METHANOL Production from Biomass

Green Pilot
Kickoff Seminar

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Swedish Methanol tests in the 1980-ies

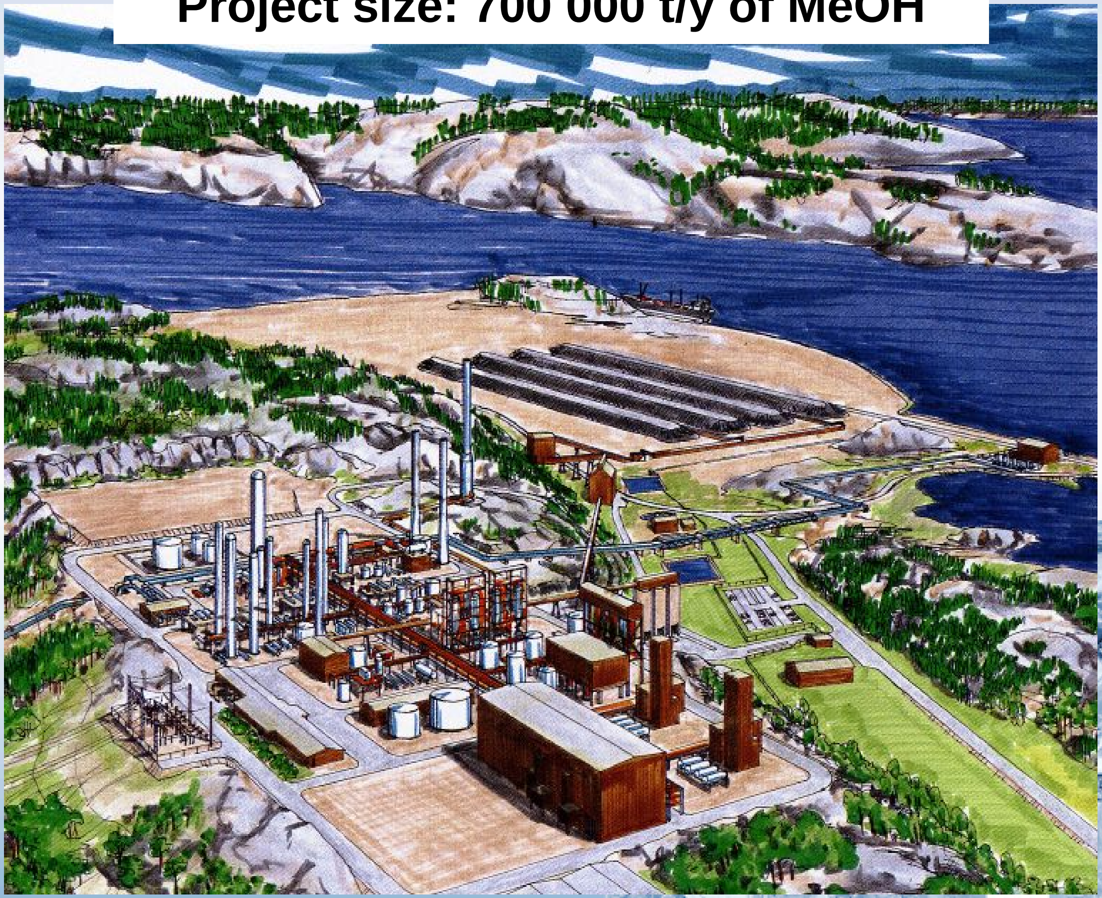
- During 1980-82 a large M15 fuel testing project was done with 1000 vehicles at 19 fuel stations and 11 car makes with 20 million km of driving. As neat fuel M100 was tested 1984-86 by SAAB-Scania and Volvo with 20 vehicles.

- Main results were same or better than for petrol in terms of engine performance, fuel handling and distribution. However, when oil prices fell 1986, investment in required infrastructure became less attractive.

Nynäshamnskombinatet 1984, 1500 MWth plant

- Project developed during 1982-84 by a Swedish team and with involvement of international contractors and process licensors.
- Engineering efforts of this and following NEX projects totaled €30 million
- Acquired technology knowledge have contributed to today’s status in development
- No methanol plant built but two IGCC plants in Italy and spinoff into black liquor methanol in Piteå by the team

Project size: 700 000 t/y of MeOH



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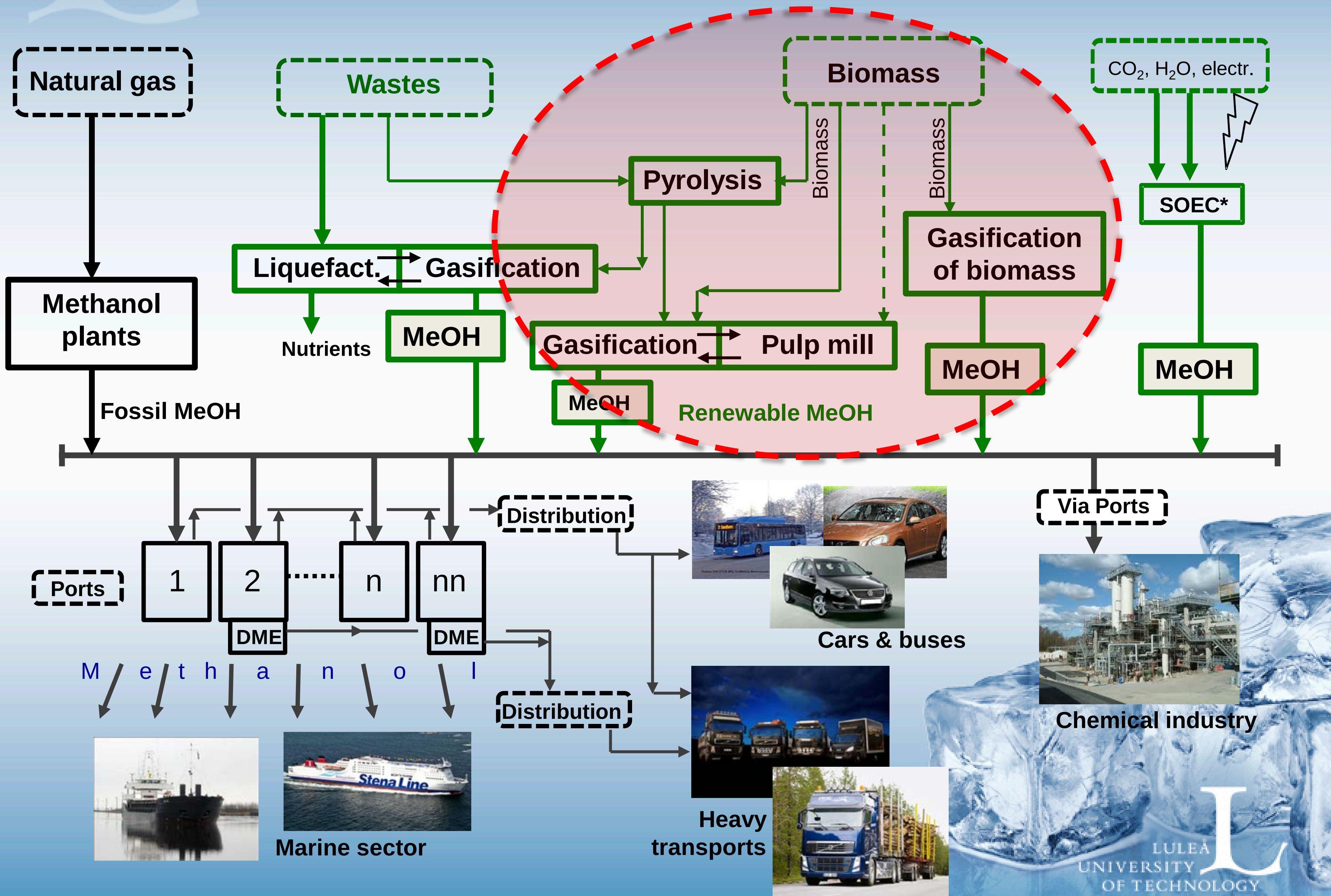
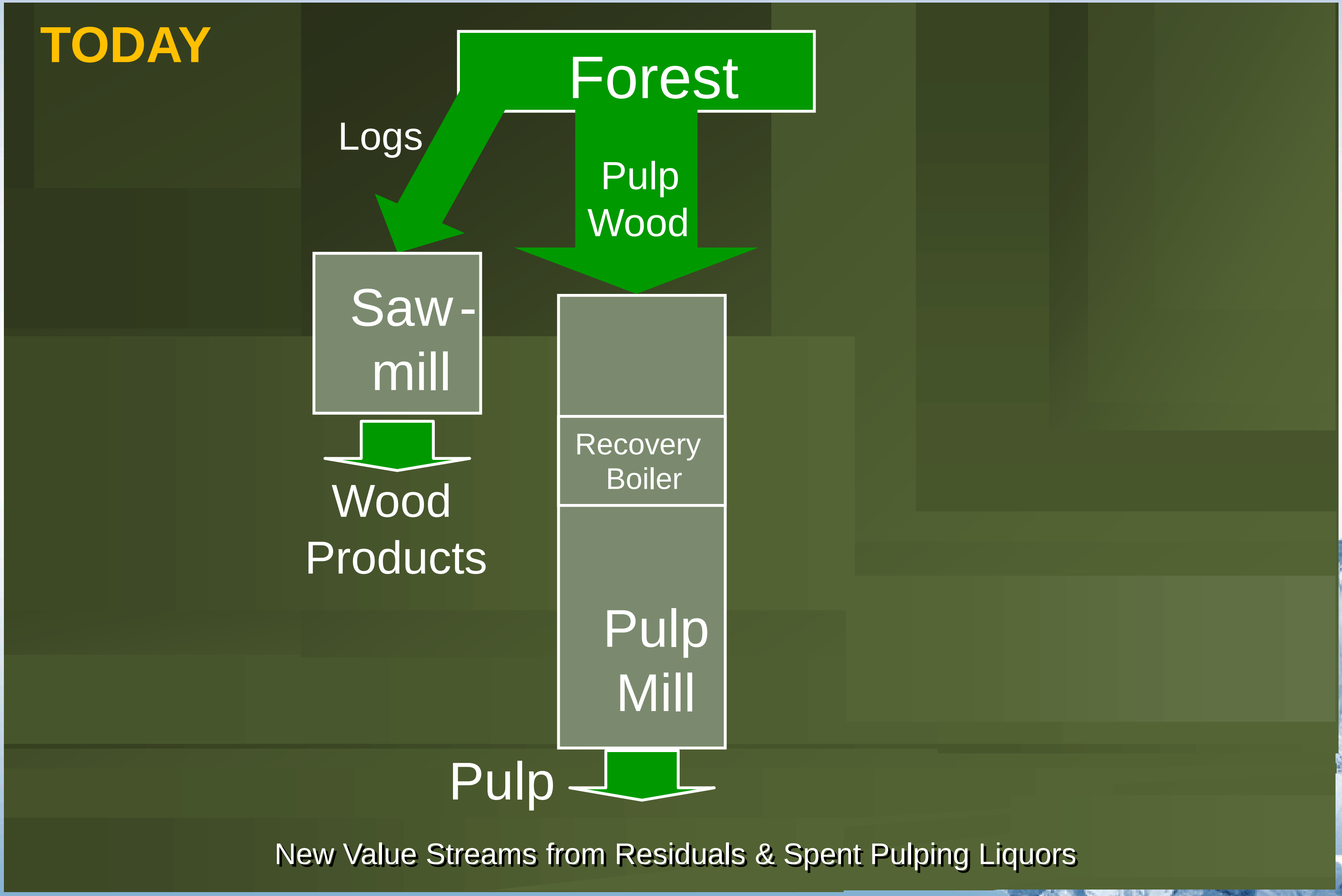
Vision for a Methanol based Energy System



