Business from technology

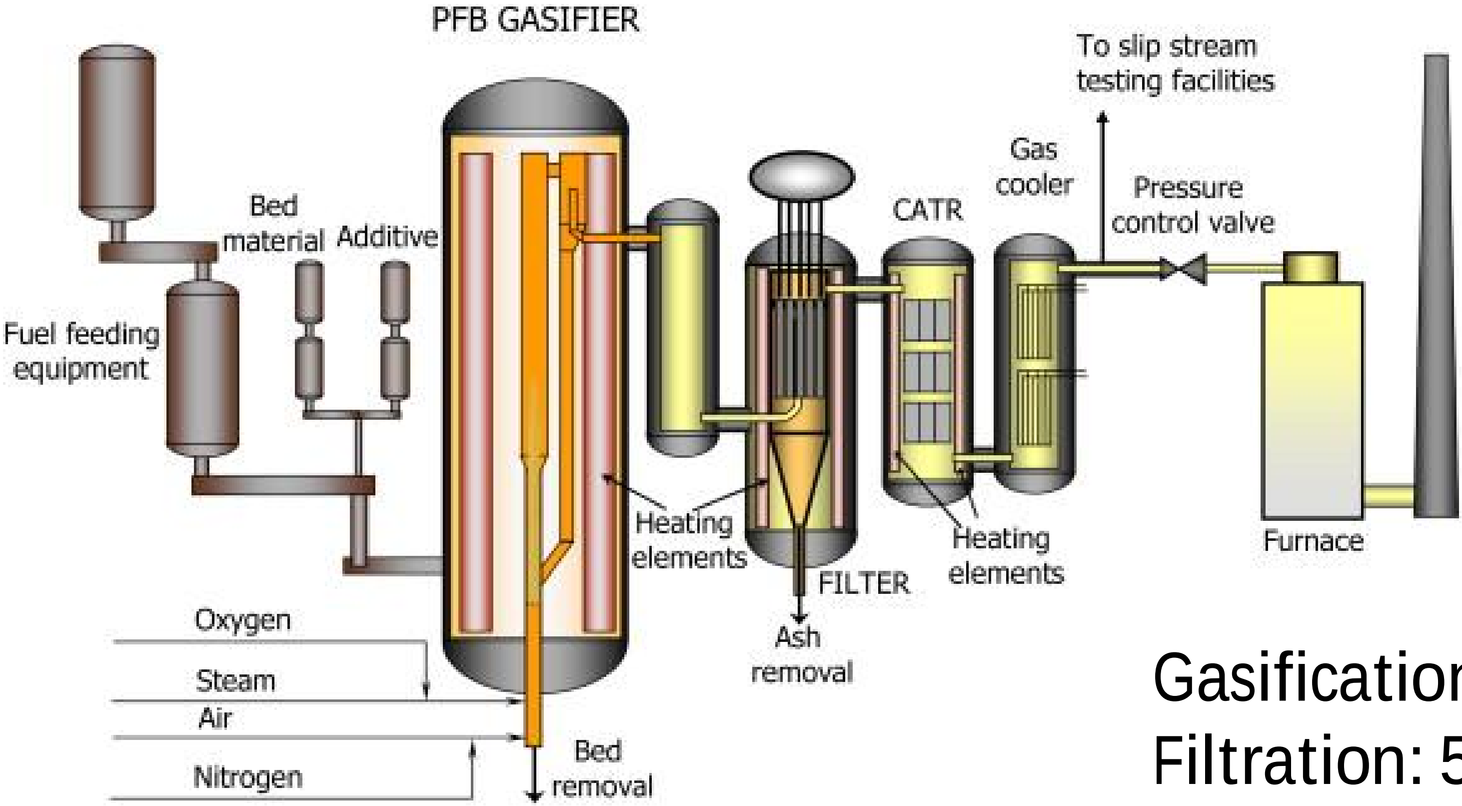
Biobased materials and fuels via methanol – The role of integration

Joint Task 33 & IETS workshop at Göteborg, Nov2013

Ilkka Hannula
VTT Technical Research Centre of Finland

Gasification and Gas Cleaning Process

- developed and tested at VTT on 0.5 MW scale
-ca. 4000 operating hours with different wood residues

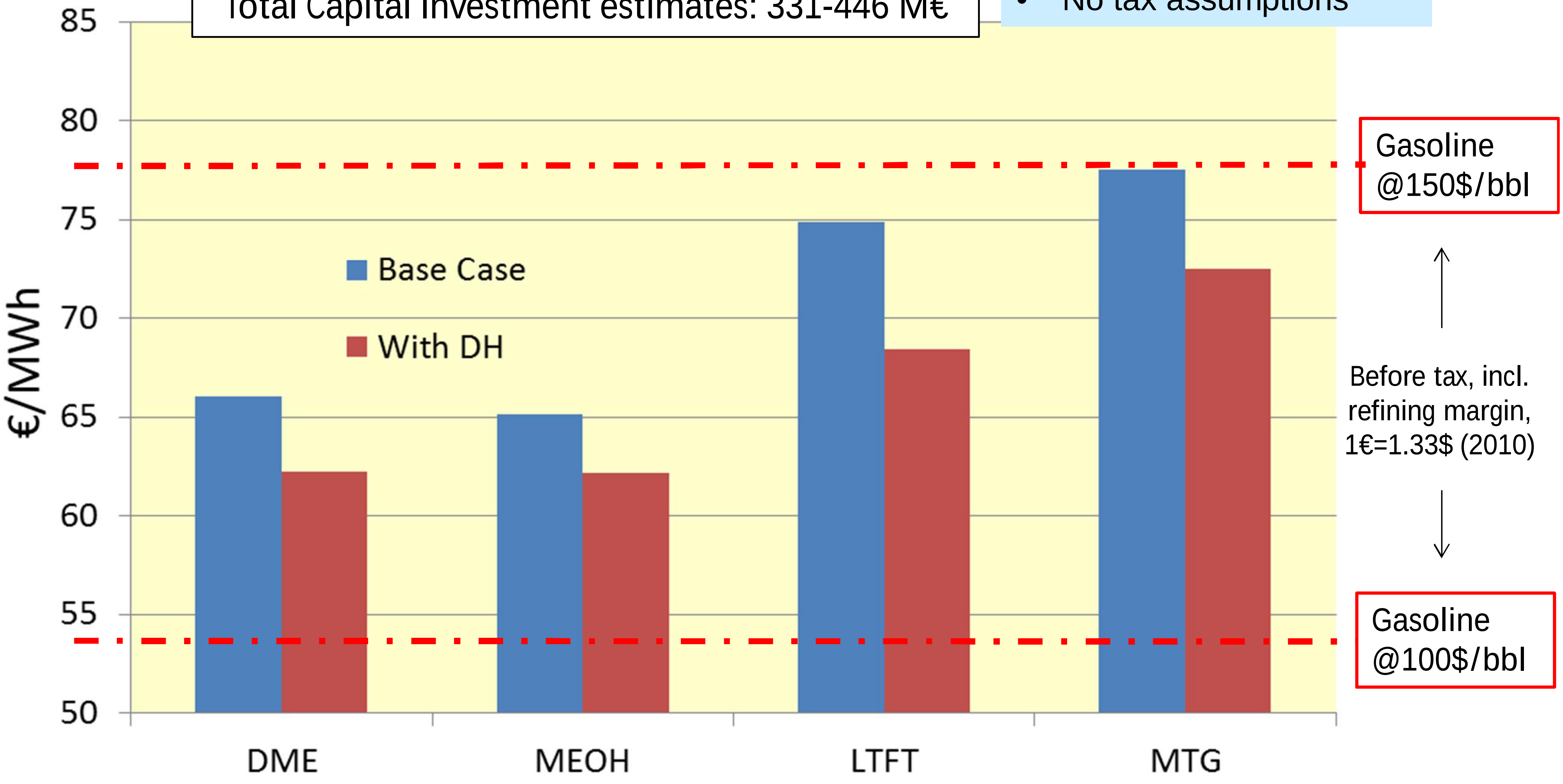


Gasification: 4 bar, 850°C
Filtration: 550°C
Reforming: 950°C,
~95 % CH_4 conv.

Levelised production cost estimates*

300 MW biomass @ 17 €/MWh, 0.12 ann. factor
Electricity 50 €/MWh, DH 30 €/MWh@5500 h/a
Total Capital Investment estimates: 331-446 M€

- Mature technology
- No investment support
- No CO_2 credits
- No tax assumptions

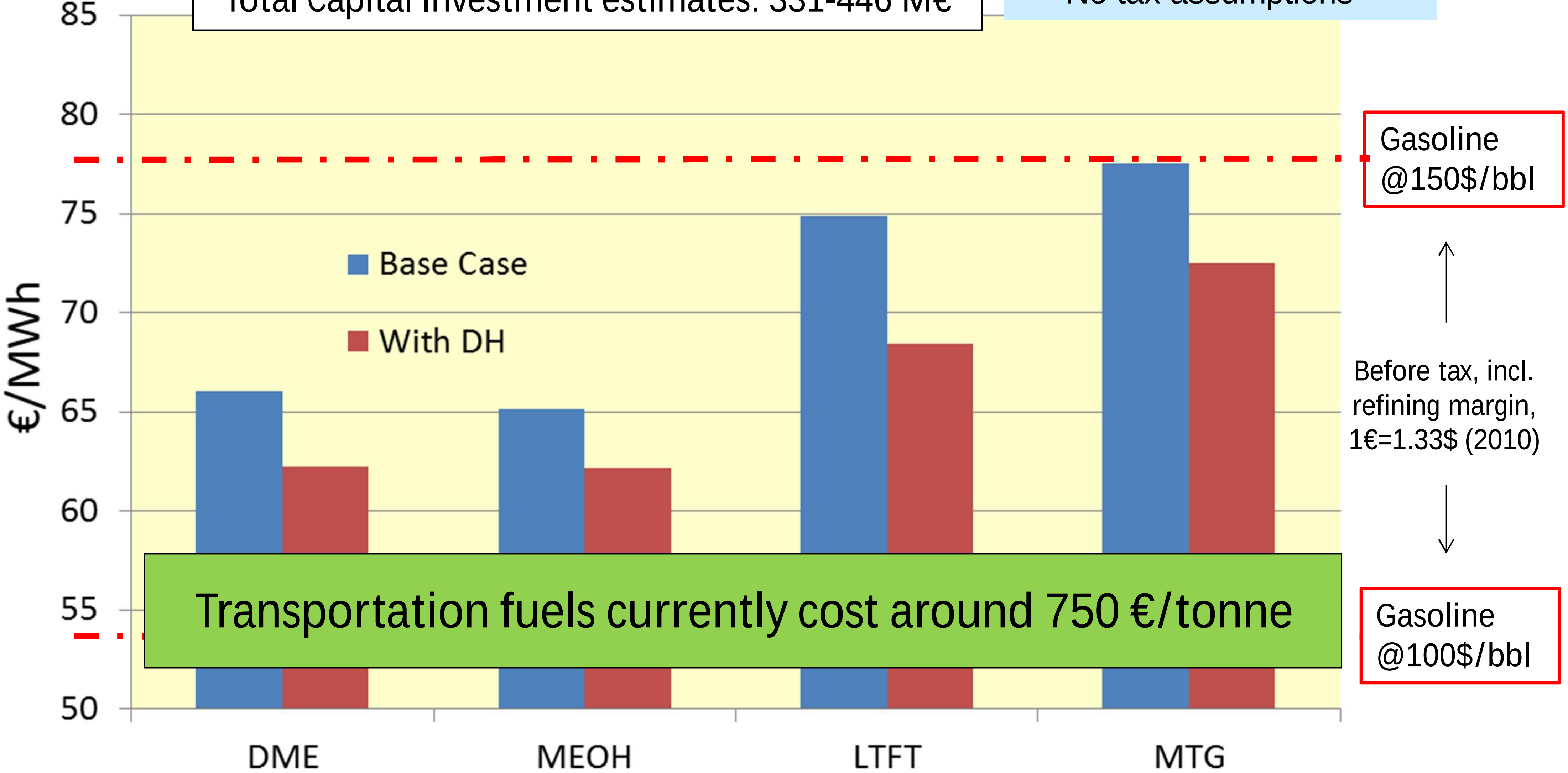


*Liquid transportation fuels via large-scale fluidised-bed gasification of lignocellulosic biomass, Hannula, Ilkka; & Kurkela, Esa 2013. VTT, Espoo. 114 p. + app. 3 p. VTT Technology: 91

Levelised production cost estimates*

300 MW biomass @ 17 €/MWh, 0.12 ann. factor
Electricity 50 €/MWh, DH 30 €/MWh@5500 h/a
Total Capital Investment estimates: 331-446 M€

