Efficient integration of fuel generation with the pulping process

EBTP / ETIP Bioenergy's
7th Stakeholder Plenary Meeting

Brussels
June 21, 2016

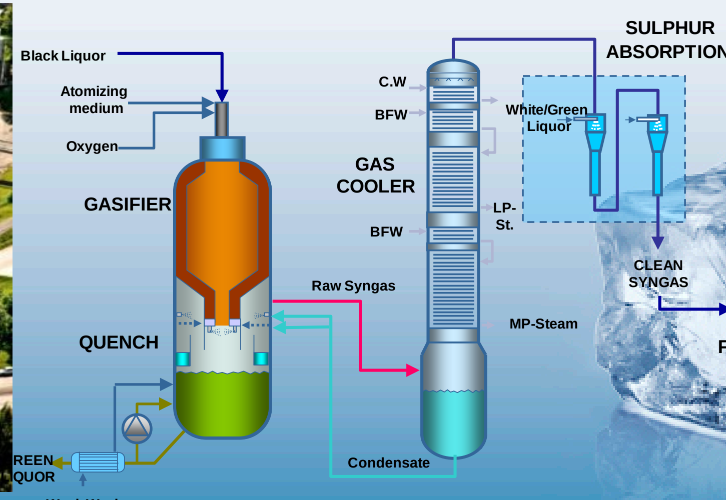
Ingvar Landälv
Senior Project Manager
Luleå University of Technology

LULEÅ UNIVERSITY OF TECHNOLOGY

Status Chemrec technology 2013 post 2012

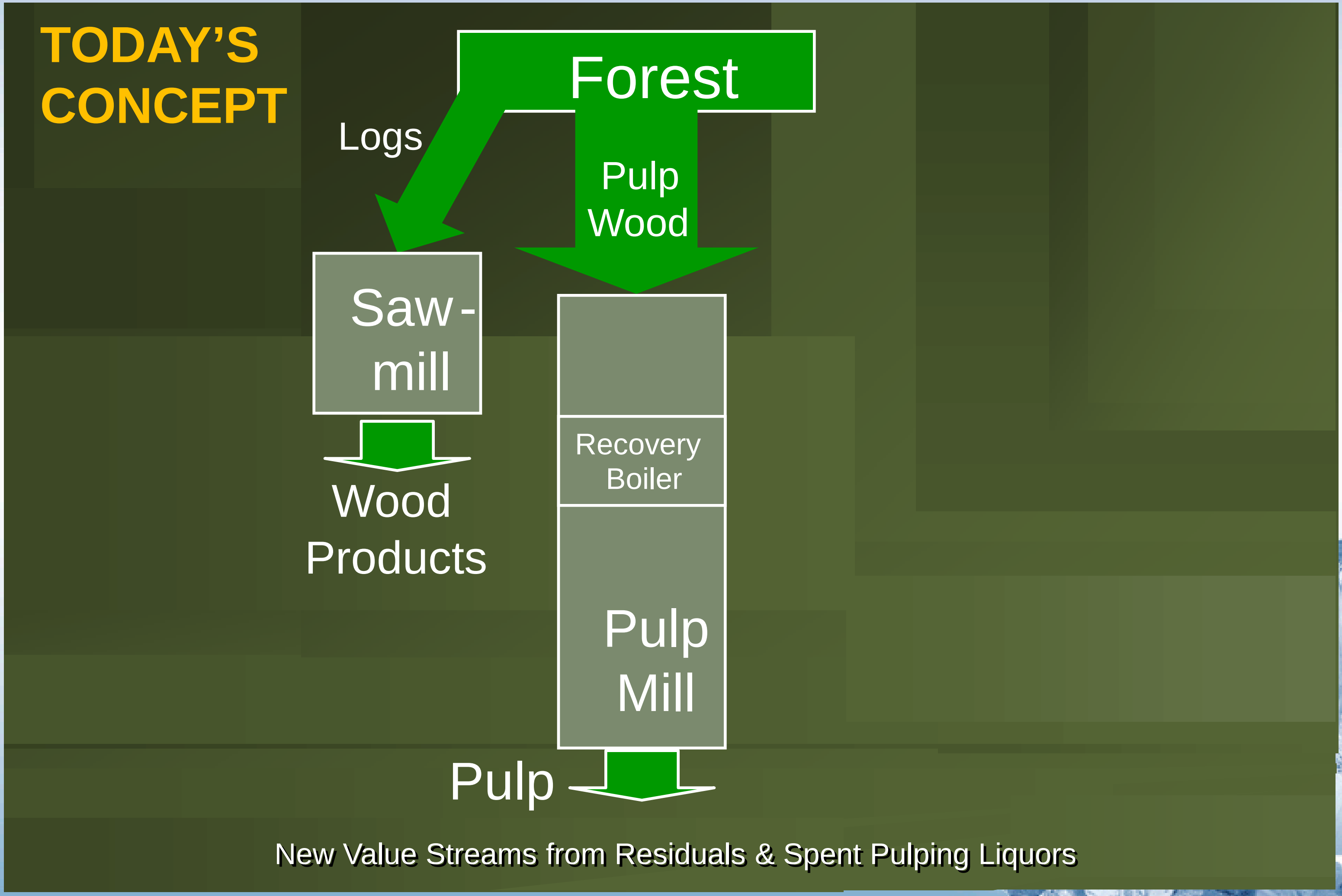
Where do we go from here?