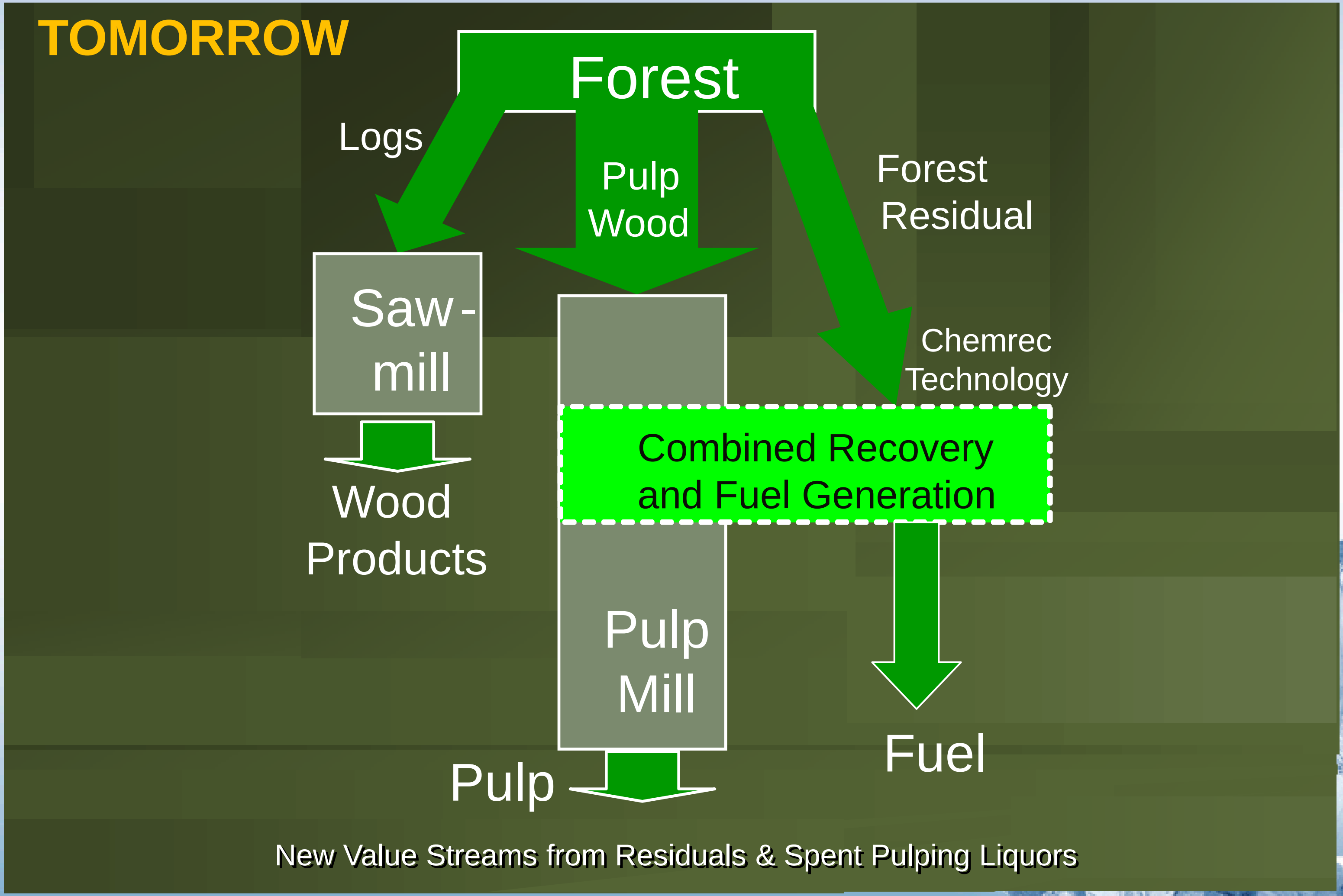
Different Biomass Conversion Alternatives

- Chemrec black liquor gasification (BLG)
- Biomass gasification
- Addition of pyrolysis oil to BLG
- Renewable power to boost syngas production

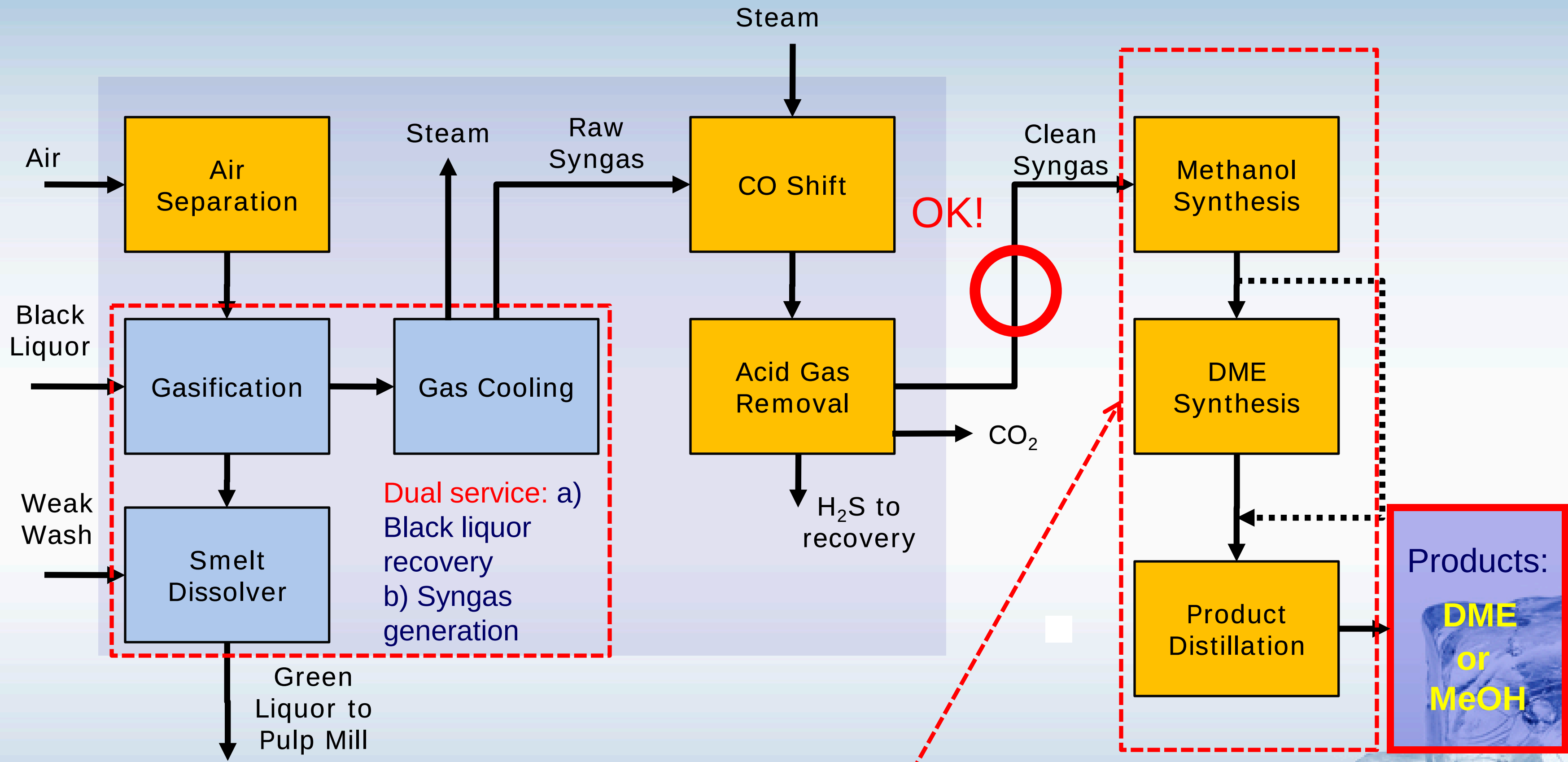
Today's commercial Forrest Industry has two main legs