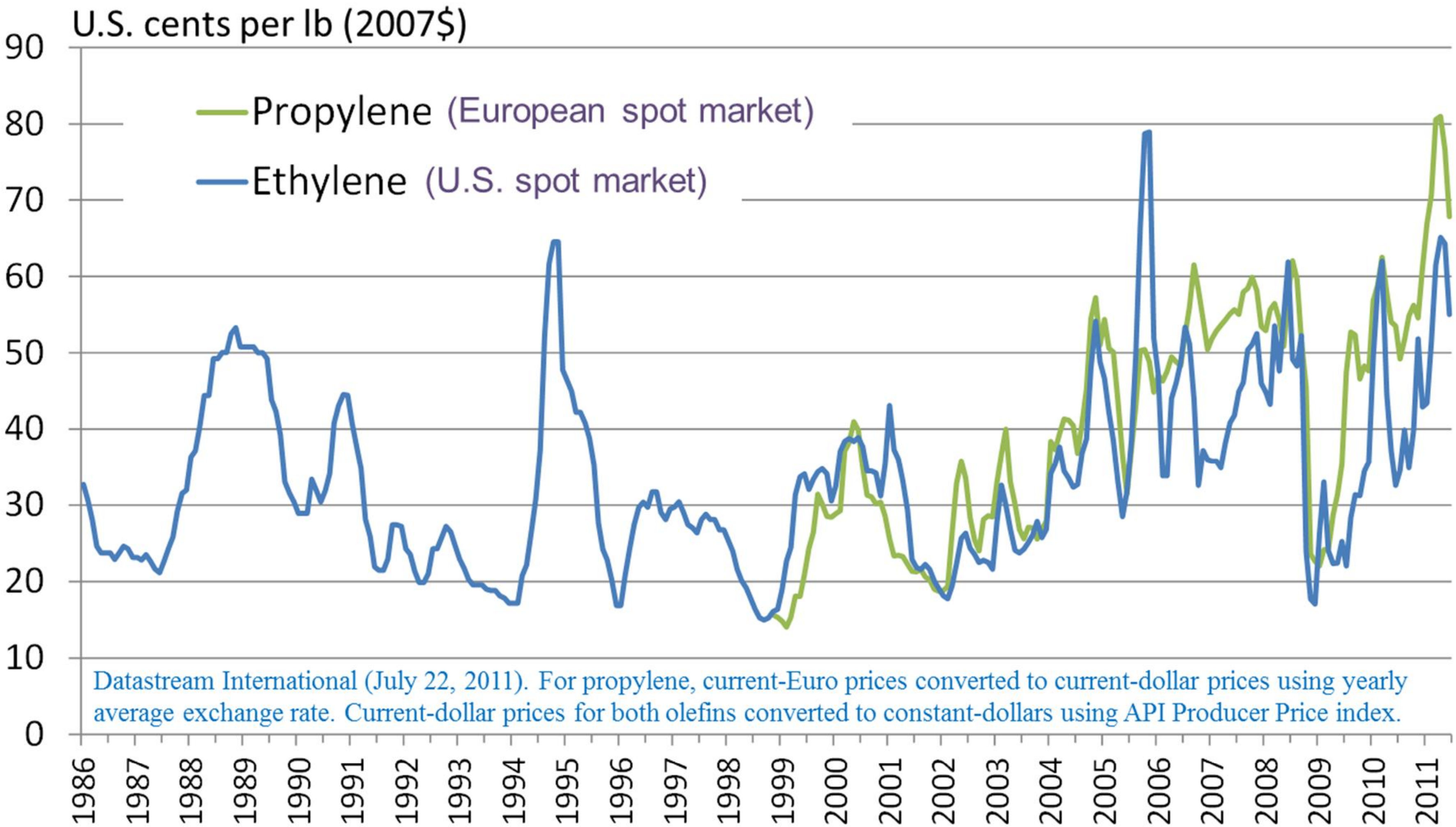
- Mature technology
- No investment support
- No CO_2 credits
- No tax assumptions



Transportation fuels currently cost around 750 €/tonne

*Liquid transportation fuels via large-scale fluidised-bed gasification of lignocellulosic biomass, Hannula, Ilkka; & Kurkela, Esa 2013. VTT, Espoo. 114 p. + app. 3 p. VTT Technology: 91

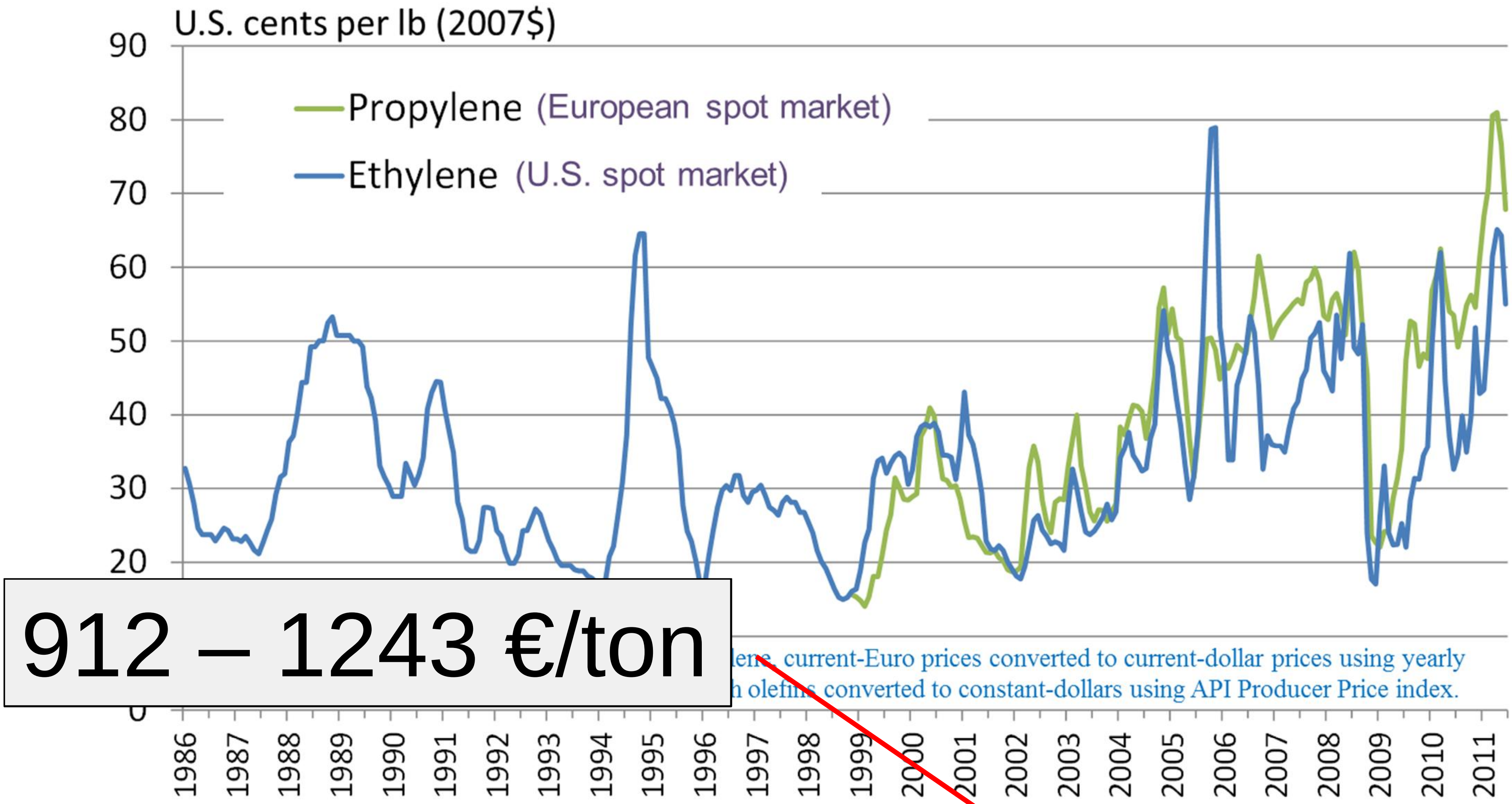
Olefin prices



CMAI-reported benchmark contract olefin prices (current dollars). Actual for 2010 and projected for 2015.

	C_2H_4 ($/lb)	C_3H_6 ($/lb)	Avg $/lb	Avg $/GJ
2010	0.50	0.60	0.55	26
2015	0.67	0.82	0.75	35

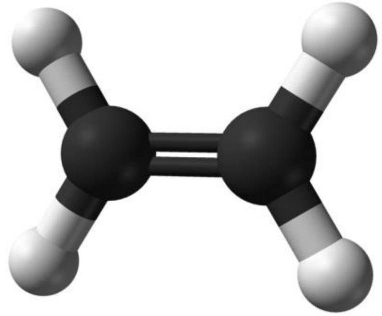
Olefin prices



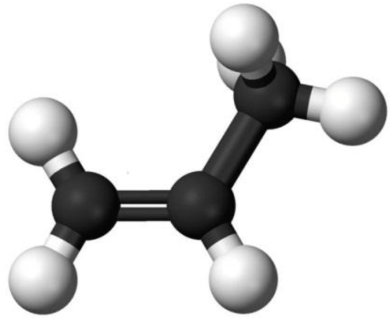
CMAI-reported benchmark contract olefin prices (current dollars). Actual for 2010 and projected for 2015.

	C_2H_4 ($/lb)	C_3H_6 ($/lb)	Avg $/lb	Avg $/GJ
2010	0.50	0.60	0.55	26
2015	0.67	0.82	0.75	35

Light Olefins



Ethylene (C_2H_4)

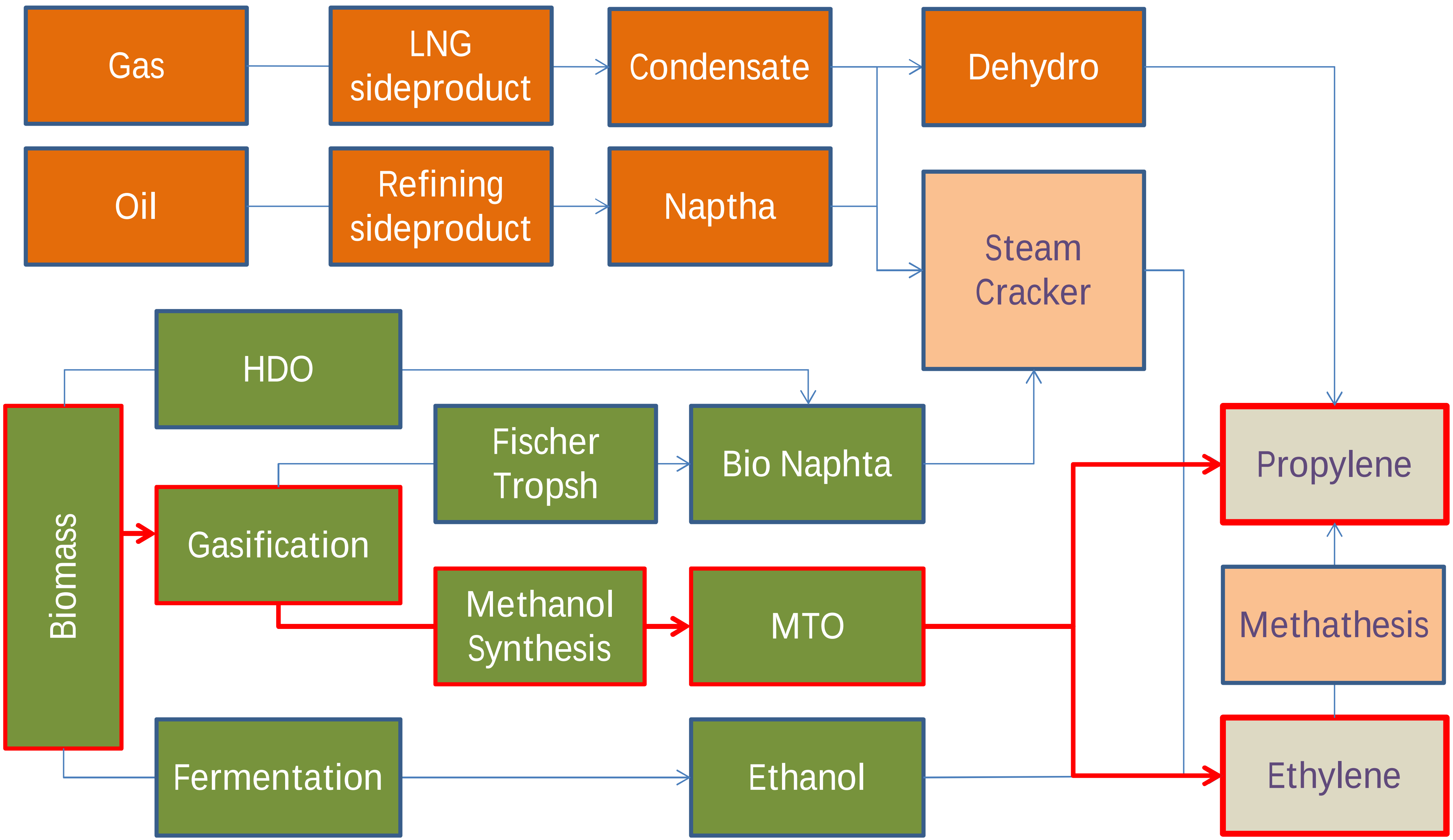


Propylene (C_3H_6)

Olefins ethylene and propylene form the main petrochemical platform

- Main plastics (polyethylene and polypropylene), elastromers, rubbers
- Ethylene is used for monomers like ethylene glycol, ethylene oxide , styrene, vinyl- and fluoromonomers
- Propylene is used also formonomers like acrylic acid, acrylnitrile, propylene oxide
- Several base chemicals like acitic acid, surfactants, base oils, etc.

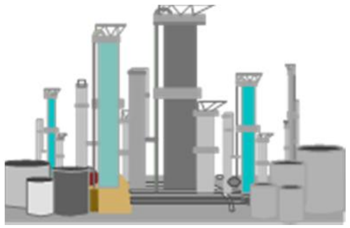
Olefin routes



The proposed 2-step concept

Methanol-to-Olefins

- MTO was first developed by Mobil in the mid-1980s as a spin-off to MTG in New Zealand.
- Technology went unused until the mid-1990's when UOP & Norsk Hydro build a pilot plant in Norway.
- A successful 100 bbl/d demonstration later operated in Germany.
- Since then, Lurgi has also developed its own version (MTP).
- Dalian Institute of Chemical Physics has recently developed a similar process (DMTO).



