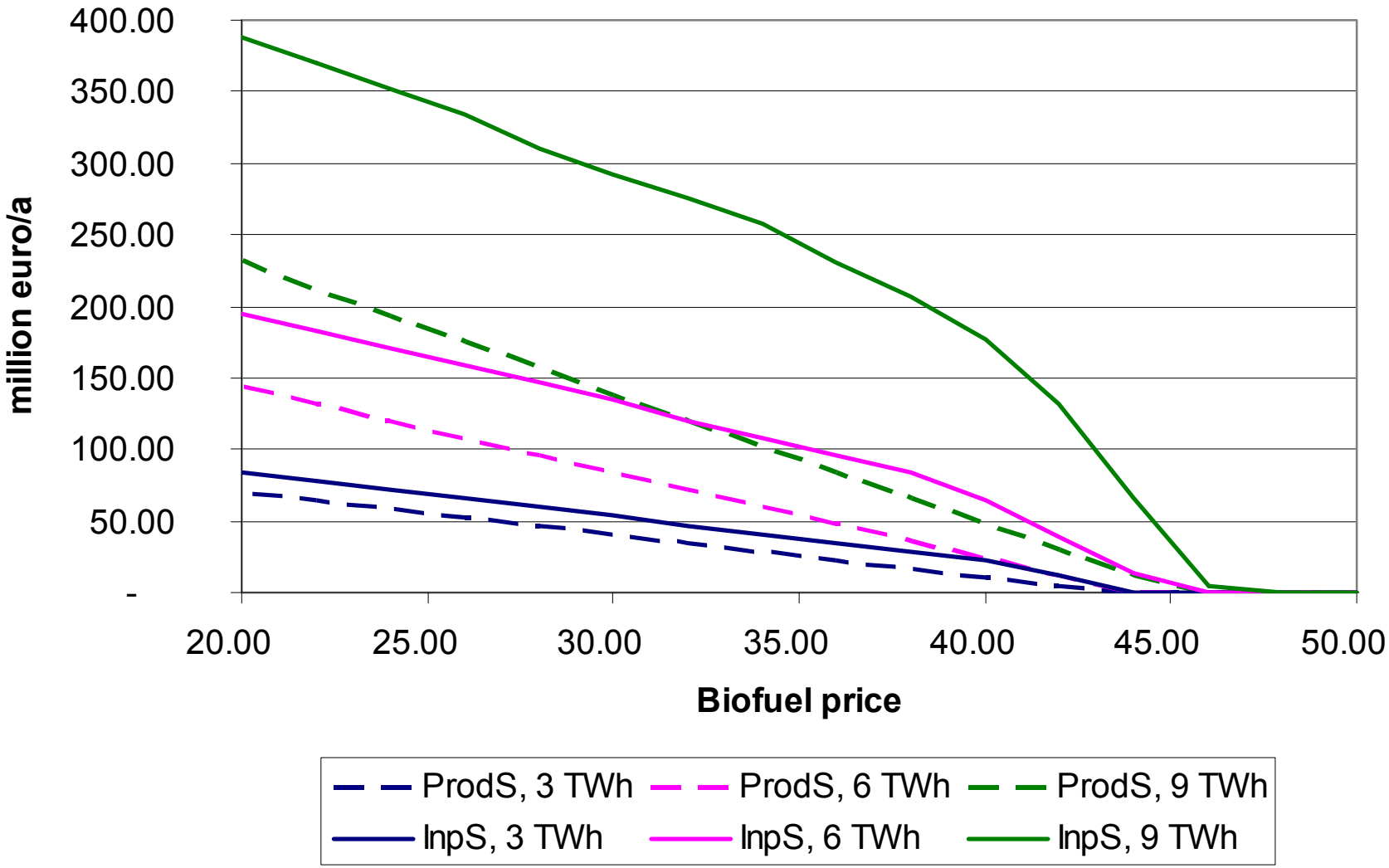


- Input subsidy:



- Notice: difficulties in finding the optimal value for input subsidy (6 and 9 TWh) for high fuel prices

RESULTS (2): Policy costs



METLA

RESULTS (3): Investments

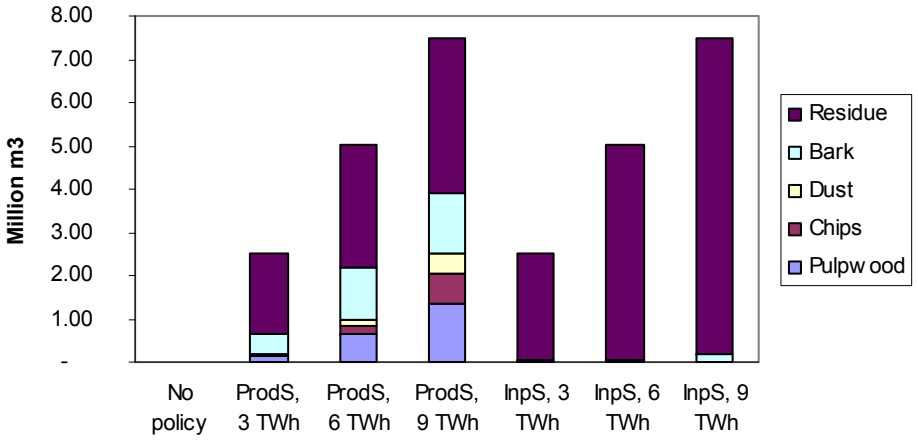
- With both policy instrument, all biorefineries use wood gasifying technology