The Vision: Tomorrow's Biomass flow to the Forrest Industry

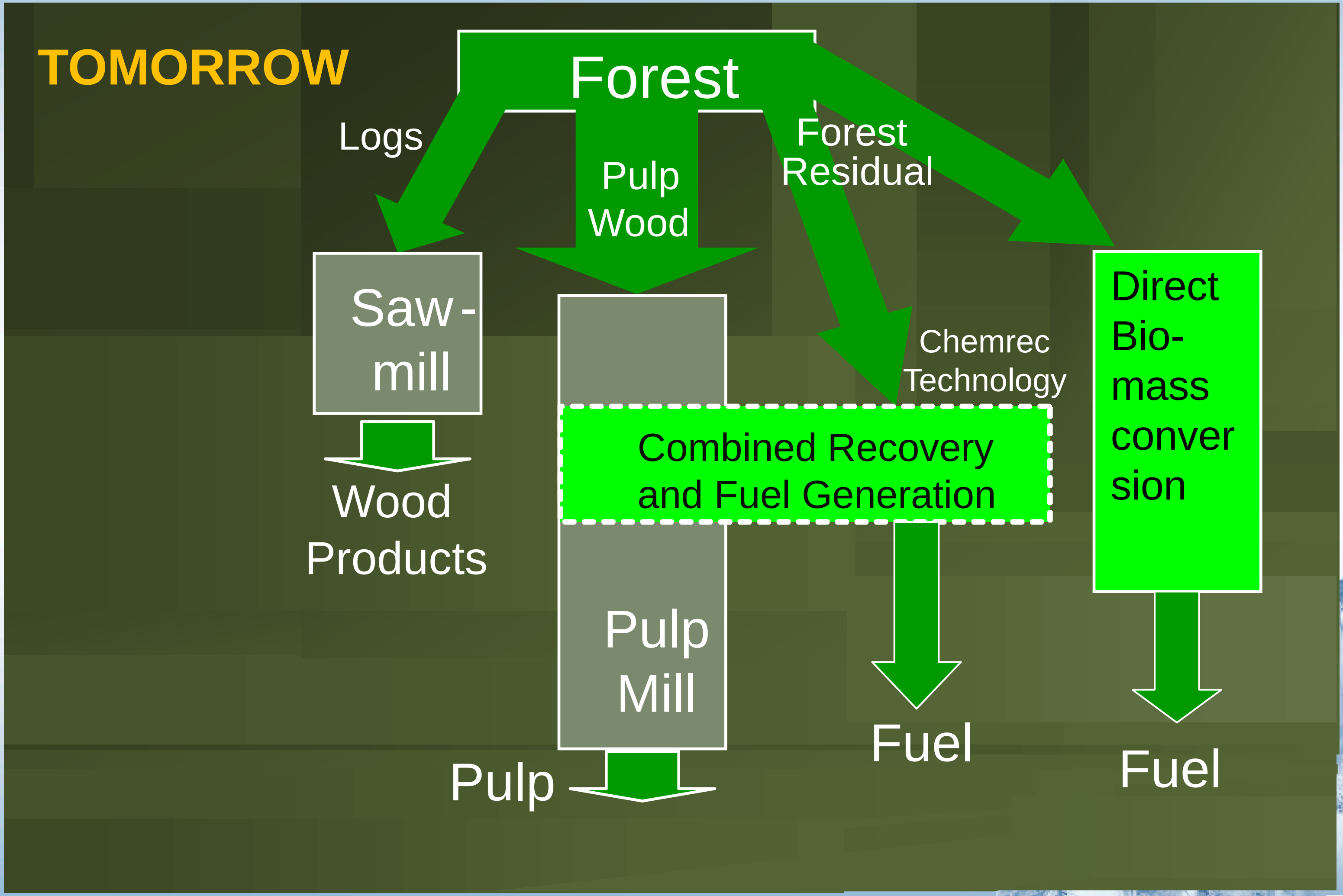


MeOH / DME Process - Block Flow Diagram

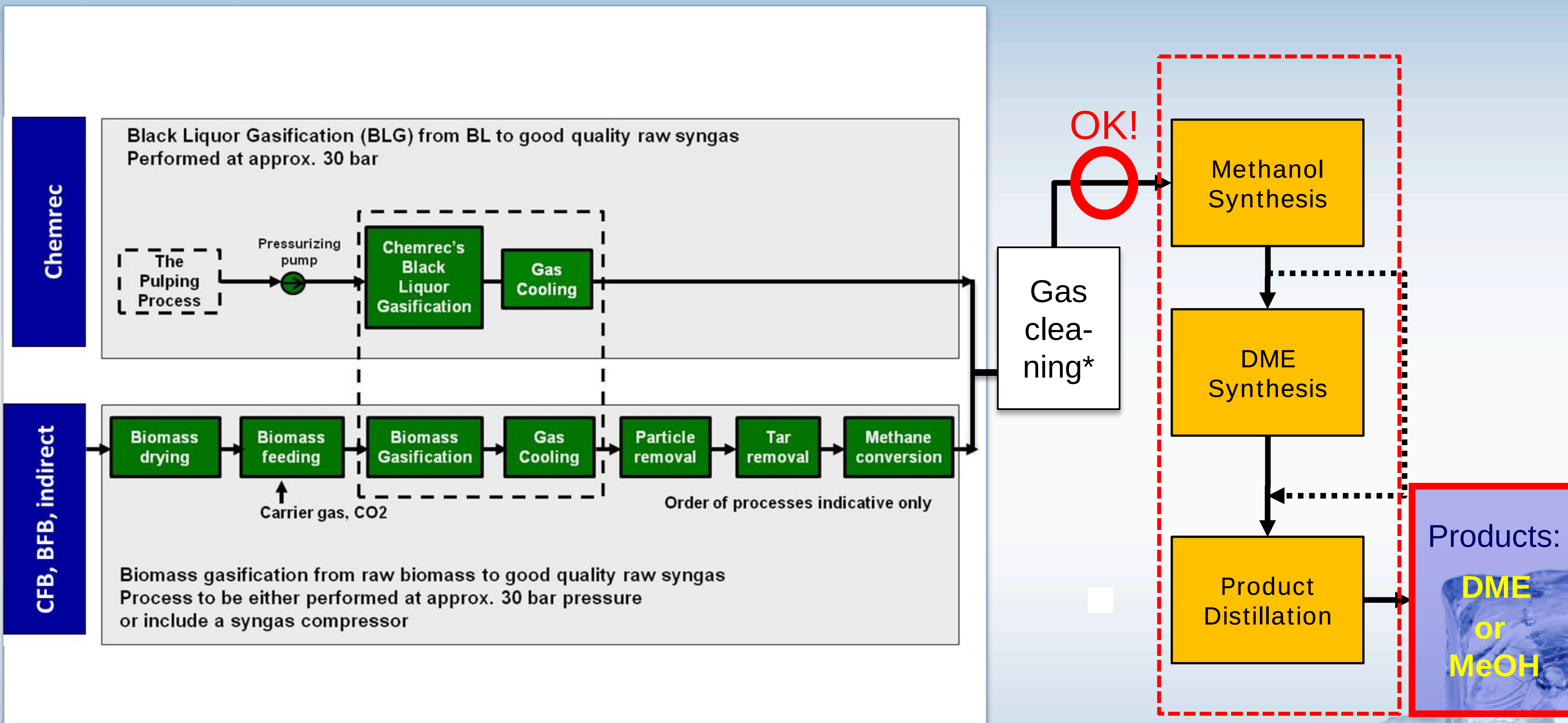


"Simple" once-through system.
Market-ready products.
Product flexibility.