Possibilities for two types of integration examined:

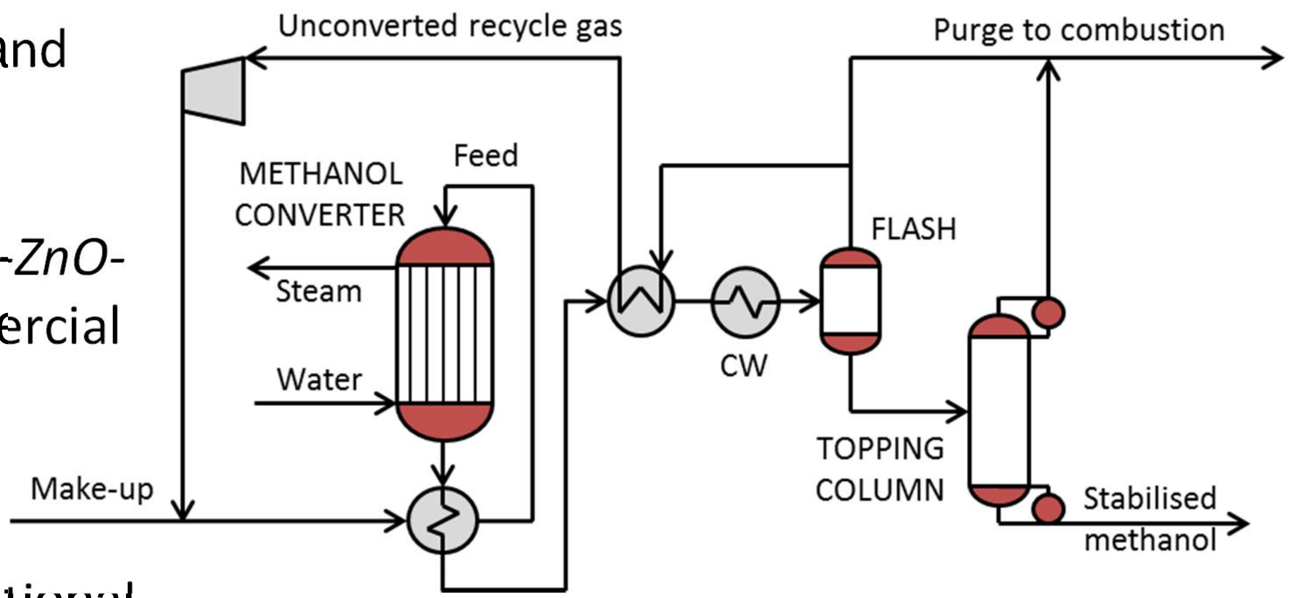
- Heat integration
- Equipment sharing

Biomass-to-Methanol

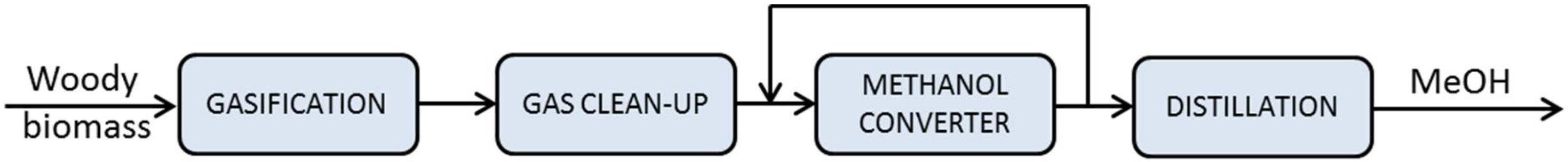
- First described by Patart [43] and soon after produced by BASF chemists in Leuna, Germany in 1923. [44]
- Low pressure methanol synthesis, pioneered by engineers at ICI has become the exclusive production process since 1960's
- Methanol is the largest product from synthesis gas after ammonia
- Can be utilised as chemical feedstock or to supplement liquid fuels.
- Can also be converted to various chemicals or used as a portal to hydrocarbon fuels through the conversion to dimethyl ether (DME) or gasoline (MTG).
- In 2011 the annual consumption of methanol amounted to 47 million tons

Biomass to Methanol

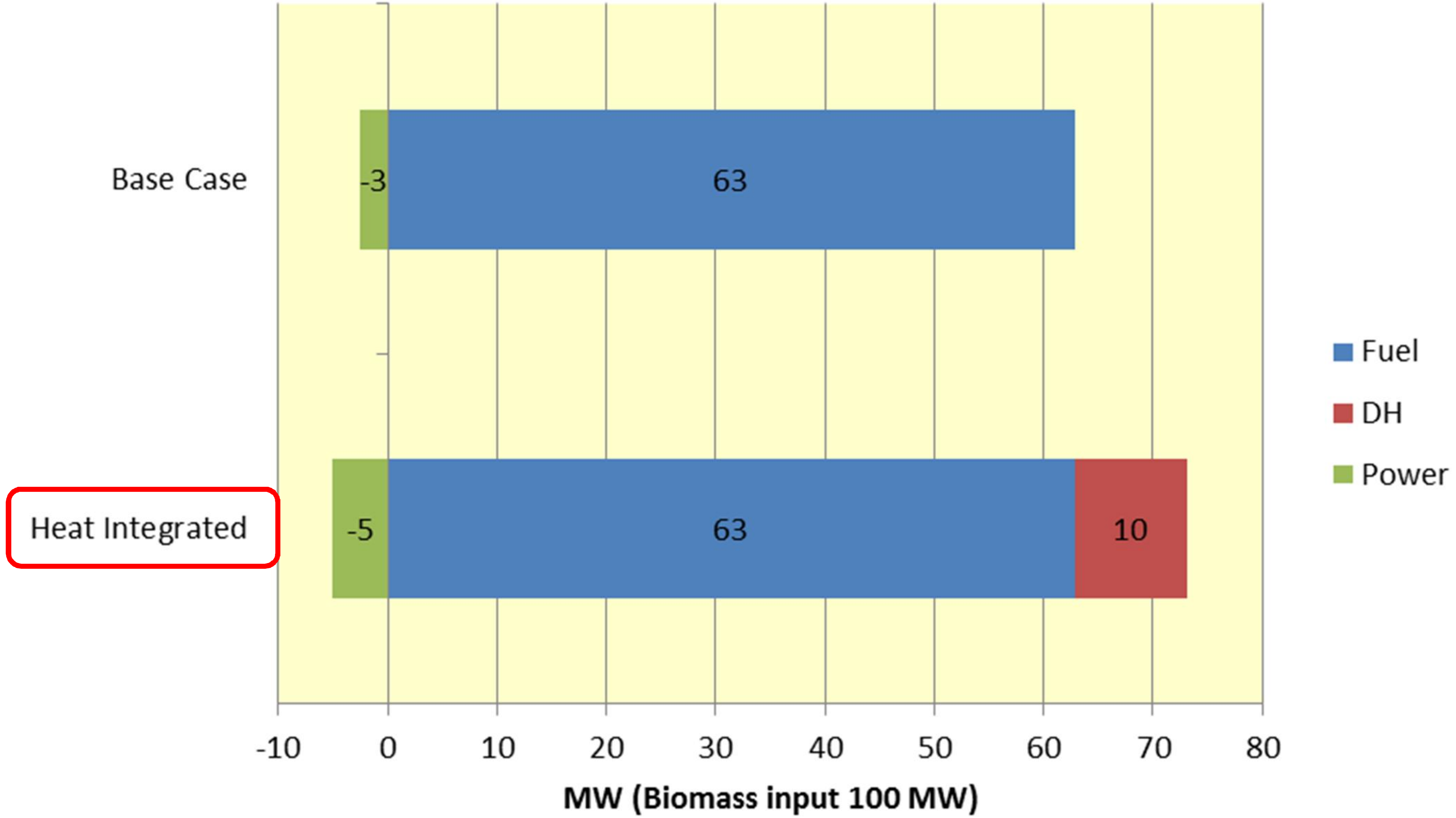
- CFB gasification with O_2 at 4 bar and 850 °C.
- Catalytic reforming of tars and hydrocarbons
- Rectisol acid gas removal
- Highly selective (99.9 %) *Cu-ZnO-Al_2O_3* or *Cr_2O_3* based commercial methanol catalysts
- Synthesis conditions 250 °C and 80 bar.
- Final purification by conventional distillation



Simplified layout of the methanol synthesis loop, product recovery and distillation section.



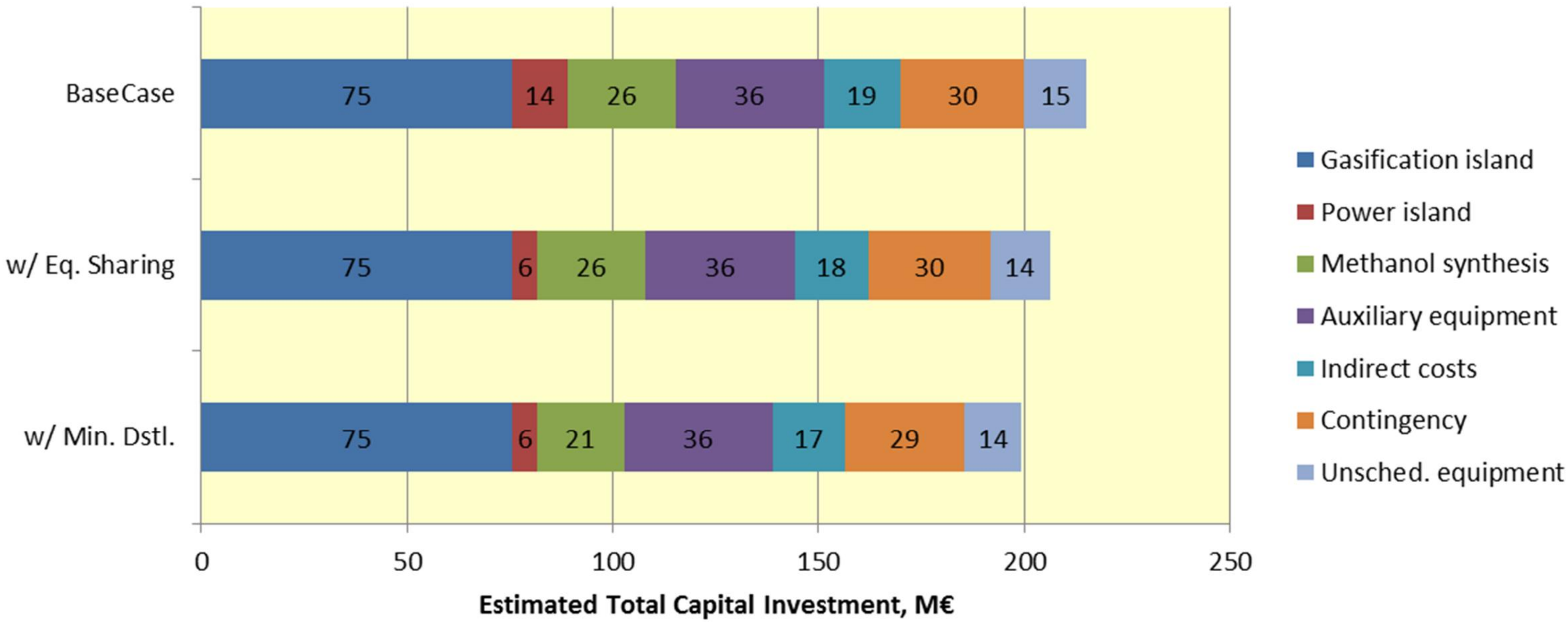
Thermal efficiency to methanol and by-products



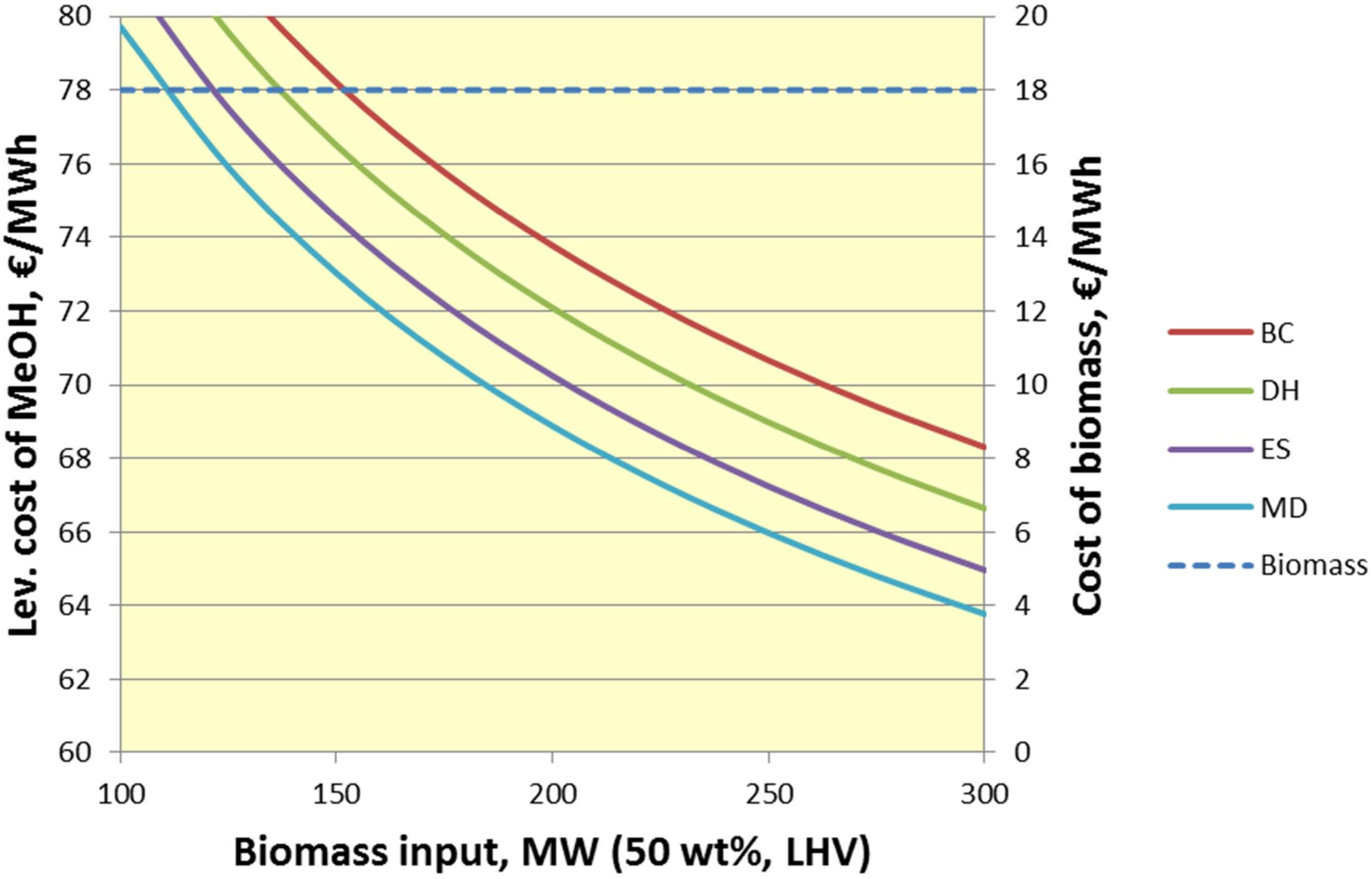
EQUIPMENT COST ESTIMATES	Base Case	Equipment Sharing	Minimum Distillation
Auxiliary equipment	36	36	36
Site preparation	8	8	8
Oxygen production	18	18	18
Feedstock pretreatment	10	10	10
Gasification island	75	75	75
Gasification	24	24	24
Hot-gas cleaning	19	19	19
CO shift	2	2	2
Syngas cooling	4	4	4
Compression	5	5	5
Acid gas removal	21	21	21
Power island	14	6	6
HRSG (GI + AUX)	6	6	6
Aux. boiler + fluegas treatm.	3	0	0
Steam turbine + condenser	4	0	0
Methanol synthesis	26	26	21
Syngas compresssor	2	2	2
Synthesis loop	17	17	17
Distillation (minimal)	0	0	3
Distillation (chemical-grade)	8	8	0
SUM EQUIPMENT	152	144	139
CHANGE		-4.8 %	-3.6 %
			-8.2 %