- Number and size of investments:

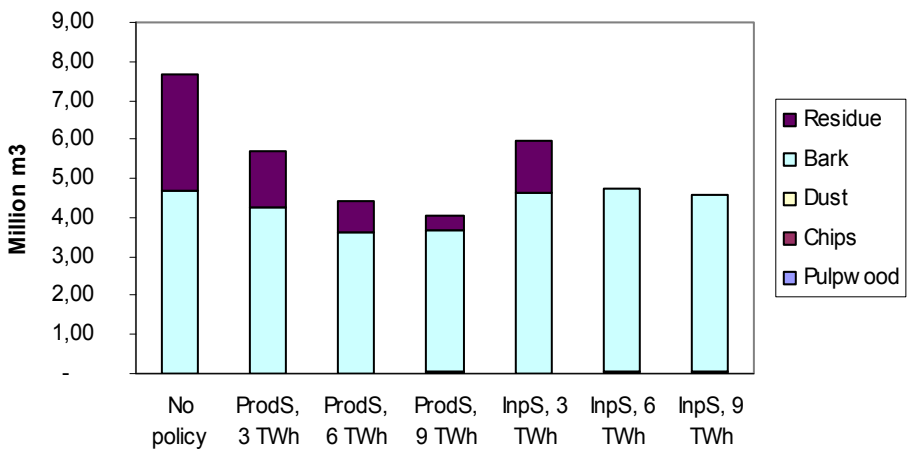
Production subsidy	3 TWh	2	~170 MW
Production subsidy	6 TWh	4	156-184 MW
Production subsidy	9 TWh	6	158-177 MW
Input subsidy	3 TWh	2	~ 170 MW
Input subsidy	6 TWh	5	128-150 MW
Input subsidy	9 TWh	7	139-151 MW