Major Biomass Flow from the Forrest including Direct Biomass Gasification



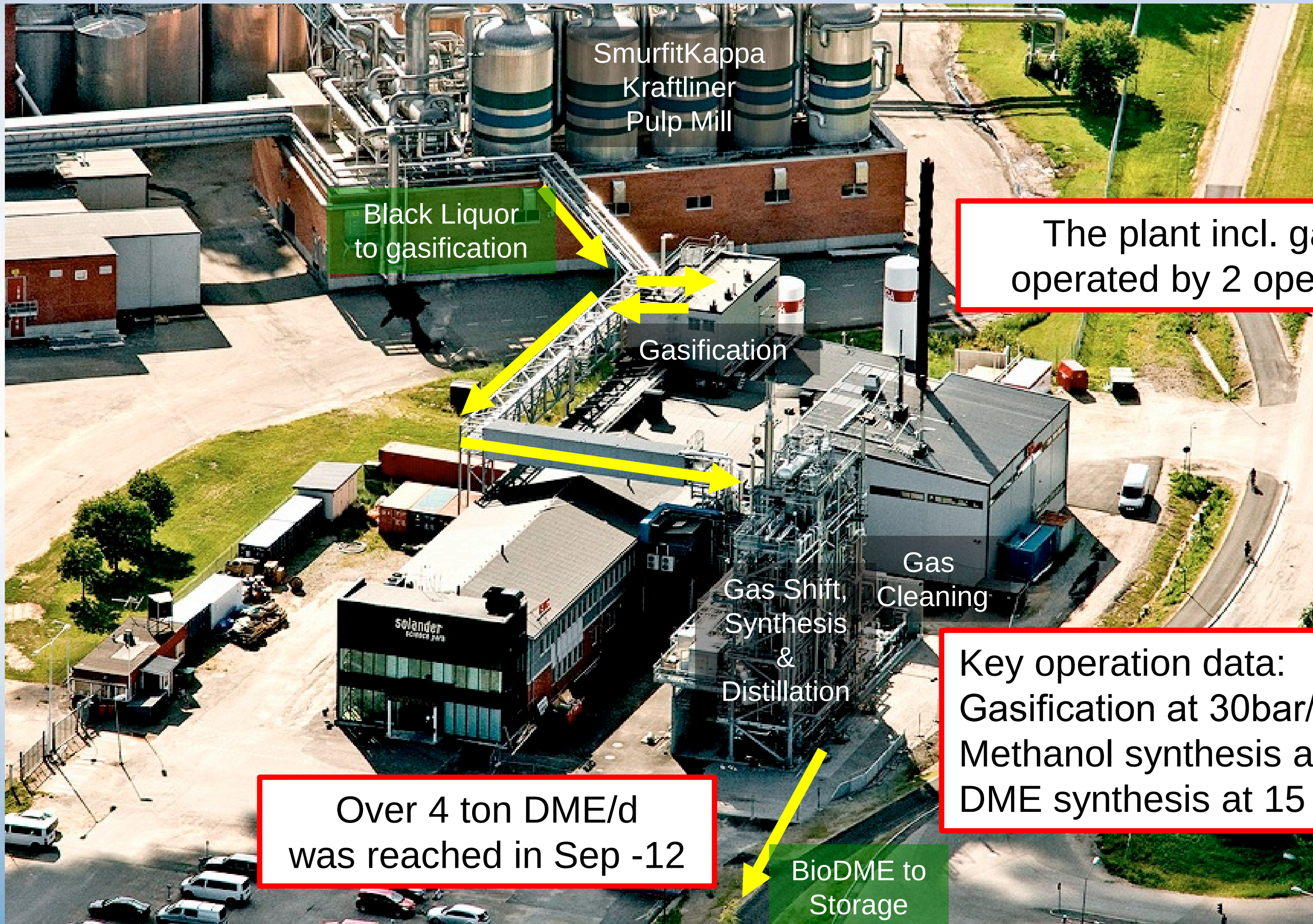
MeOH / DME Process - Block Flow Diagram



* Different processes depending on gasification technology

CHEMREC
Energy to Succeed

BioDME Production Overview

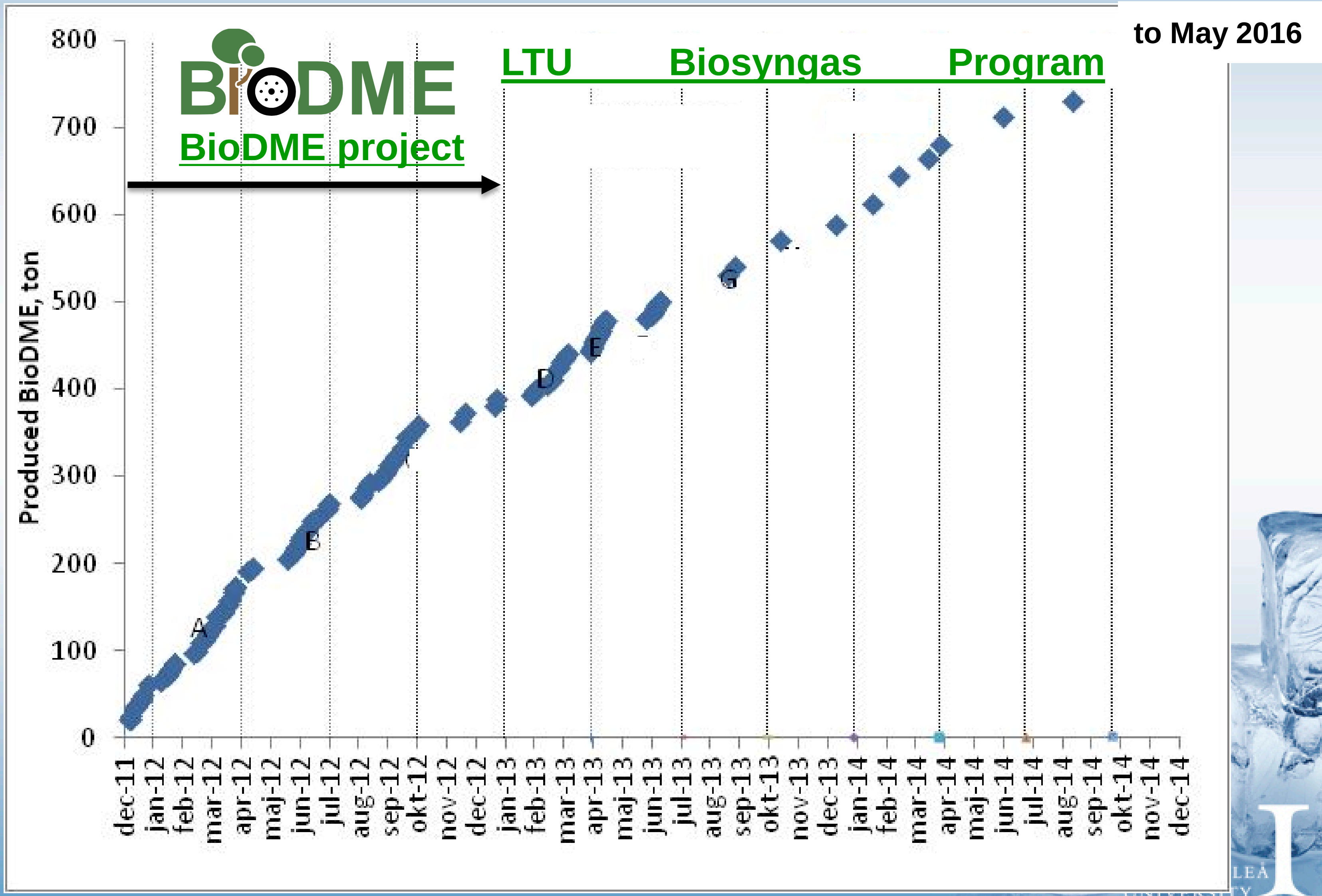


The plant incl. gasification is operated by 2 operators per shift

Key operation data:
Gasification at 30bar/1050˚C
Methanol synthesis at 130 bar
DME synthesis at 15 bar

Over 4 ton DME/d was reached in Sep -12

More than 1000 tons of BioDME has been produced since start in Nov 2011



Fuel Distribution

- Available technology modified for DME
- Safety regulations based on LPG
- ~200 k€ per filling station (+33% vs diesel)
- Easy to achieve

200 m^3 storage tank in Piteå

34 m^3 trailer

Four filling stations

BioDME

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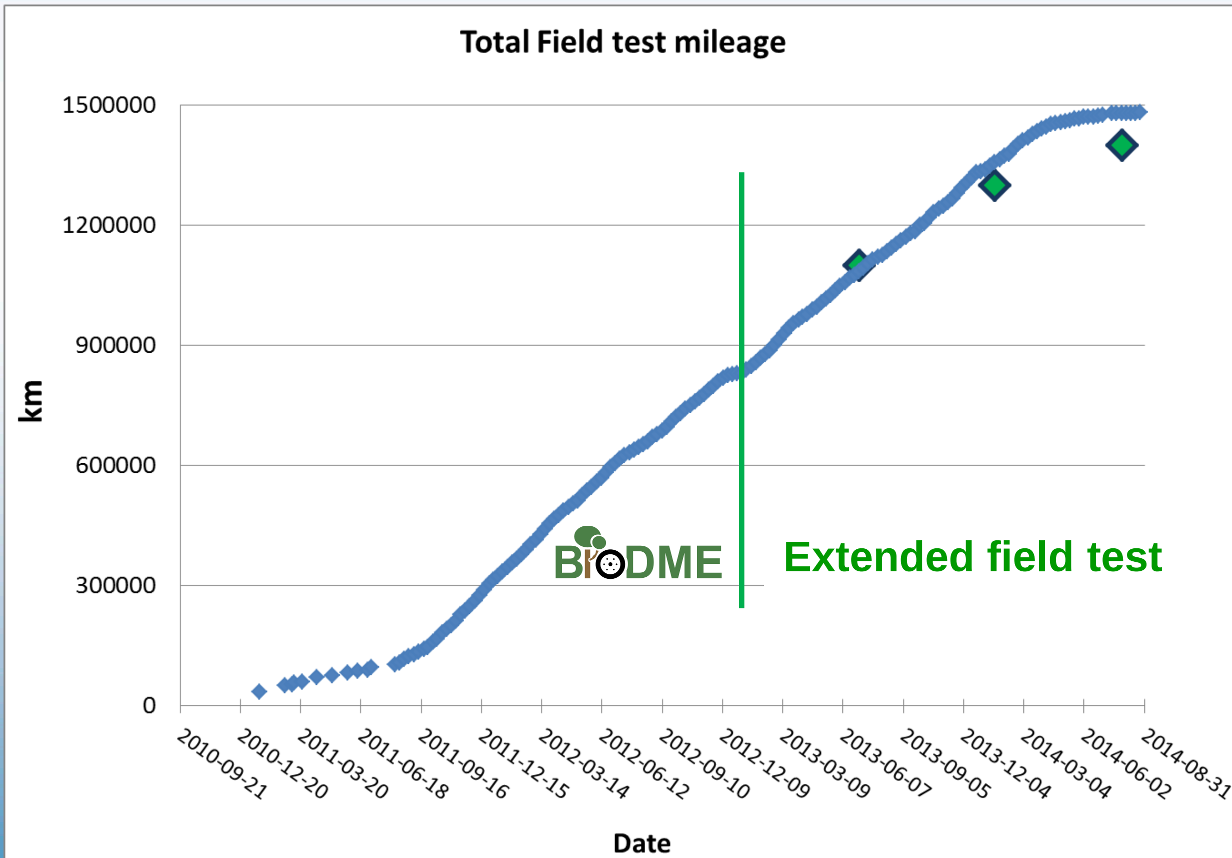
Goals achieved for the Volvo field tests

8 trucks, 2013-01-01 to 2014-06-30

Km / Mile	Status 2014-08-31	Target June 2014
Total mileage	1 485 000 / 933 000	1 400 000 / 870 000
1 truck	296 000 / 184 000	250 000 / 155 000

BIODME



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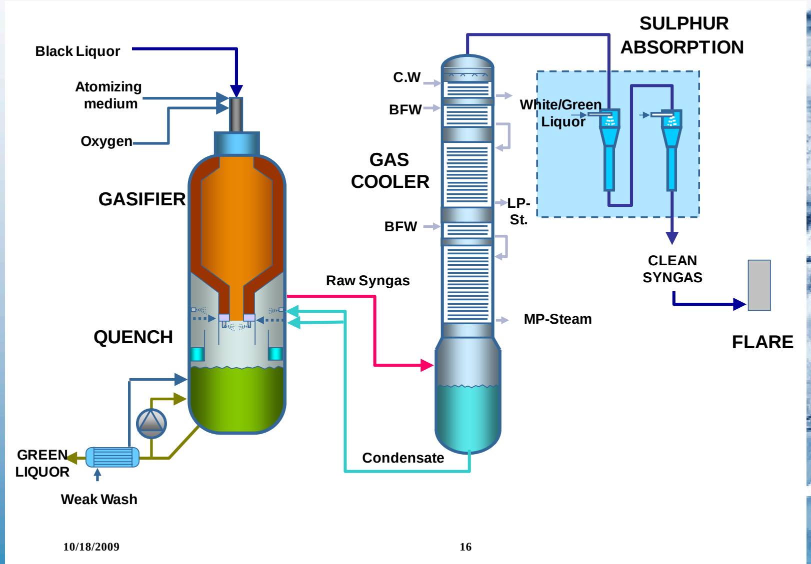
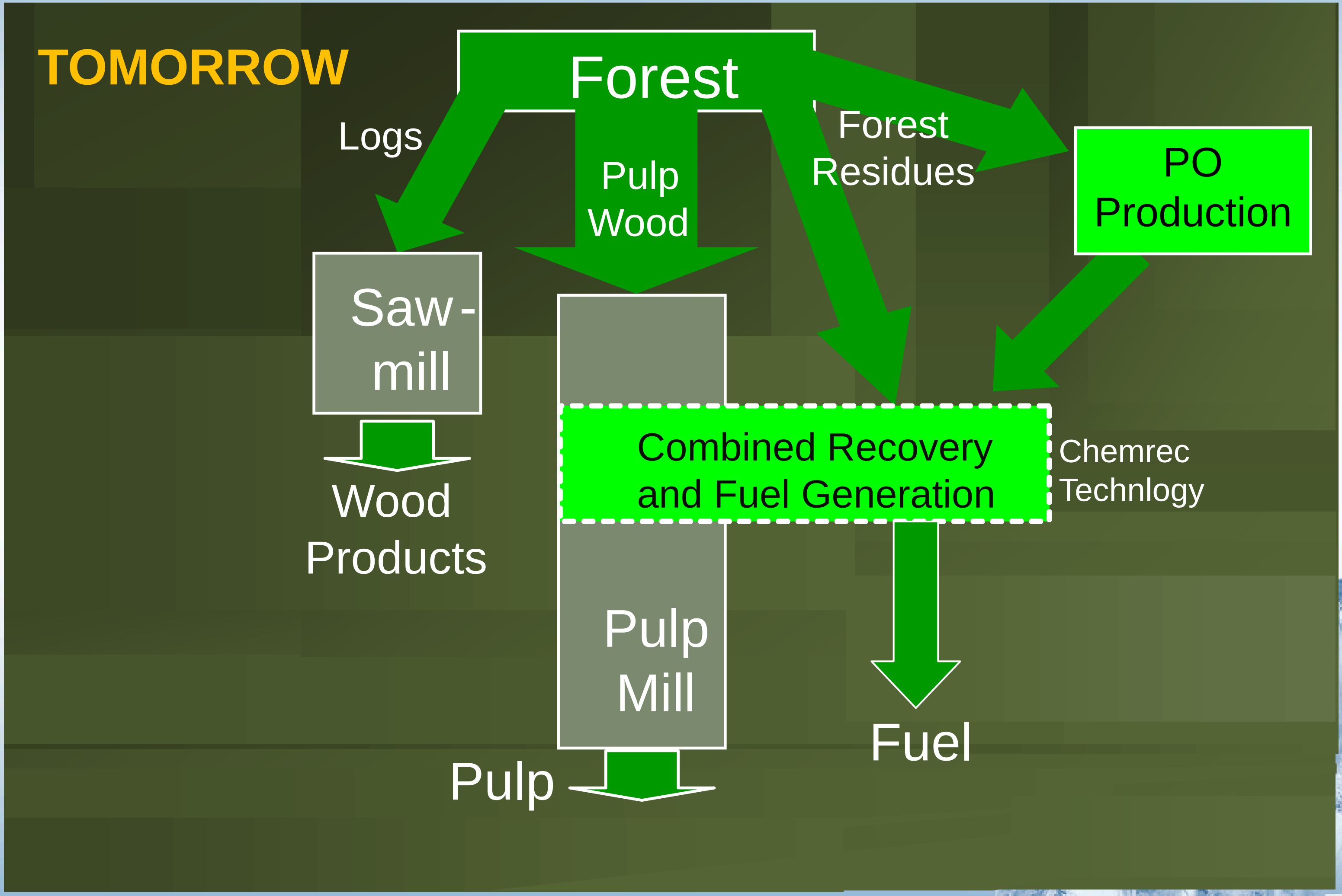
Chemrec Status as per January 2013