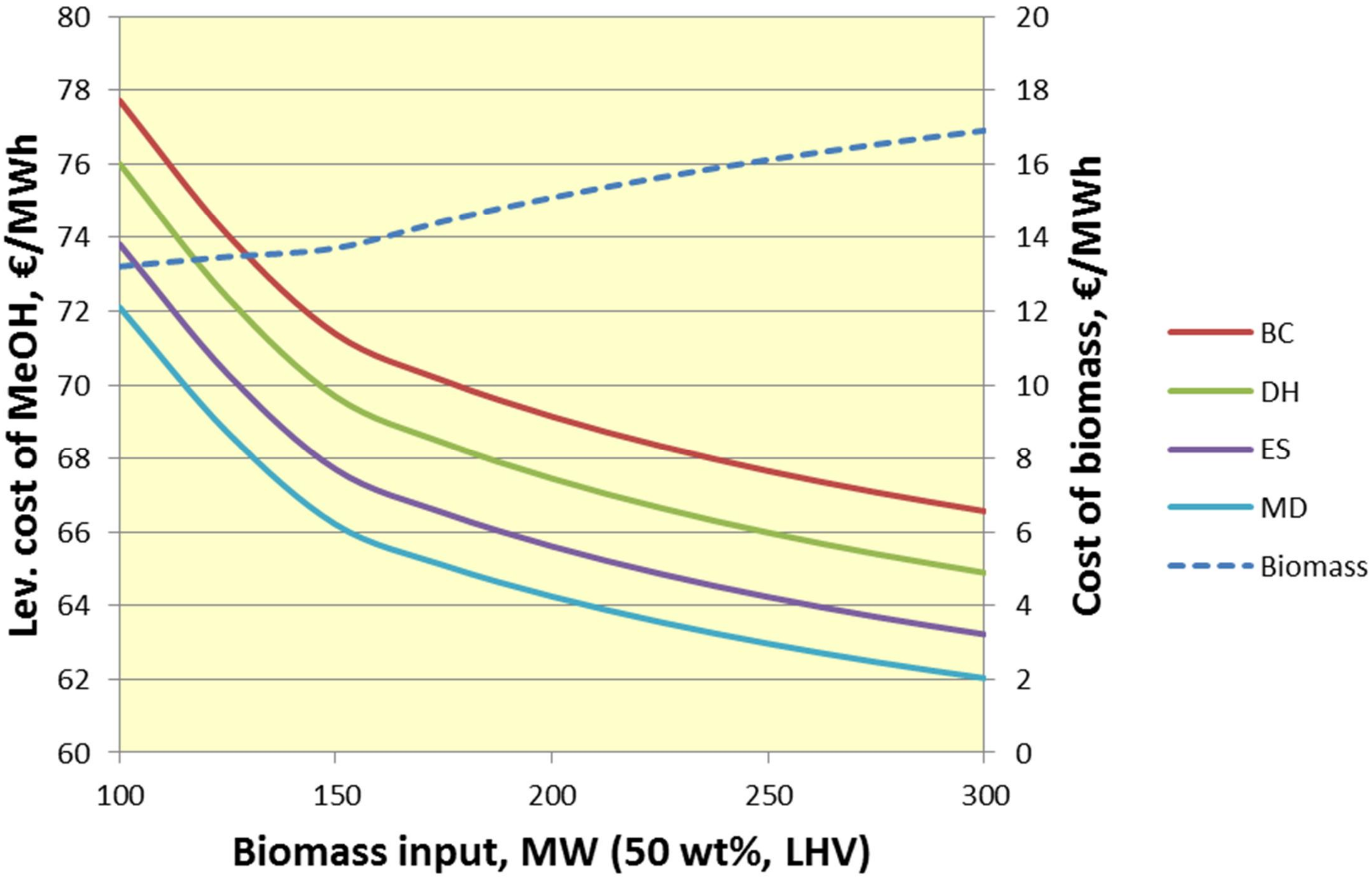
Equipment cost estimates for a plant processing 150 MW of biomasss

Equipment sharing possibilities



ESTIMATES FOR 150 MWbiom PLANT	BaseCase	w/ Eq. Sharing	w/ Min. Dstl.
TOTAL OVERNIGHT CAP. COST	215	206	199
TOTAL CAP. INV. (at 5% interest)	226	217	209
CHANGE		-4.0 %	-3.7 %
			-7.5 %


80
78
76
74
72
70
68
66
64
62
60
20
18
16
14
12
10
8
6
4
2
0
100
150
200
250
300
Lev. cost of MeOH, €/MWh
Cost of biomass, €/MWh
Biomass input, MW (50 wt%, LHV)
BC
DH
ES
MD
Biomass

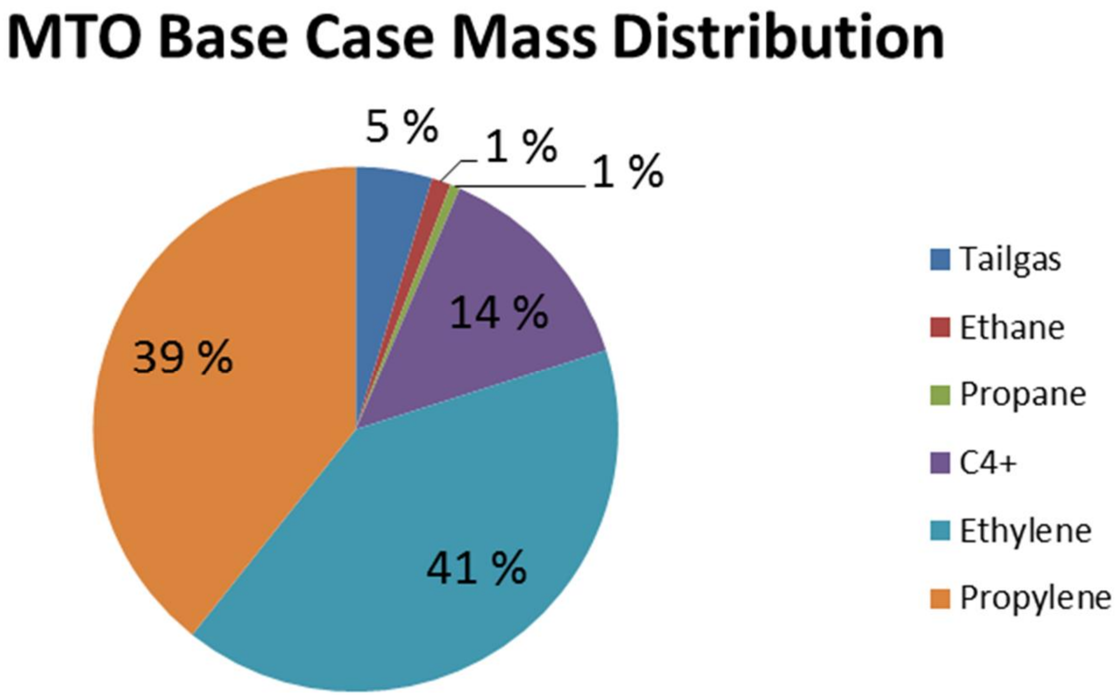


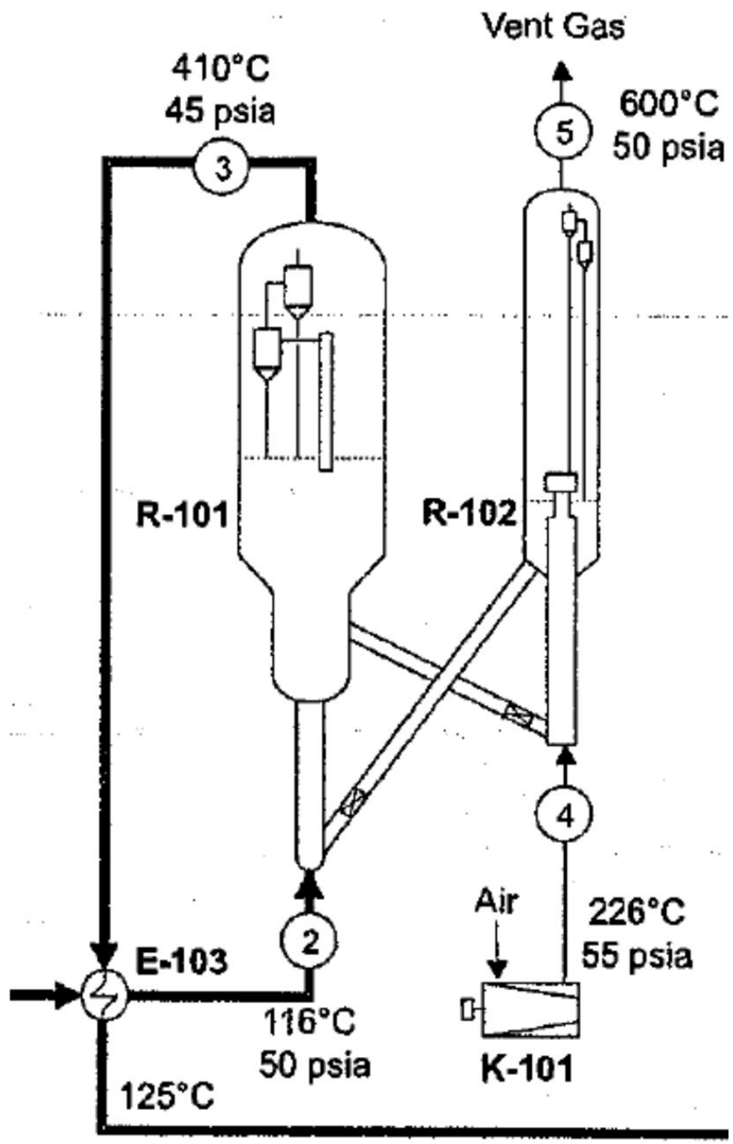
80
78
76
74
72
70
68
66
64
62
60
20
18
16
14
12
10
8
6
4
2
0
100
150
200
250
300
Lev. cost of MeOH, €/MWh
Cost of biomass, €/MWh
Biomass input, MW (50 wt%, LHV)
BC
DH
ES
MD
Biomass

Methanol to Light Olefins

UOP/Hydro's MTO process

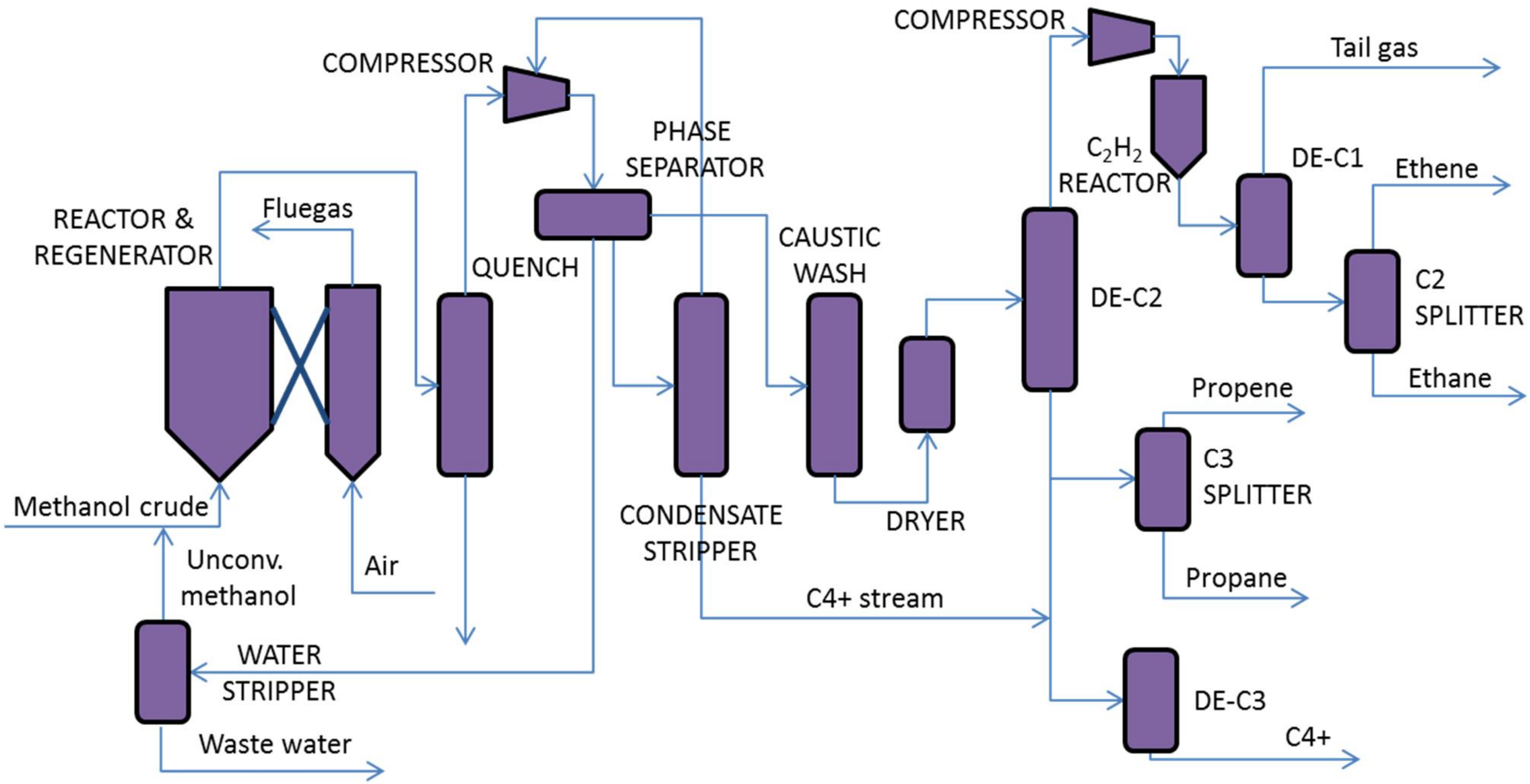
- Fluidised-bed reactor at 410 °C and 3 bar
- Ethylene and propylene mass ratio 1:1
- 99.8 % conversion of methanol
- Coke formation 4.5 wt% of feed MeOH
- Catalyst continuously regenerated in a combustor
- Multi-column cryogenic distillation required