RESULTS (4): Wood use

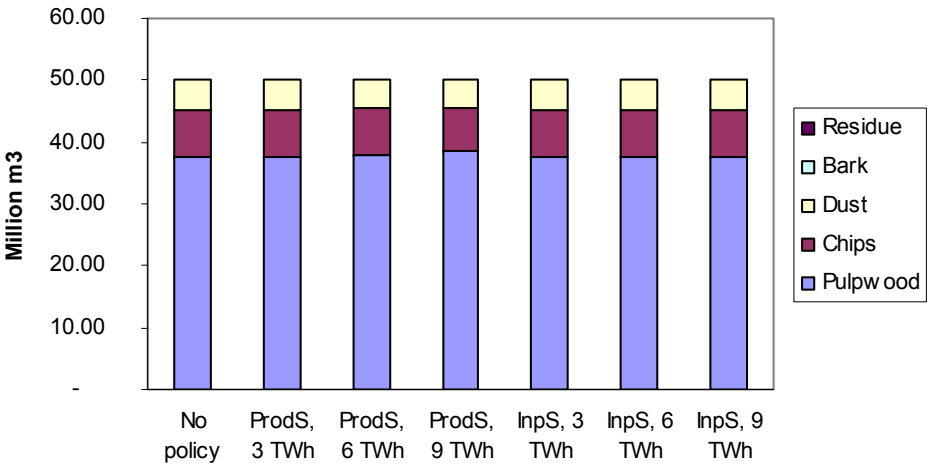
Wood use, biofuel production



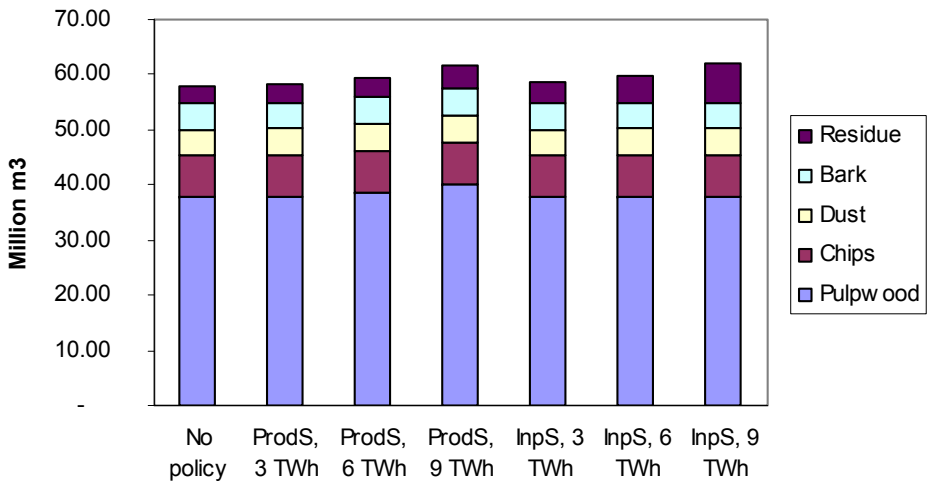
Wood use, CHP and heat production



Wood use, pulp production

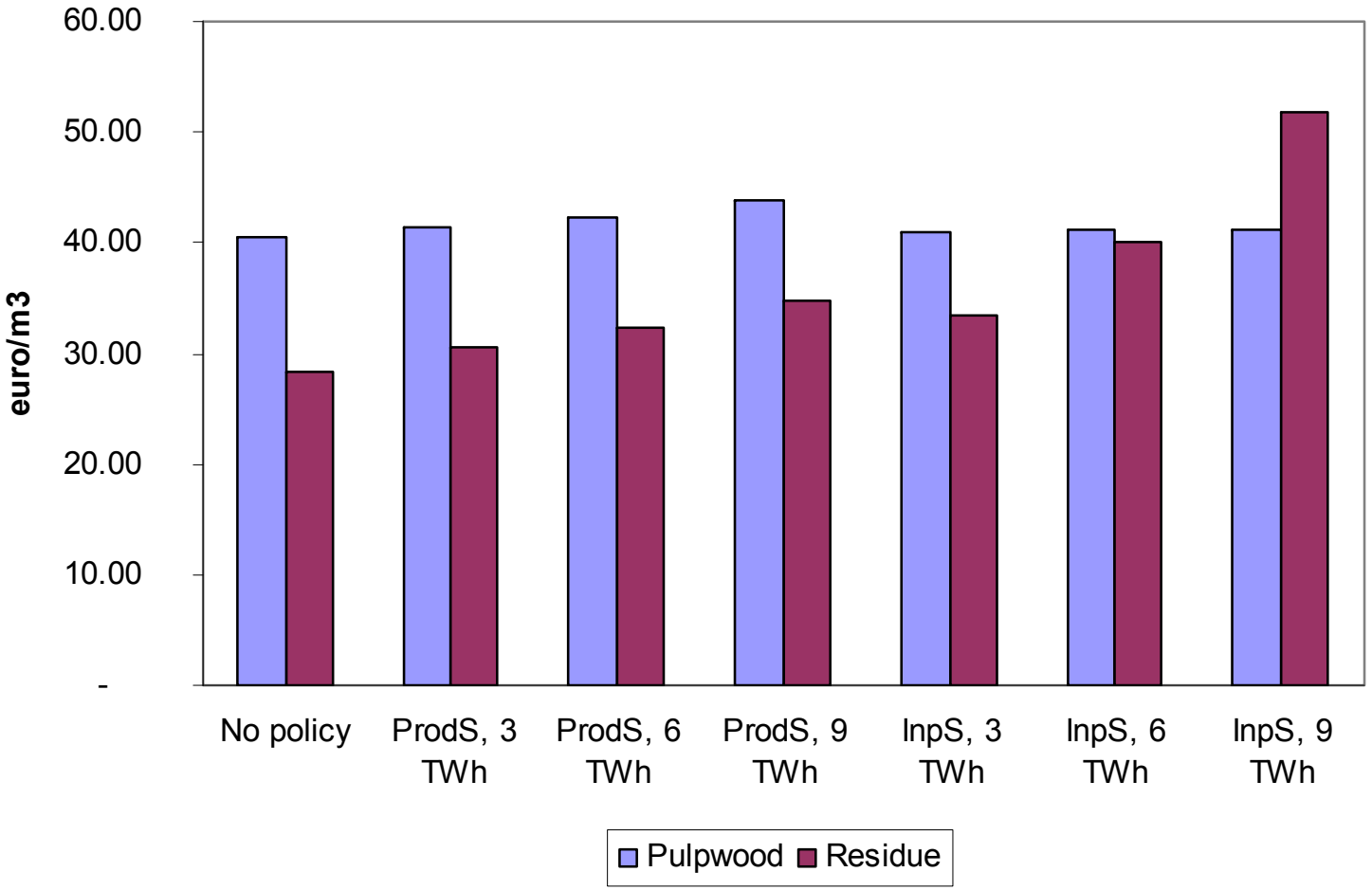


Wood use, Total



METLA

RESULTS (5): Wood price



METLA

DISCUSSION (1)

- Subsidies on biofuels are needed to boost investments
  - Support is needed if biofuel price is under 43 €/MWh
- The level of subsidy needed depends on the biofuel price
  - Subsidy can be linked e.g. to the price of crude oil
- Production subsidy is cost-efficient
  - The costs of input subsidy are notably higher for relevant biofuel prices and higher targets

DISCUSSION (2)

- Wood input in biofuel production depends on the policy instrument
  - Production subsidy: mainly forest residues, bark and pulpwood
  - Input subsidy: (almost) only forest residues
- Wood use in biofuel production is relatively small compared to the total use
  - Impact on the total use of wood is small even with 9 TWh target
- Production subsidy increases the price of pulpwood
  - Negative impact on the profitability of pulp and paper industry

THANK YOU!