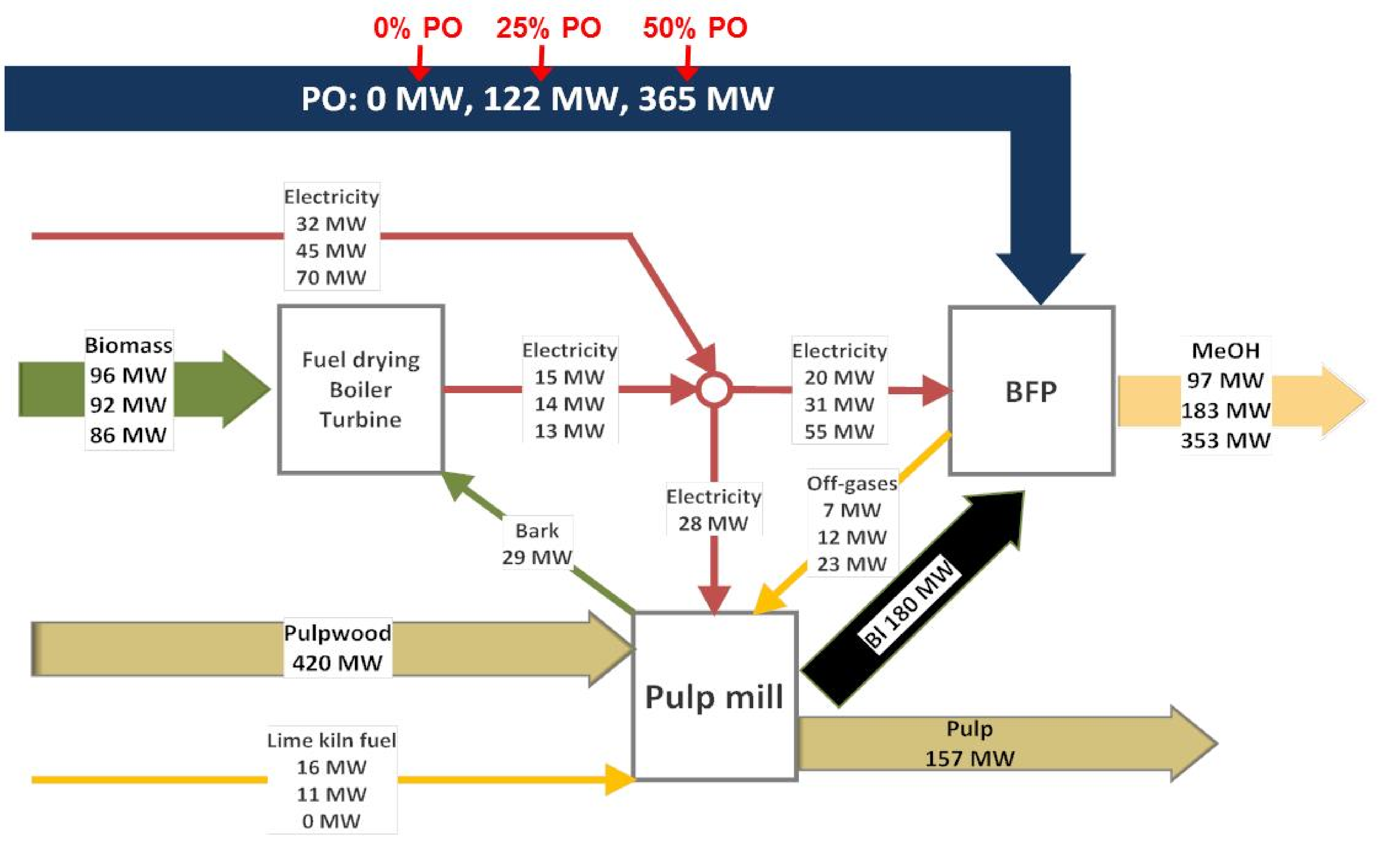
- *Dec 31, 2012*: Chemrec Piteå companies including pilot plants sold by Chemrec AB to LTU Holding AB,
- *Jan 1, 2013:* 17 pilot plant staff employed by LTU.
- *Dec 31, 2012:* License agreement between licensor Chemrec AB & HaldorTopsøe with LTU and LTU Holding. Technology rights stay with licensors.
- *Jan 30, 2013:* Consortium Agreement between parties involved in continued R&D.
- Chemrec has reduced staff **awaiting long term stable regulations for advanced biofuels**. Two Chemrec Stockholm staff temporarily on leave assigned to LTU
- Continued operation of the plants as part of LTU Biosyngas Program



Biomass flow from the forest can be increased adding pyrolysis oil to the black liquor flow

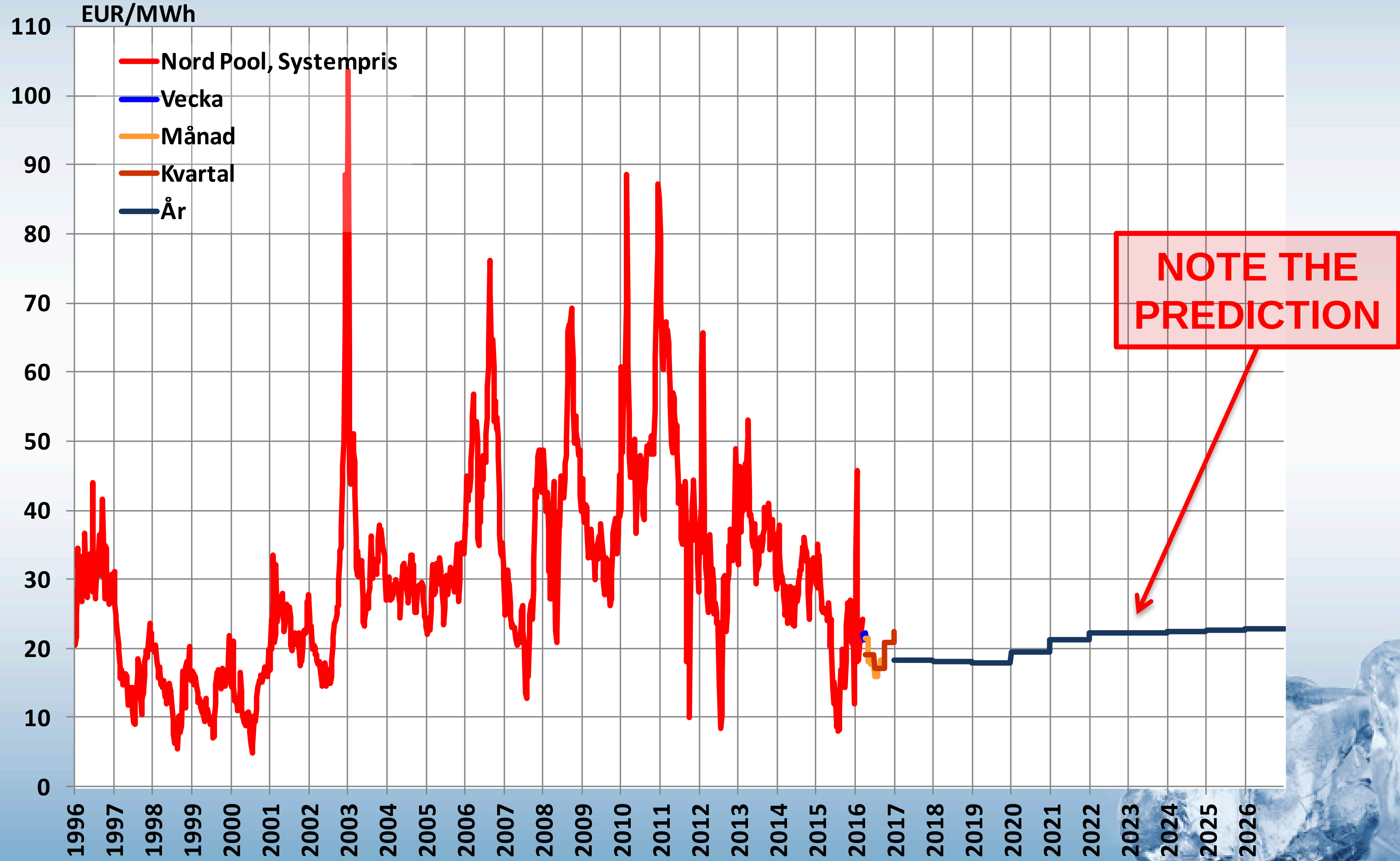


Material and energy balances



Spot Price Power in Nord Pool

Source: Nord Pool Spot, Nasdaq/OMX Commodities, Svensk Energi



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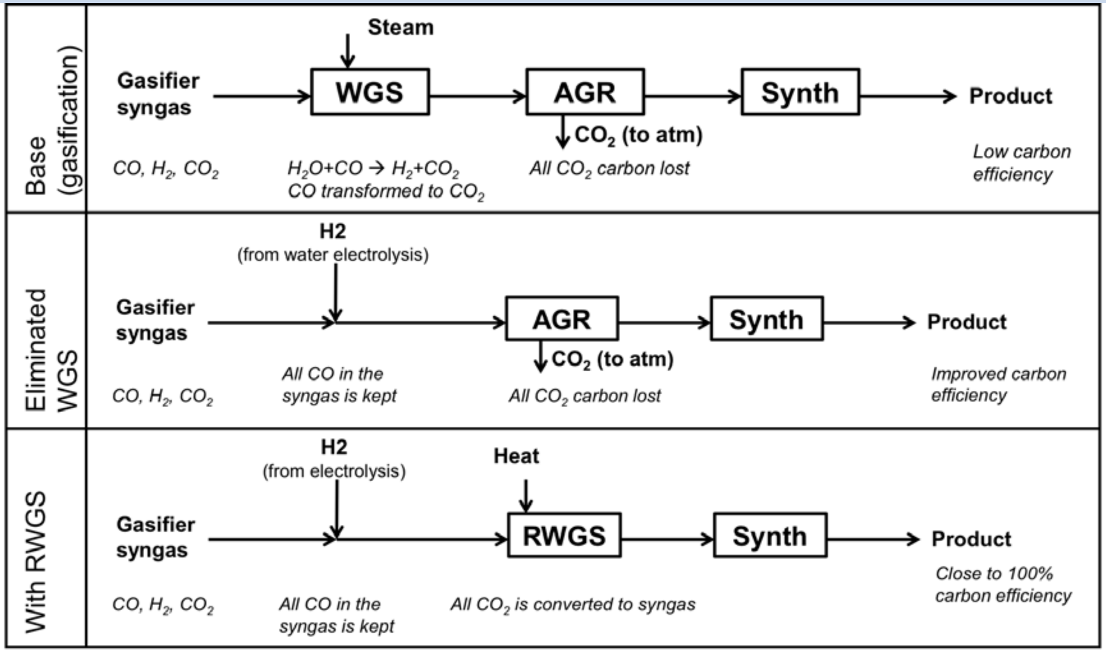
Power-to-liquids in a biorefinery