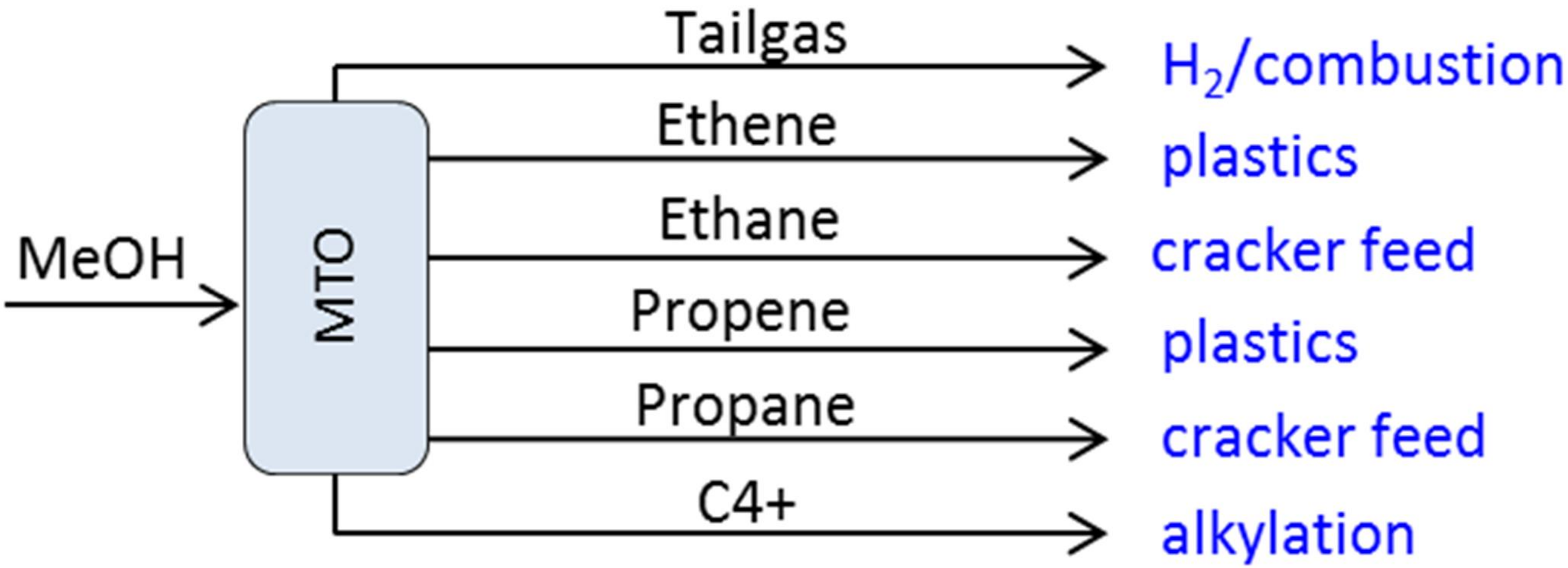


Fast-fluidised MTO reactor

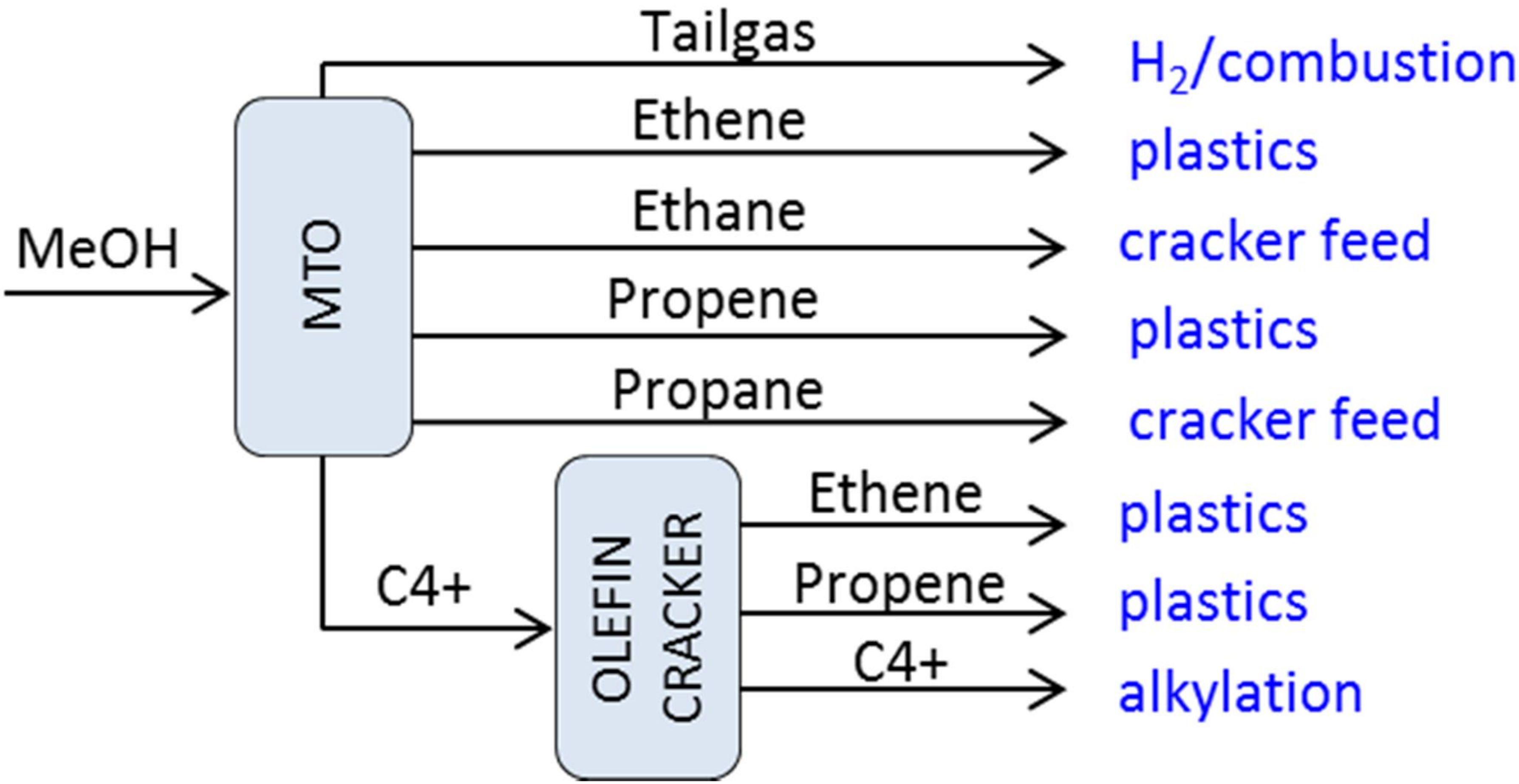
UOP/Hydro's Methanol-to-Olefins process



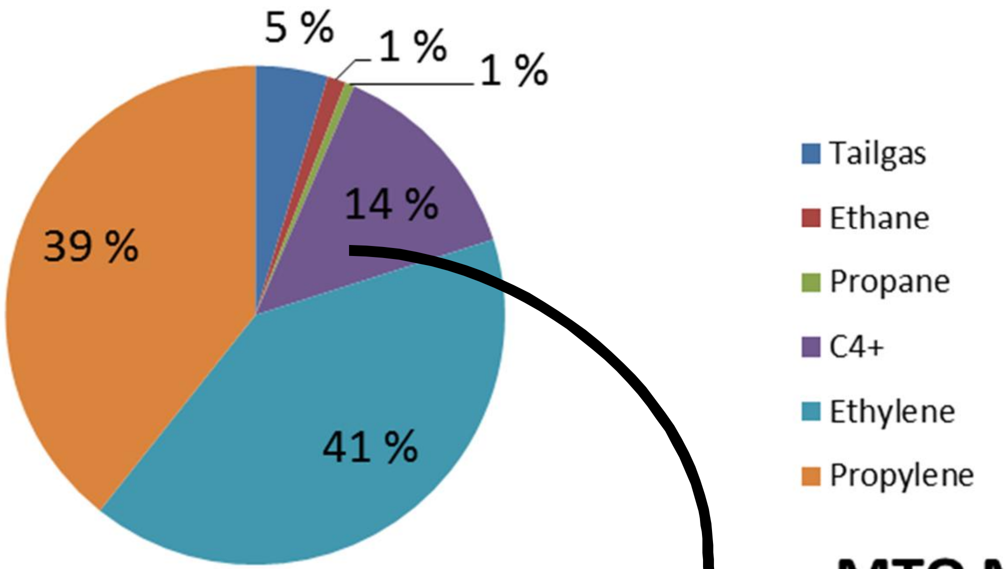
Product integration



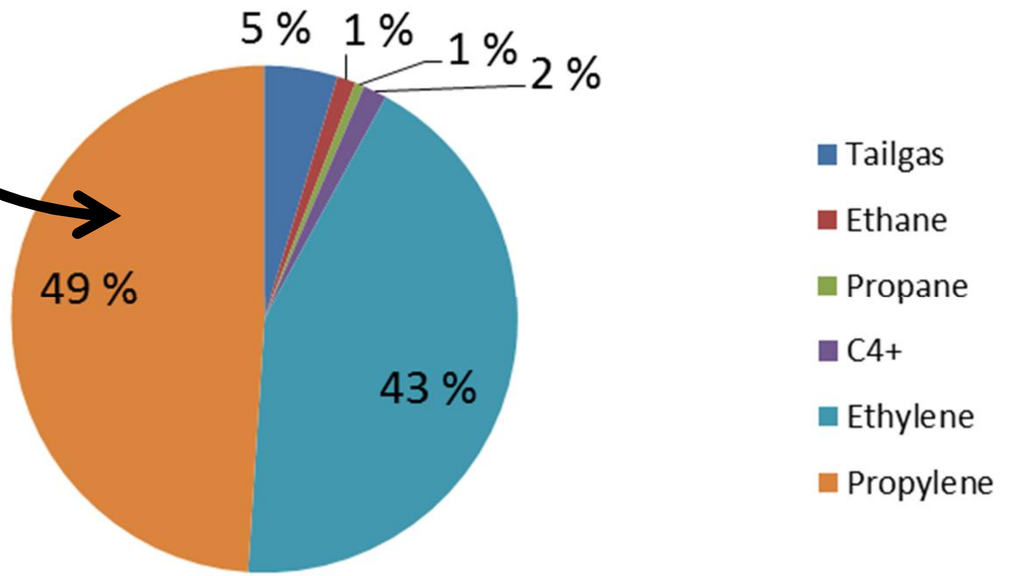
Olefin boosting


Tailgas
Ethene
Ethane
Propene
Propane
MeOH
MTO
C4+
OLEFIN CRACKER
Ethene
Propene
C4+
H2/combustion
plastics
cracker feed
plastics
cracker feed
plastics
plastics
alkylation