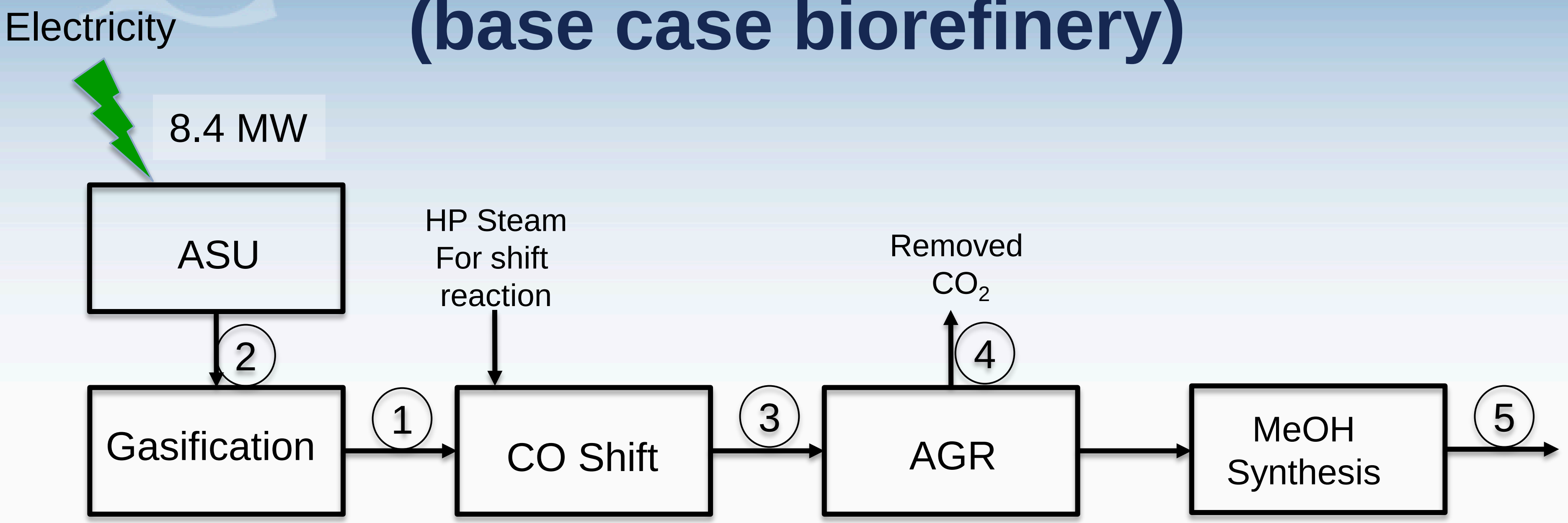
Base case

Hydrogen addition
60% improvement

Reverse shift
150% improvement

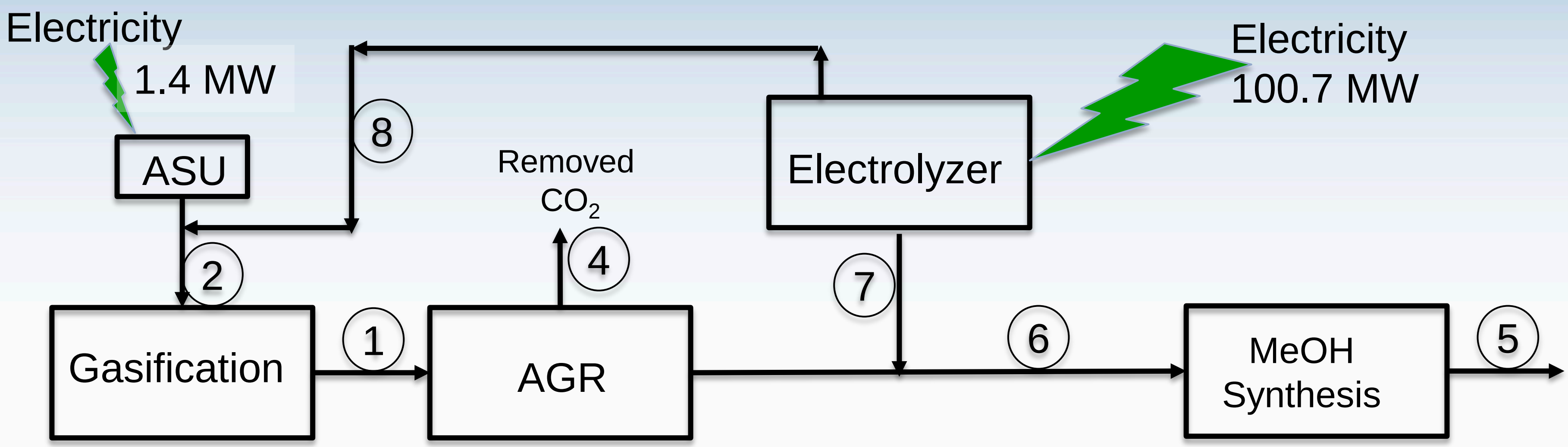
- In a conventional process 60% of the carbon is vented to the atmosphere as CO2
- The process yield increases 150% if all CO2 is converted to CO with RWGS
- The process yield in the demonstration increases by 76% (once-through RWGS that shifts about 50% of the CO2 to CO)
- The concept works with all gasification based BtX processes, e.g. BioDME, Bioliq and Gobigas

Main Process Blocks (base case biorefinery)



Kompo-nent	(1) Rågas, Nm3/h	(2) Oxygen	(3) Shifted Gas MW	(4)Removed CO_2 Nm3/h	(5) MeOH, MW / Ton/h			
H_2	22351 (67MW)		128,1 MW	CO_2 16819	102.5 / 18.6			
CO	19416 (67,9 MW)							
O_2		12874						

Main Process Blocks (Power to Liquid Case)



Kompo-nent	(1) Rågas, Nm3/h	(2) Oxygen	(3) Shifted Gas MW	(4)Removed CO_2 Nm3/h	(5) MeOH, MW / Ton/h	(6) Gas after H_2 injektion, Nm3/h	(7) Added H_2, Nm3/h	(8) Added O_2, Nm3/h
H_2	22351 (67MW)		----	CO_2 11412	159.3 / 28.9	43775 (131,2 MW)	21424 (64,2 MW)	
CO	19416 (67,9 MW)					19416 (67,9MW)		
O_2		12874						10712

Some key conclusions - 1

- Methanol from raw gas via shift:

$(\overset{H_2}{67} + \overset{CO}{67.9})$ x 0.95 x 0.8 = 102.5 MW

- Methanol from raw gas with H_2 addition:

$(67 + 67{,}9 + \overset{\text{Extra } H_2}{64{,}2})$ x 0,8 = 159,3 MW

- Increased production from a given amount of feedstock: 159.3 / 102.5 x 100 = **55%**
- Conversion efficiency of hydrogen energy to methanol energy:

100 x (159.3 – 102,5) / $\overset{\text{Extra } H_2}{64{,}2}$ = **88%**

Some key conclusions - 2

<u>Power price 60 €/MWh</u>

- If Power price is 60€ / MWh then the cost of power in the hydrogen production cost is 60 / 0.64 = 94€ / MWh.
- Savings on power needs for oxygen production corresponds to 7 MW. If this is credited the power consumption for hydrogen the conversion efficiency becomes 64.2 / (100.7-7) = 68.5%
- *Cost of power in the hydrogen production* cost then becomes 60 / 0.685 = 88€ / MWh.

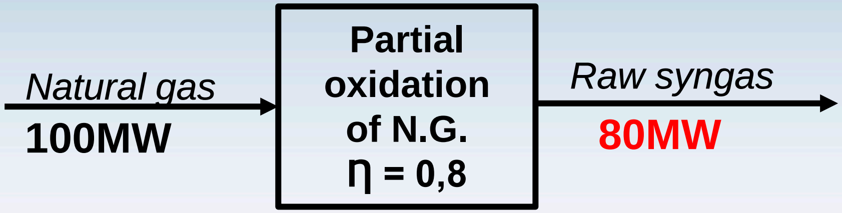
<u>Power price 45 €/MWh</u>

- *If average power price is 45€ / MWh the corresponding cost element is 66 €/MWh*

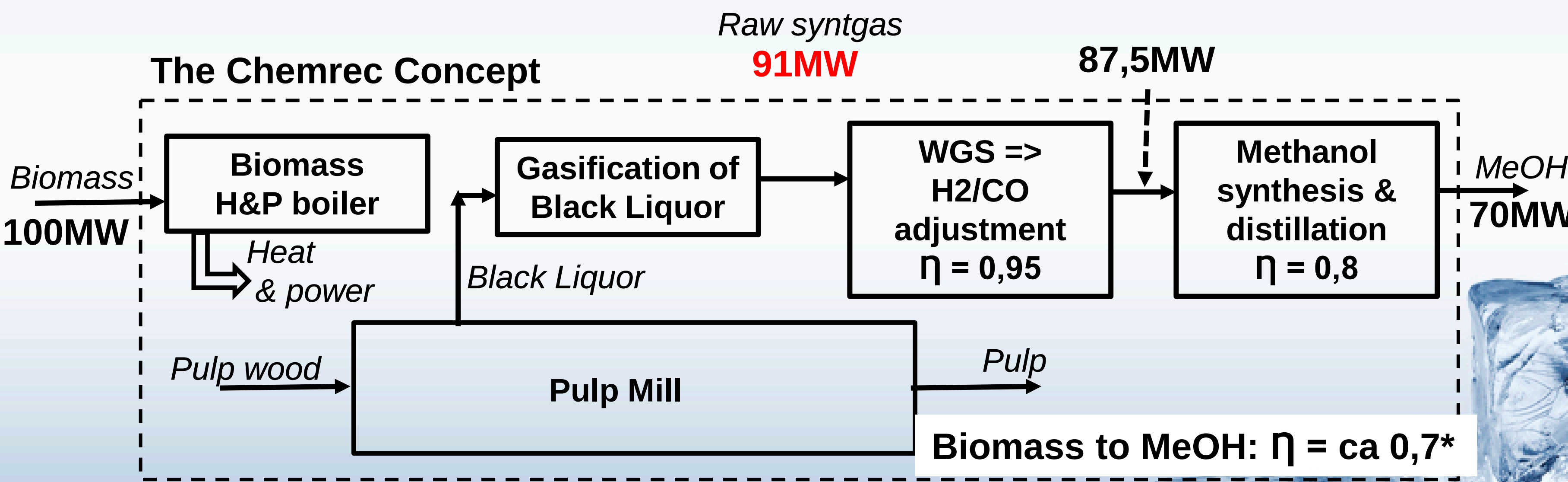
Some key conclusions - 3

- If Power price average is 45€ / MWh then the cost of power in the methanol production cost is 45 / 0.685 / 0.8 = 82 € / MWh.
- This concept is economically at least as good as adding capacity via pyrolysis oil addition to black liquor

Raw syngas from natural gas and biomass respectively utilizing black liquor in pulp mills (energy balances)