MTO Base Case Mass Distribution

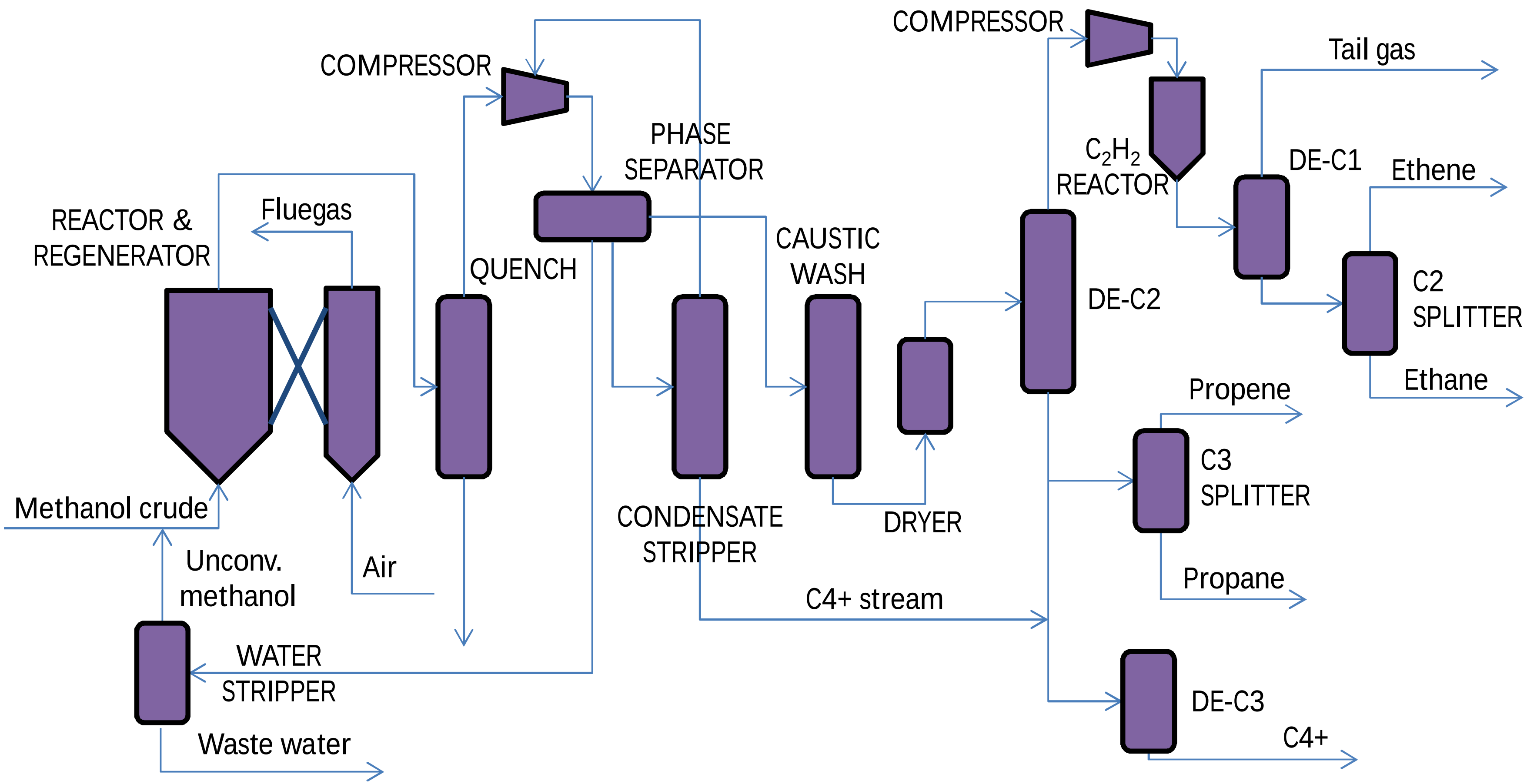


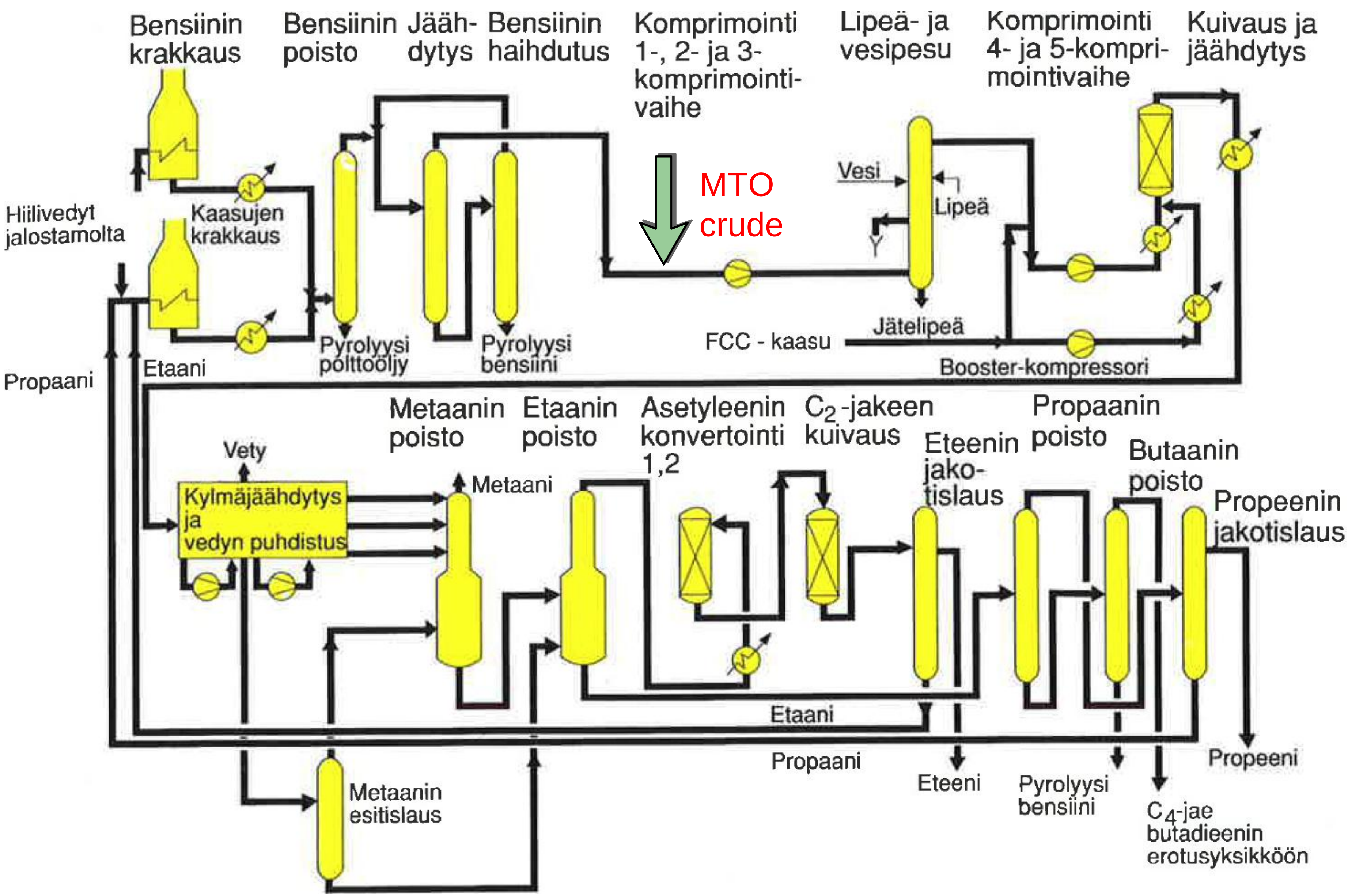
MTO Max. Olefins Mass Distribution



MTO integration with an Ethene Plant

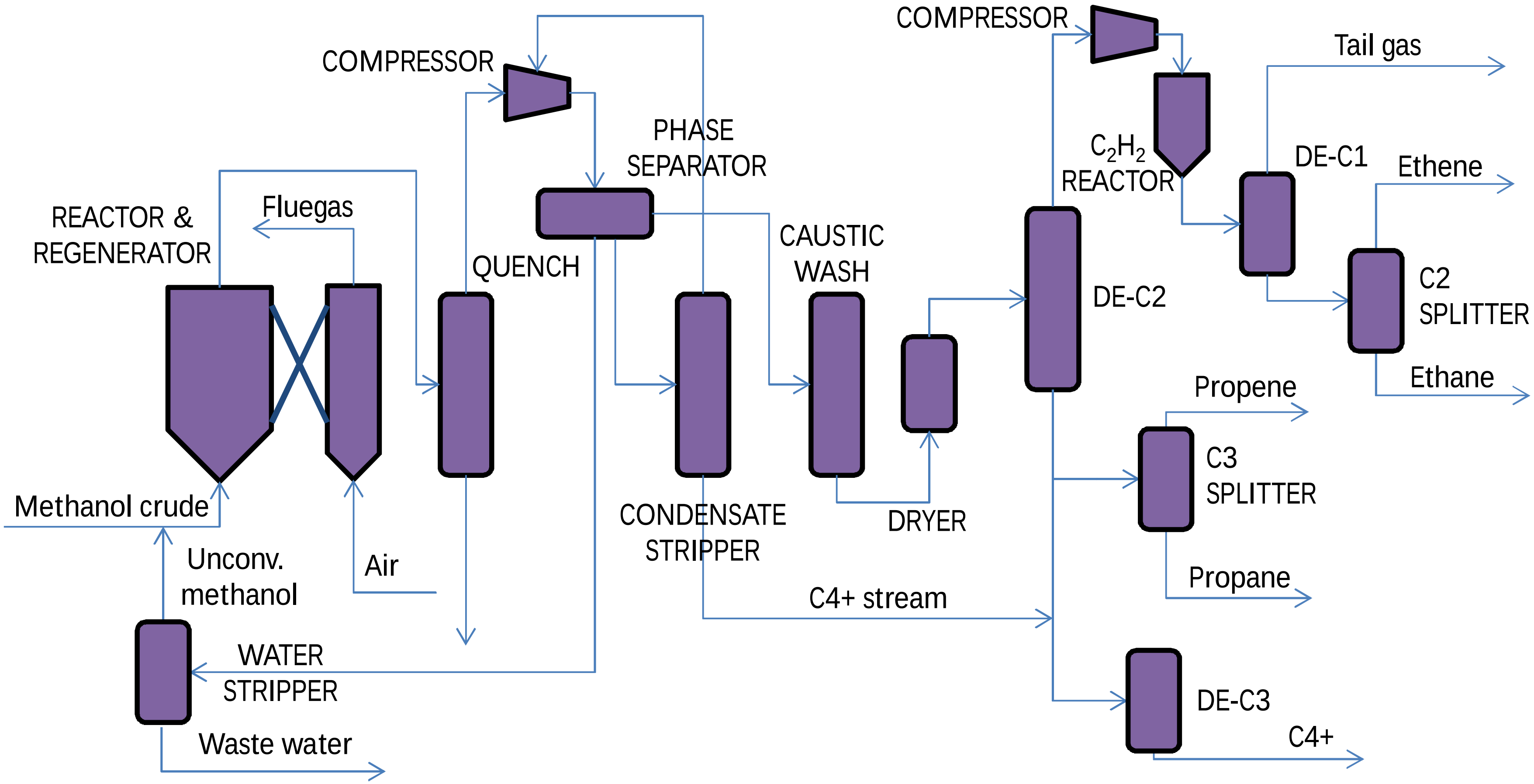
UOP/Hydro's Methanol-to-Olefins process

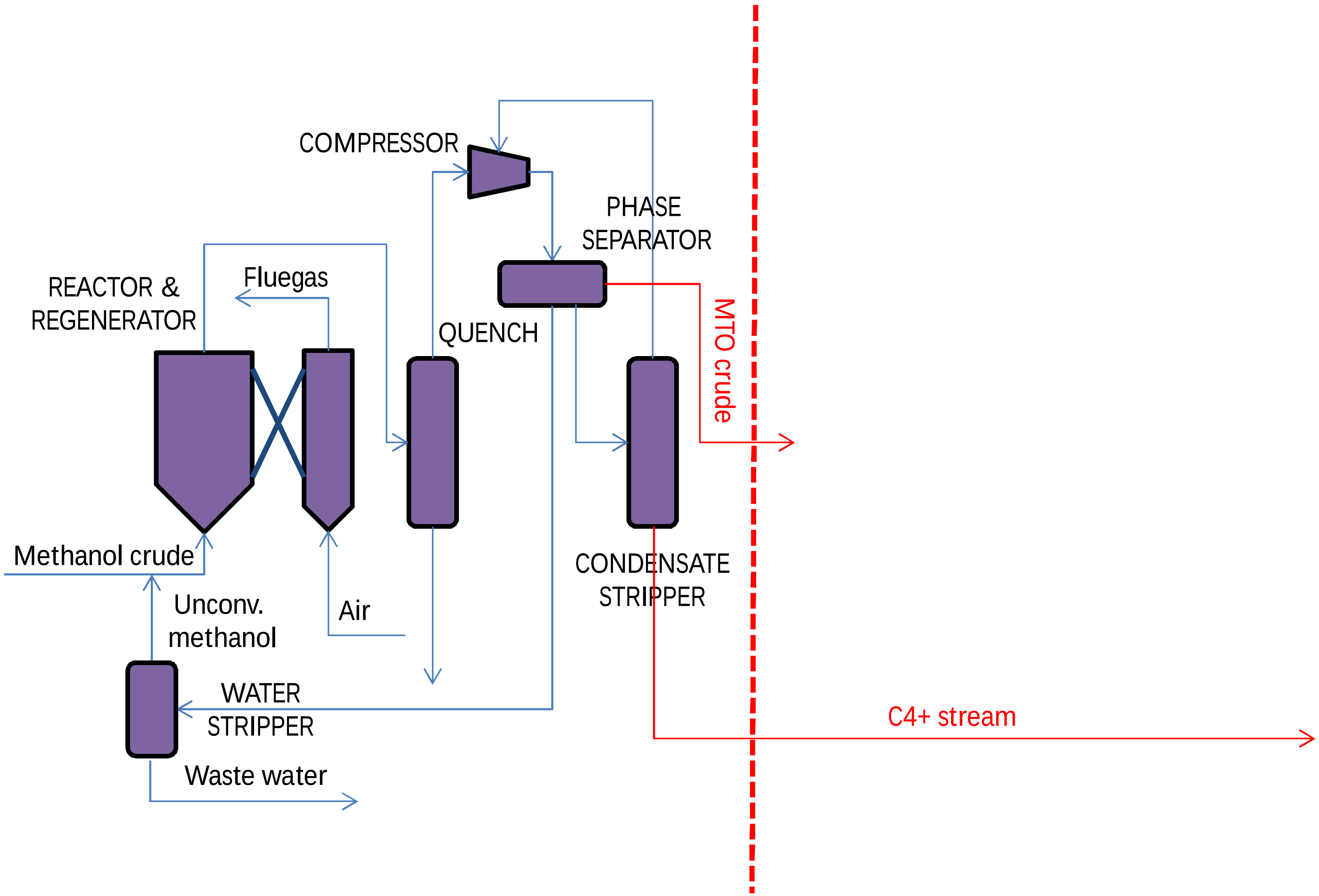




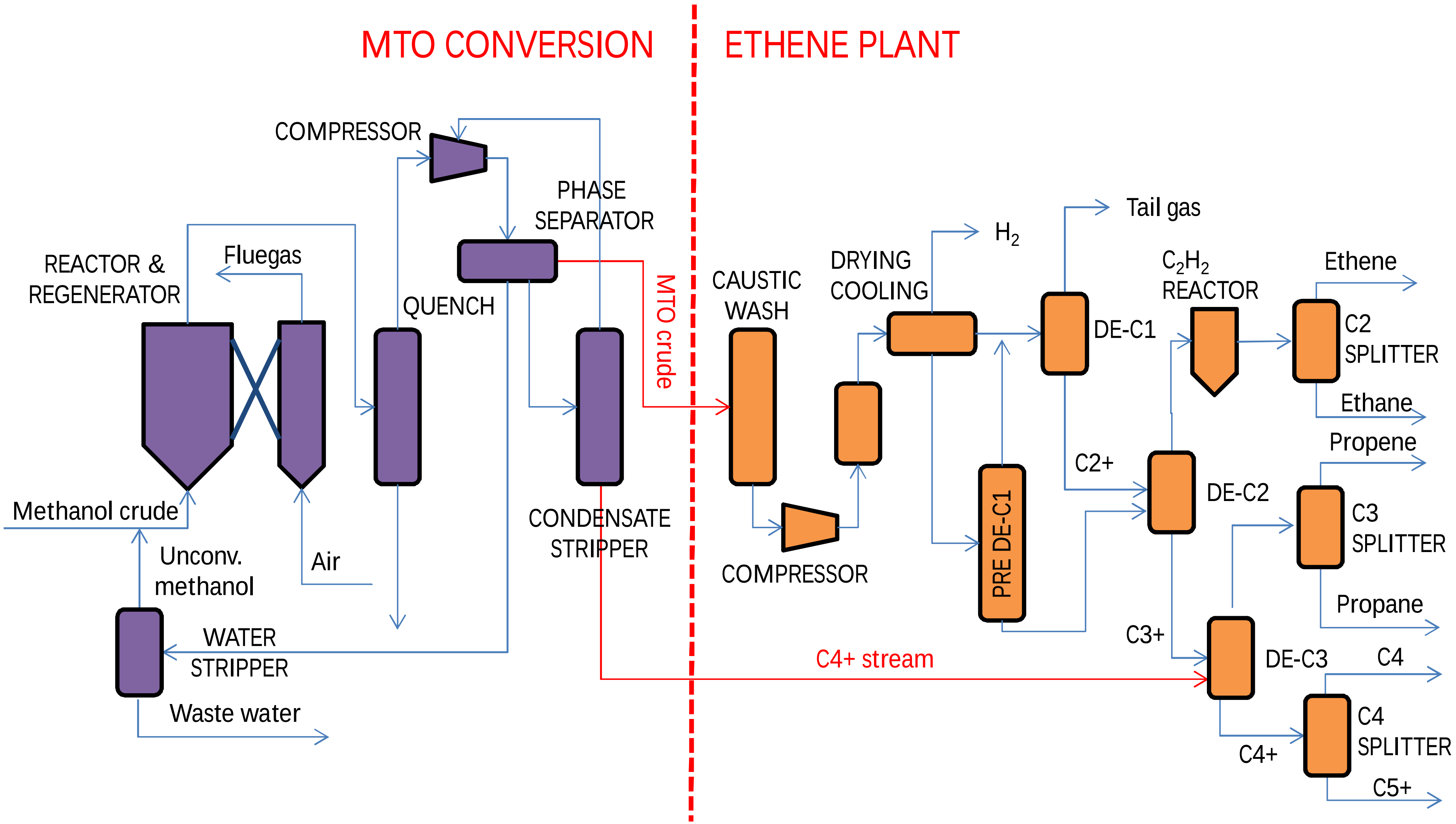
Kilpilahti Ethene Plant
Source: Öljystä muoveihin (1992), Neste Oyj.

UOP/Hydro's Methanol-to-Olefins process

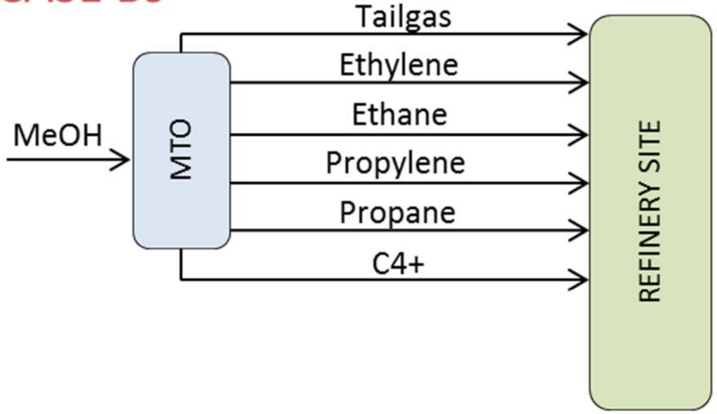



COMPRESSOR
PHASE SEPARATOR
REACTOR & REGENERATOR
Fluegas
QUENCH
MTO crude
Methanol crude
Unconv. methanol
Air
CONDENSATE STRIPPER
WATER STRIPPER
Waste water
C4+ stream

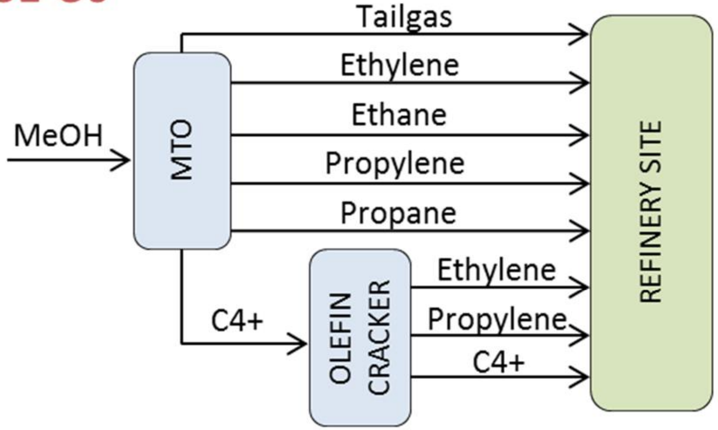
Separations when integrated to a refinery