η=energy conversion efficiency
(chemically bounded energy OUT/IN)



- Se e.g.. http://www.princeton.edu/pei/energy/publications/texts/Princeton-Biorefinery-Study-Final-Report-Vol.-1.pdf p. 56
  - http://www.chemrec.se/admin/UploadFile.aspx?path=/UserUploadFiles/2003 BLGMF report.pdf p 111

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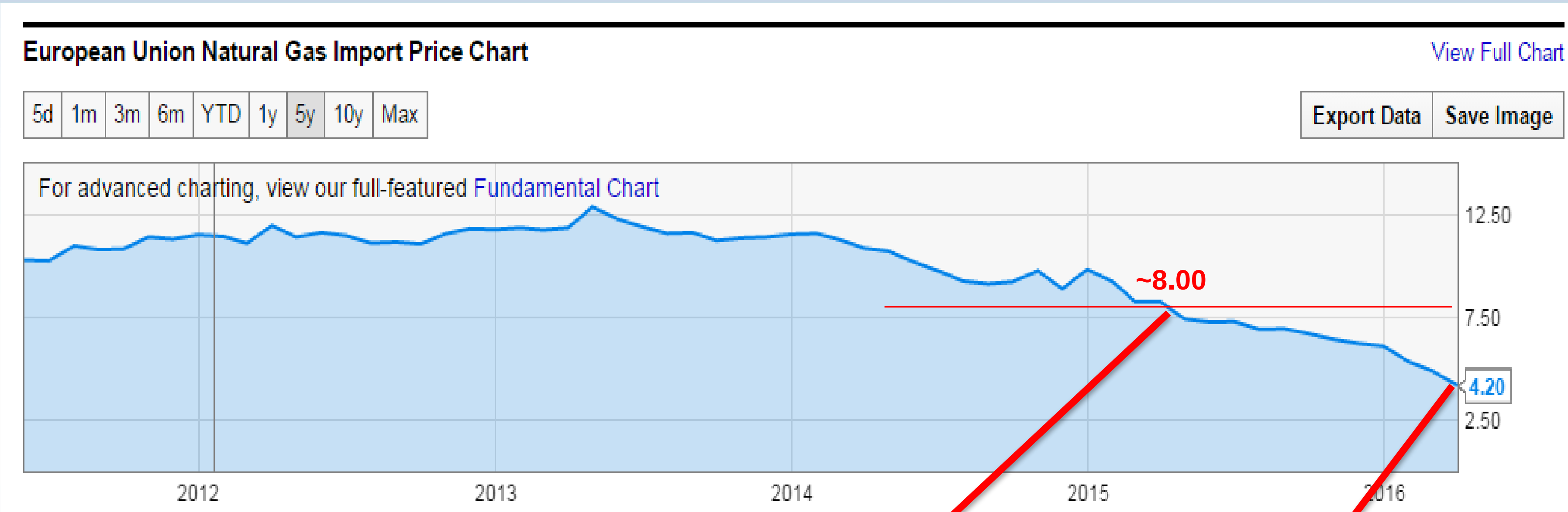
European Union Natural Gas Import Price

(USD/MMBtu)



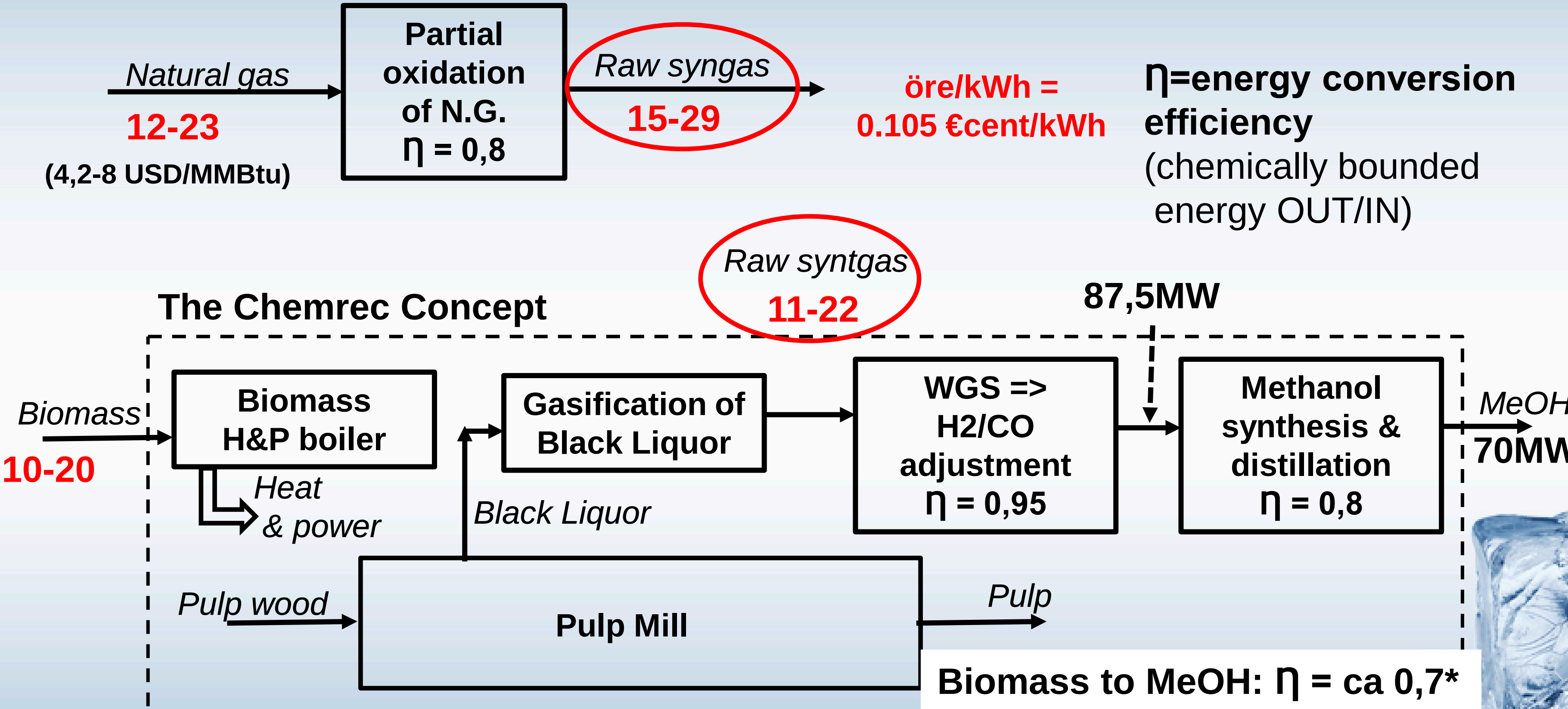
1 MWh = 3,4095 MMBTU
1 USD = 8,5 SEK

23 öre/kWh

12 öre/kWh

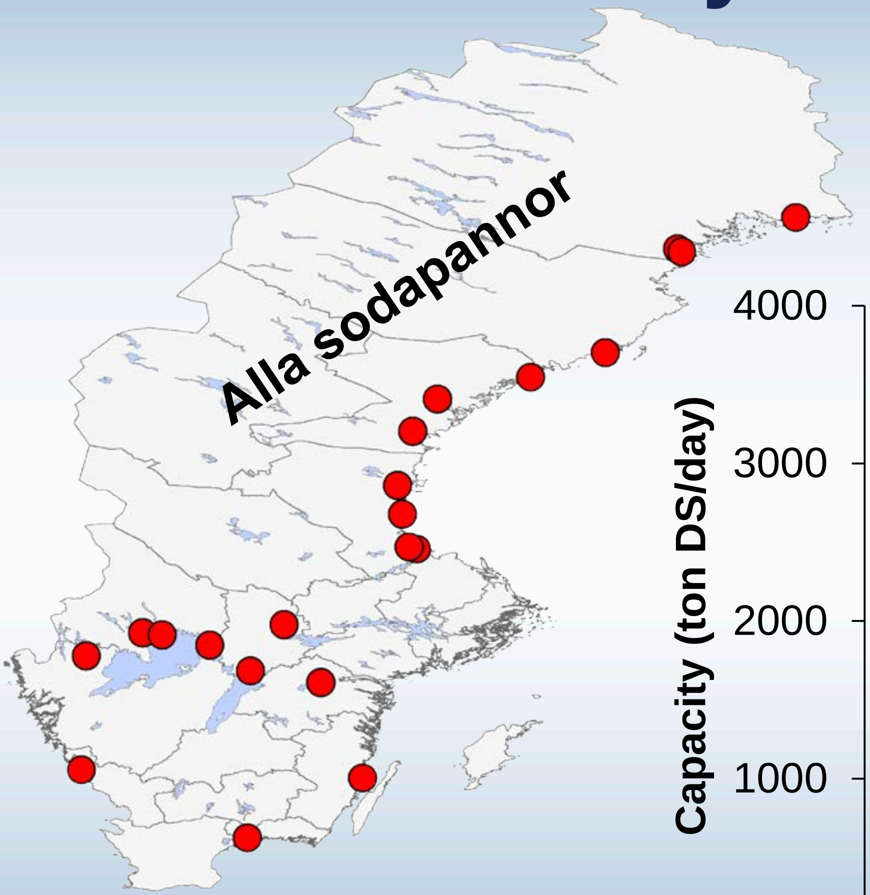
Source: https://ycharts.com/indicators/europe_natural_gas_price

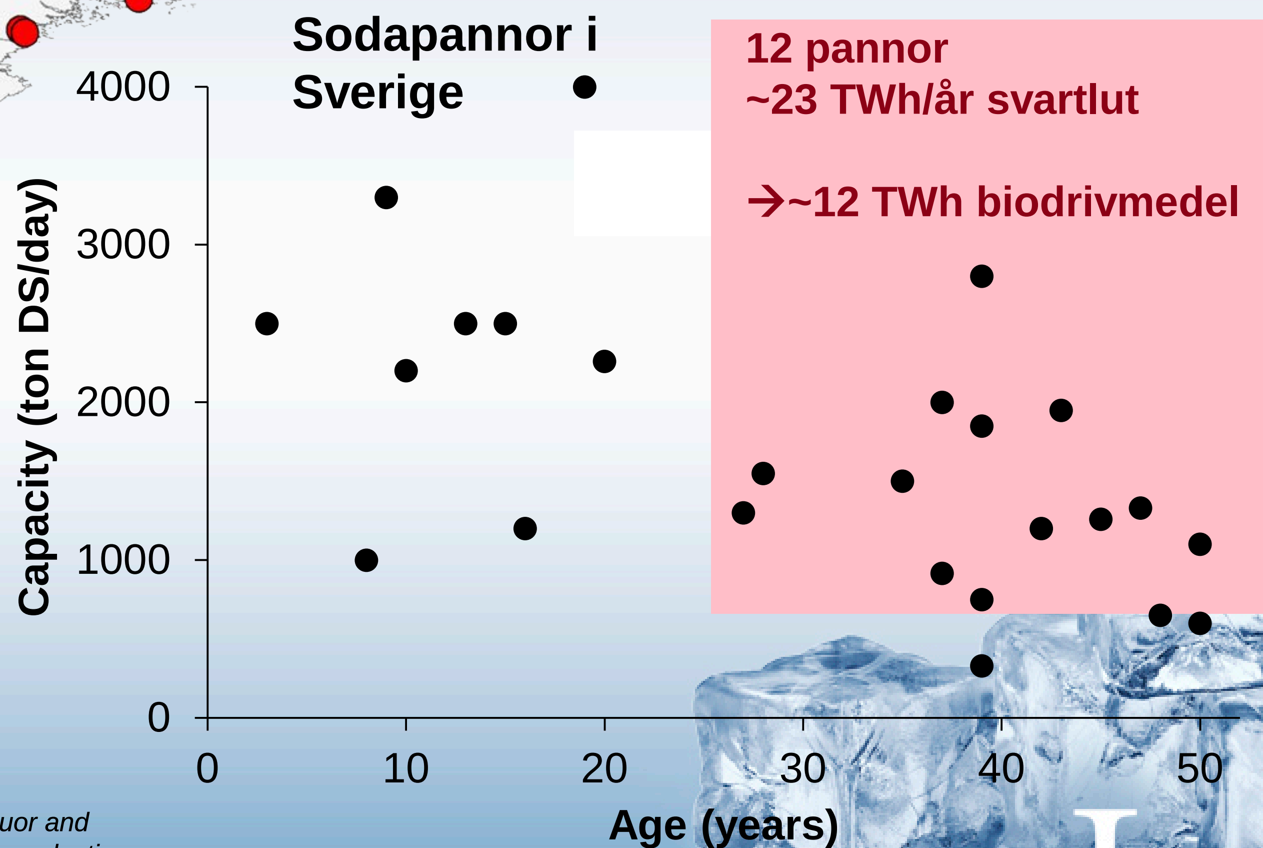
Raw syngas from natural gas and biomass respectively utilizing black liquor in pulp mills (Cost of feedstock vs cost of raw syngas)



- Se e.g.. http://www.princeton.edu/pei/energy/publications/texts/Princeton-Biorefinery-Study-Final-Report-Vol.-1.pdf p. 56
    - http://www.chemrec.se/admin/UploadFile.aspx?path=/UserUploadFiles/2003 BLGMF report.pdf p 111

Recovery boilers in Sweden





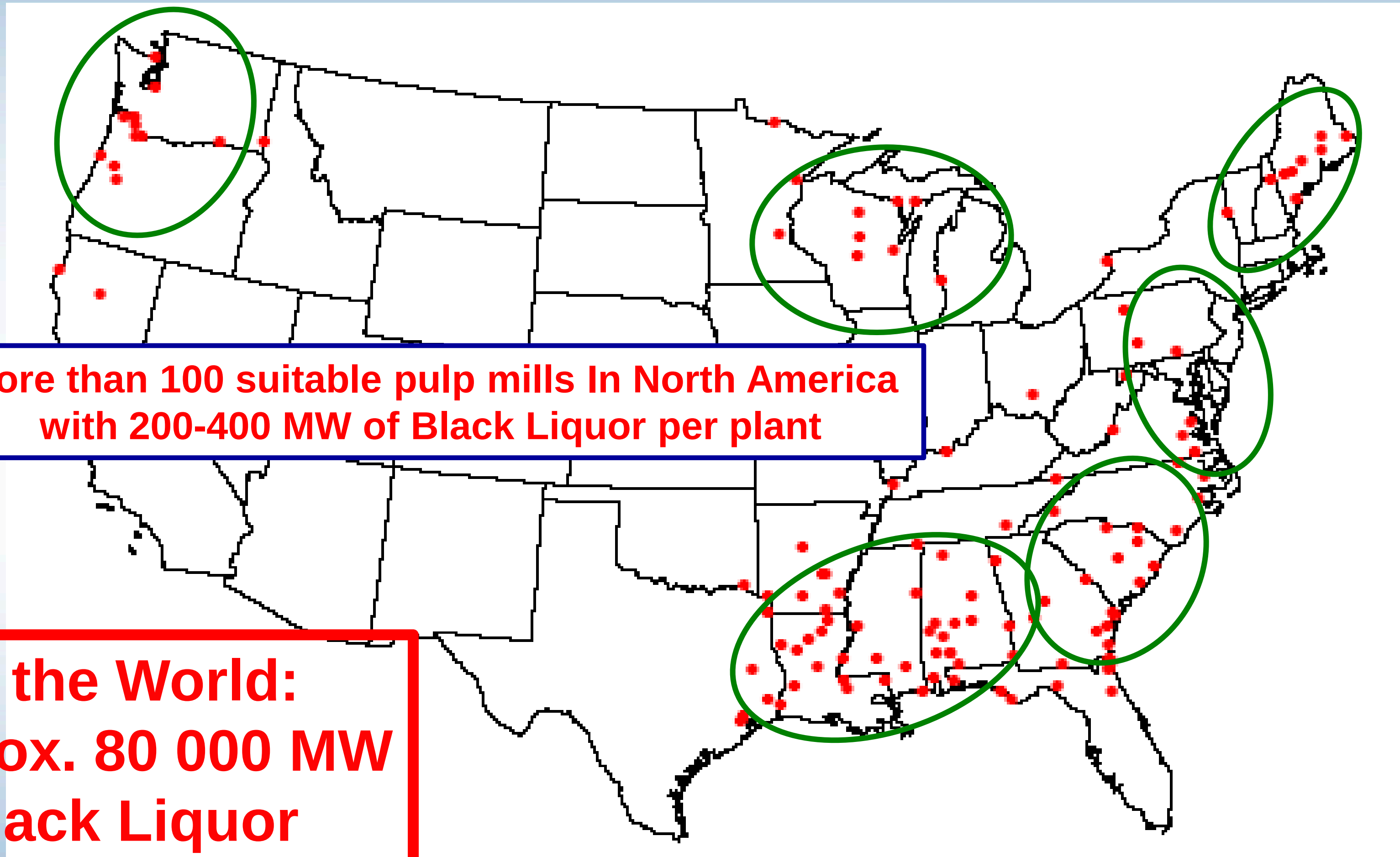
Andersson J, et al. (2016) Co-gasification of black liquor and pyrolysis oil: Evaluation of blend ratios and methanol production capacities. Energy Conversion and Management 110:240-248

Methanol production potential from EU Black liquor (BL) capacity combined with addition of Pyrolysis Liquid (PL) and electricity
NOTE: Approximate calculation only

	TWh/y	Toe/y	% of EU estimate* of transport fuel in 2030 (350 Mtoe)
BL in Europe	140	--	--
MeOH fr BL in Europe	77	6,7	1.9
PL part 25% BL + PL: Production x 2	155	13,4	3.8
PL part 50% in BL+PL: Production x 3	230	20	5.7
Add H2 instead of shift	370	32	9.1
Add Reversed shift	580	50	14.3

* https://ec.europa.eu/energy/sites/ener/files/documents/trends_to_2050_update_2013.pdf

BL Energy is a substantial energy source in some states in the US e.g. Georgia



More than 100 suitable pulp mills In North America with 200-400 MW of Black Liquor per plant

In the World: approx. 80 000 MW Black Liquor or 250 – 300 large plants

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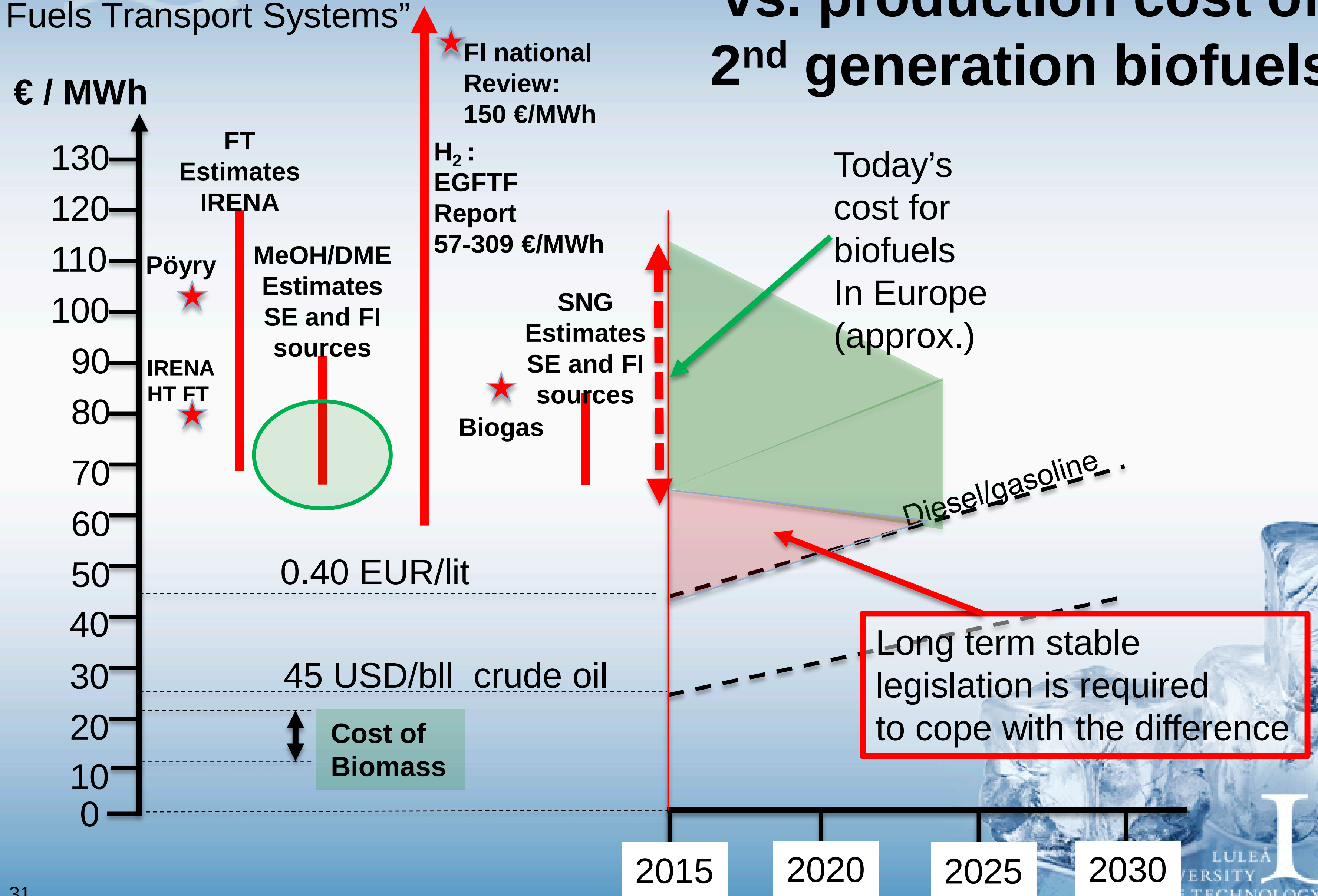
Cost of Crude Oil vs. production cost of 2nd generation biofuels

Source: EGFTF report 2015
"State of the Art on Alternative Fuels Transport Systems"



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