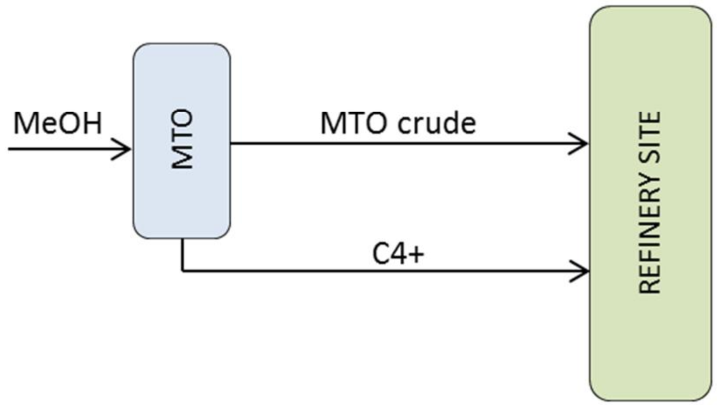
CASE Bs



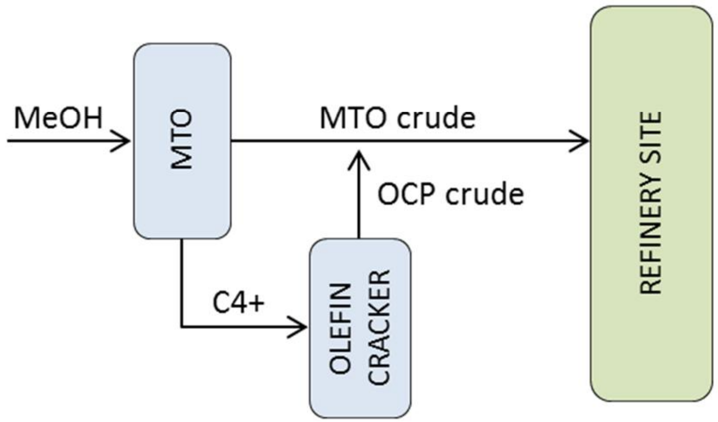
CASE Os



CASE Bi



CASE Oi



At what scale?

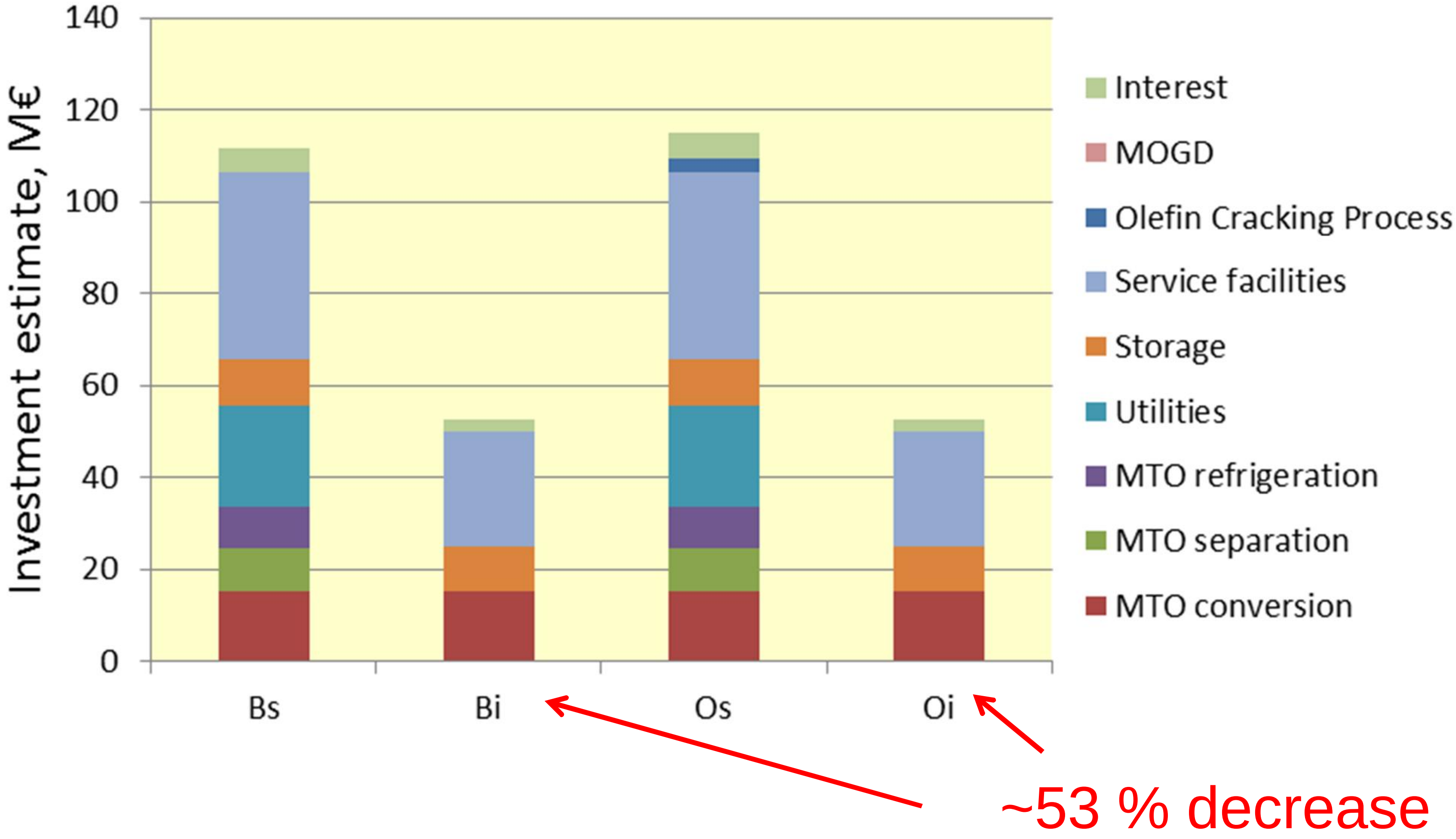
Case Example: Crackers of the Kilpilahti Refinery in Finland

Krakkausuunin tunnus	Teho, MW	Mitoituskapasiteetti, t/h	Koksinpolttokaasut johdetaan uunin tulipesään
BA-12101	19,6	10 (etaani)	EI
BA-12102	19,6	10 (etaani)	EI
BA-12103	22,95	10 (nafta)	KYLLÄ (vuodesta 2003)
BA-12104	22,95	10 (nafta)	KYLLÄ (vuodesta 2001)
BA-12105	20,7	10 (nafta)	KYLLÄ (vuodesta 2001)
BA-12106	20,7	10 (etaani/propaani)	KYLLÄ (vuodesta 2003)
BA-12107	23,4	12 (pentaani/nafta)	EI
BA-12111	29,1	15 (nafta)	KYLLÄ (vuodesta 2007)
BA-12112	36,9	25 (nafta)	KYLLÄ (vuodesta 1997)
BA-12114	36,9	30 (nafta)	KYLLÄ (vuodesta 2003)

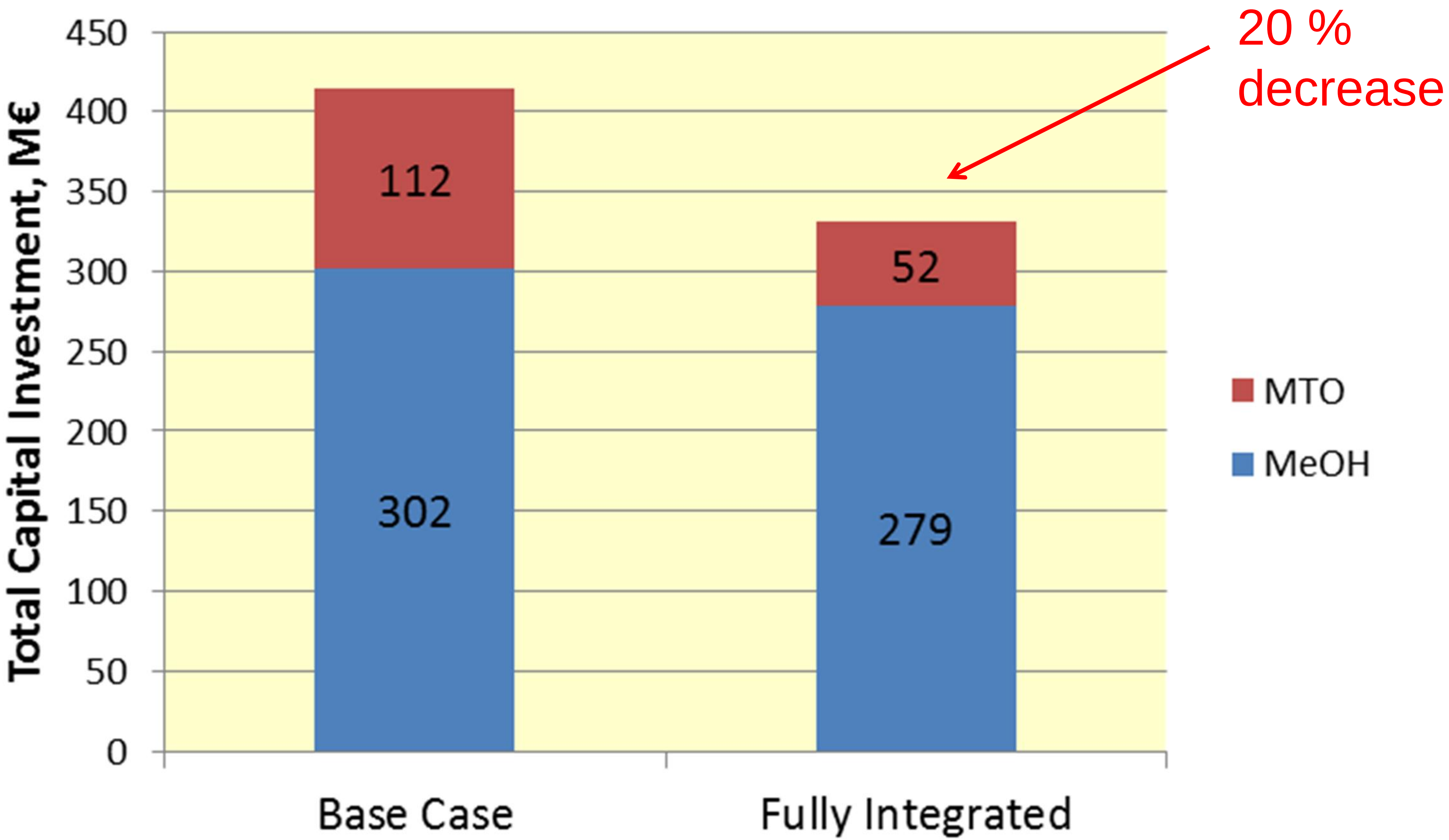
Naphtha replacement: 2.6 kg/kg MeOH/naphtha

10 t/h naphtha = 208 kton/a of methanol

Investment cost estimates for MTO



Investment cost estimates for MTO



Production cost estimates

Naphtha replacement:

- To replace 10 t/h of naphtha requires 208 kton/a of methanol
- To produce 208 kton of methanol requires 341 kton of biomass
- Assuming 90% availability gives 232 MW biomass requirement

Production cost estimates for such plant:

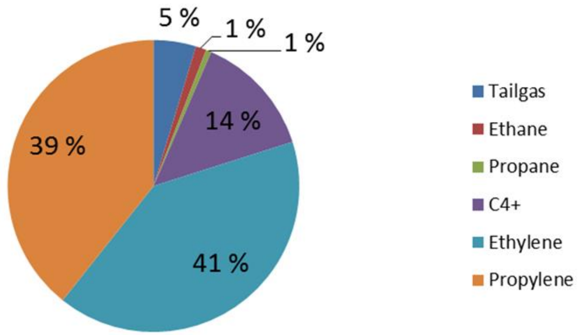
	€/MWh	€/GJ	€/tonne
Base Case	71	19.8	395
DH	70	19.4	386
w/ Eq. Sharing	68	18.9	376
w/ Min. Dstl.	67	18.5	369

Assumed product prices

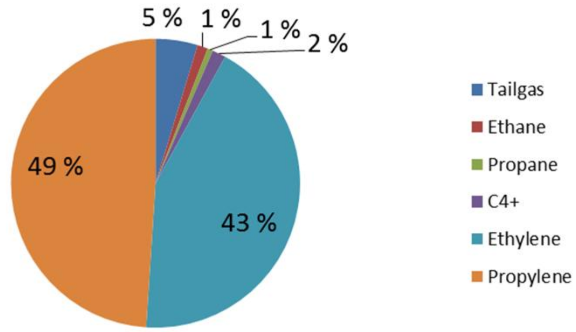
Prices		Base Case	Double Counting
Electricity	€/MWh	50	50
Tailgas (H2)	€/tonne	1200	1200
Ethane	€/tonne	332	332
Propane	€/tonne	332	332
LPG	€/tonne	332	332
C4+	€/tonne	600	1120
Ethene	€/tonne	829	829
Propene	€/tonne	995	995
Gasoline	€/tonne	750	1400
Distillate	€/tonne	700	1300

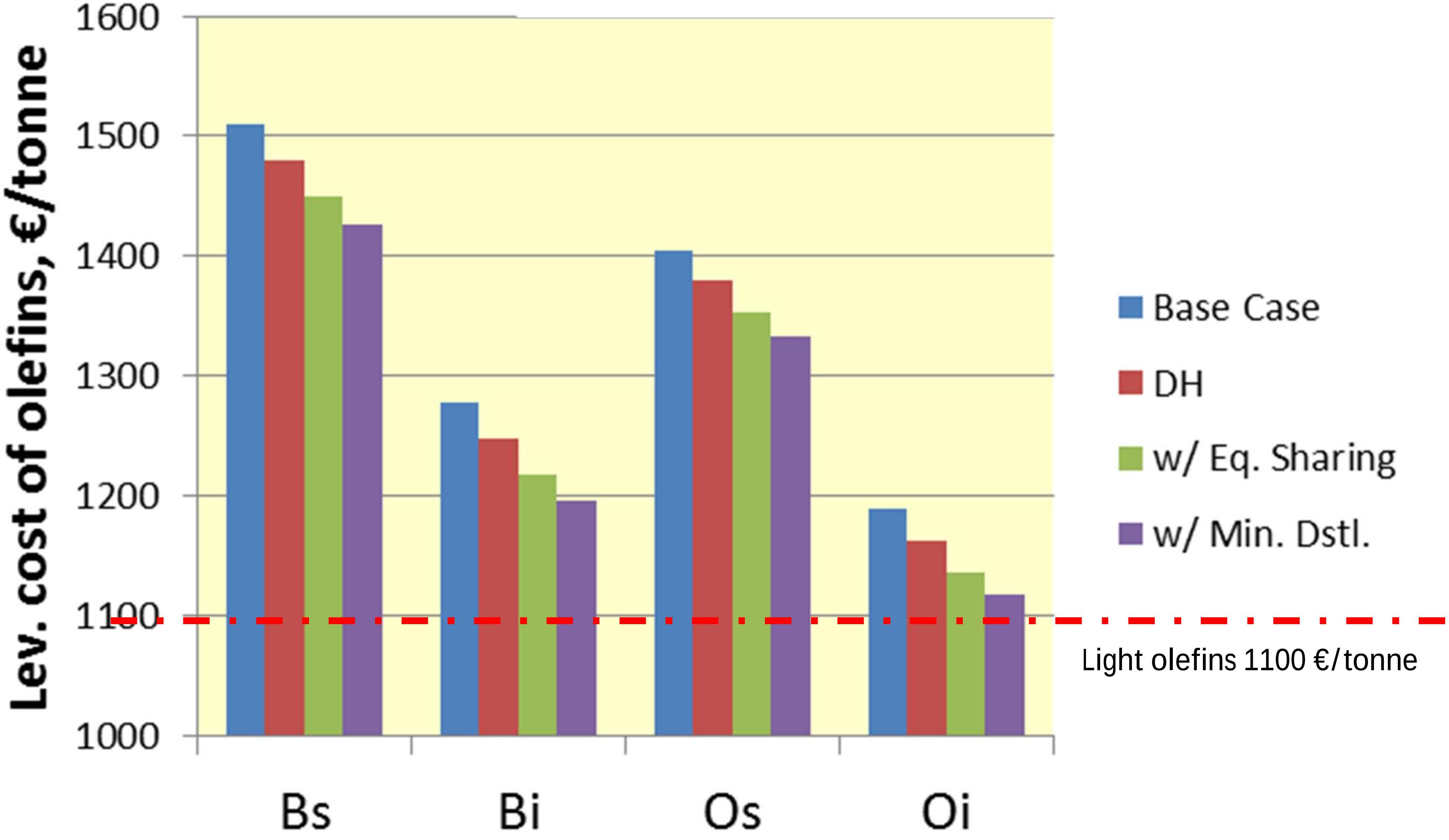
80% of gasoline price

MTO Base Case Mass Distribution



MTO Max. Olefins Mass Distribution





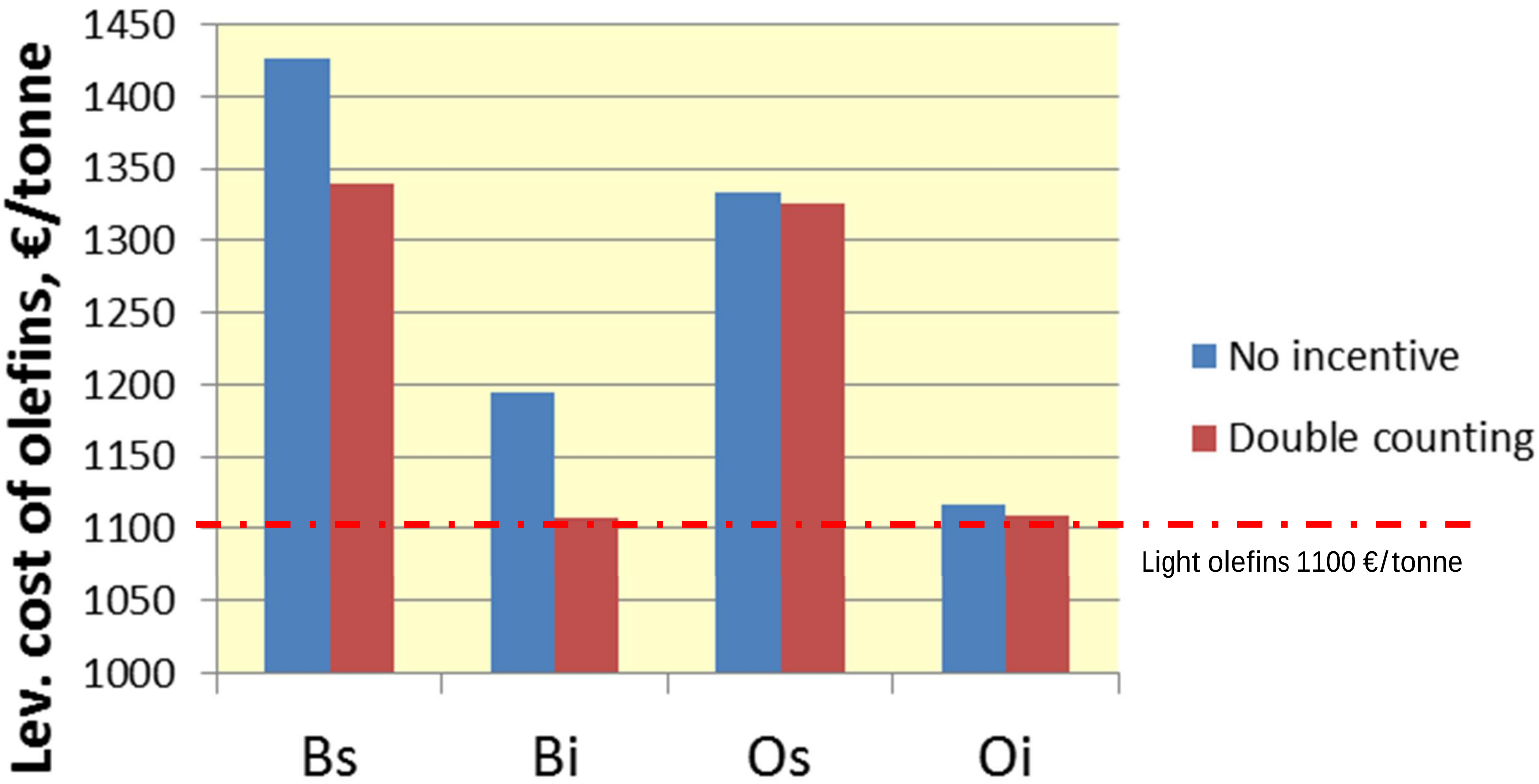
Assumed product prices

Prices		Base Case	Double Counting
Electricity	€/MWh	50	50
Tailgas (H2)	€/tonne	1200	1200
Ethane	€/tonne	332	332
Propane	€/tonne	332	332
LPG	€/tonne	332	332
C4+	€/tonne	600	1120
Ethene	€/tonne	829	829
Propene	€/tonne	995	995
Gasoline	€/tonne	750	1400
Distillate	€/tonne	700	1300

80% of gasoline price

Double counting ~120 €/MWh?

Fully integrated plants



Summary of the biomass conversion step

- Two types of integration examined:
  - Equipment sharing
  - Heat integration
- For synthetic methanol production
  - 16 % increase in overall efficiency can be achieved via heat integration (depending on the produced fuel and steam cycle design)
  - 7.5 % decrease in TCI can be achieved via equipment sharing
  - Combined effect to the cost of methanol: 395 ---> 369 €/tonne (6.6 % decrease)

Summary of the methanol conversion step

- Significant decrease in TCI can be achieved via equipment sharing
  - 112 ---> 52 M€ (53 % decrease) For Basecase MTO
- When no incentives are in place Max Olefins yields the lowest production cost
- ”Double Counting” incentive makes Base Case MTO slightly more attractive than Max Olefins

- Overall role of integration in the two-step production concept enables
  - 414 ---> 331 M€ (20 % decrease) in TCI and
  - 1510 ---> 1196 €/tonne (21 % decrease) in Levelised cost of light olefins.

Thank you for your attention!

LinkedIn: ihannulaprofile
twitter: @ilkkahannula