- ***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 employed by LTU
- ***Jan 2013 – May 2016:*** Continued operation of the plants as part of LTU Biosyngas Program
- **June 2016:** Application filed for mothballing the plant. Alternative: Dismantling

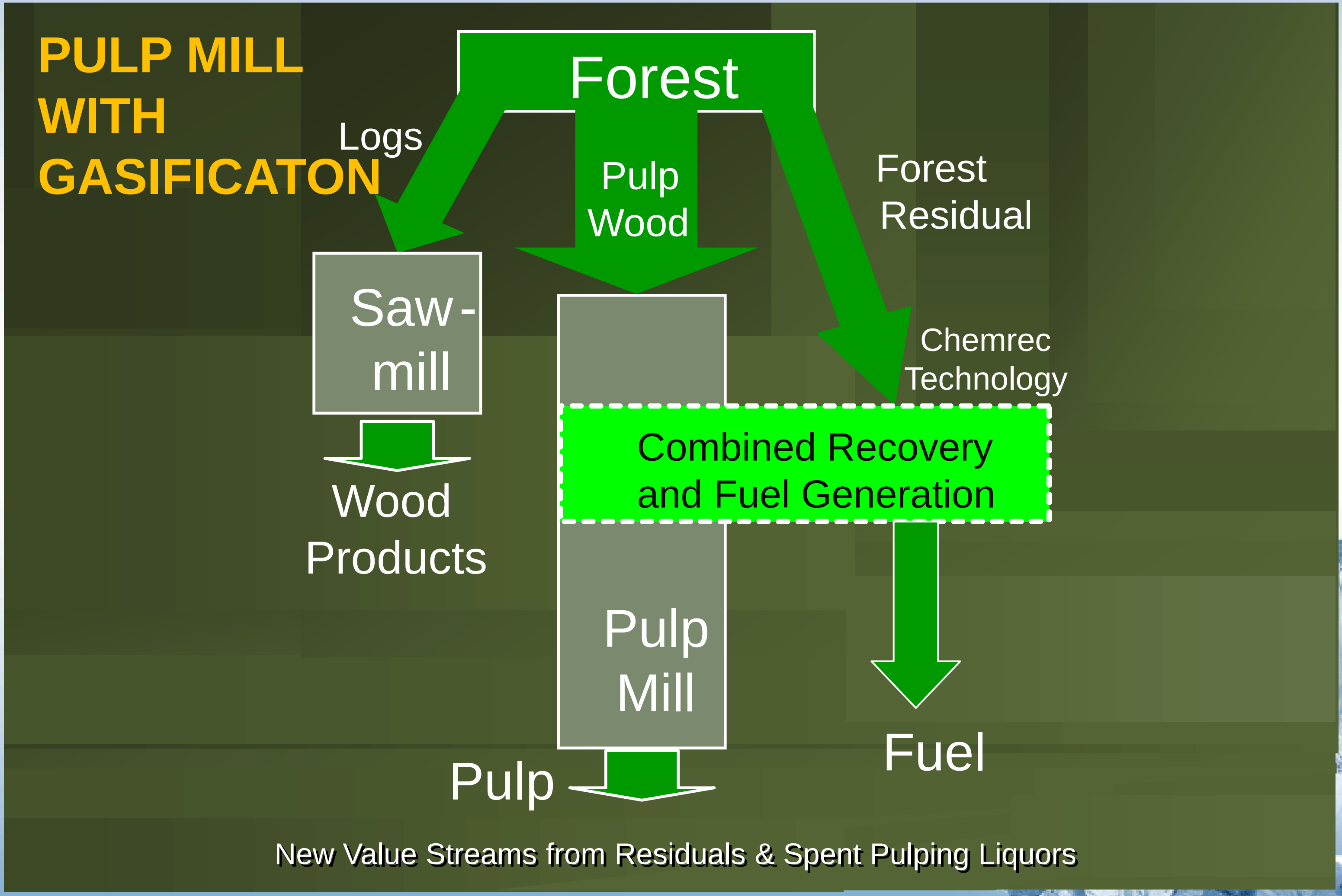


LULEÅ UNIVERSITY OF TECHNOLOGY

Today's commercial Forrest Industry has two main legs

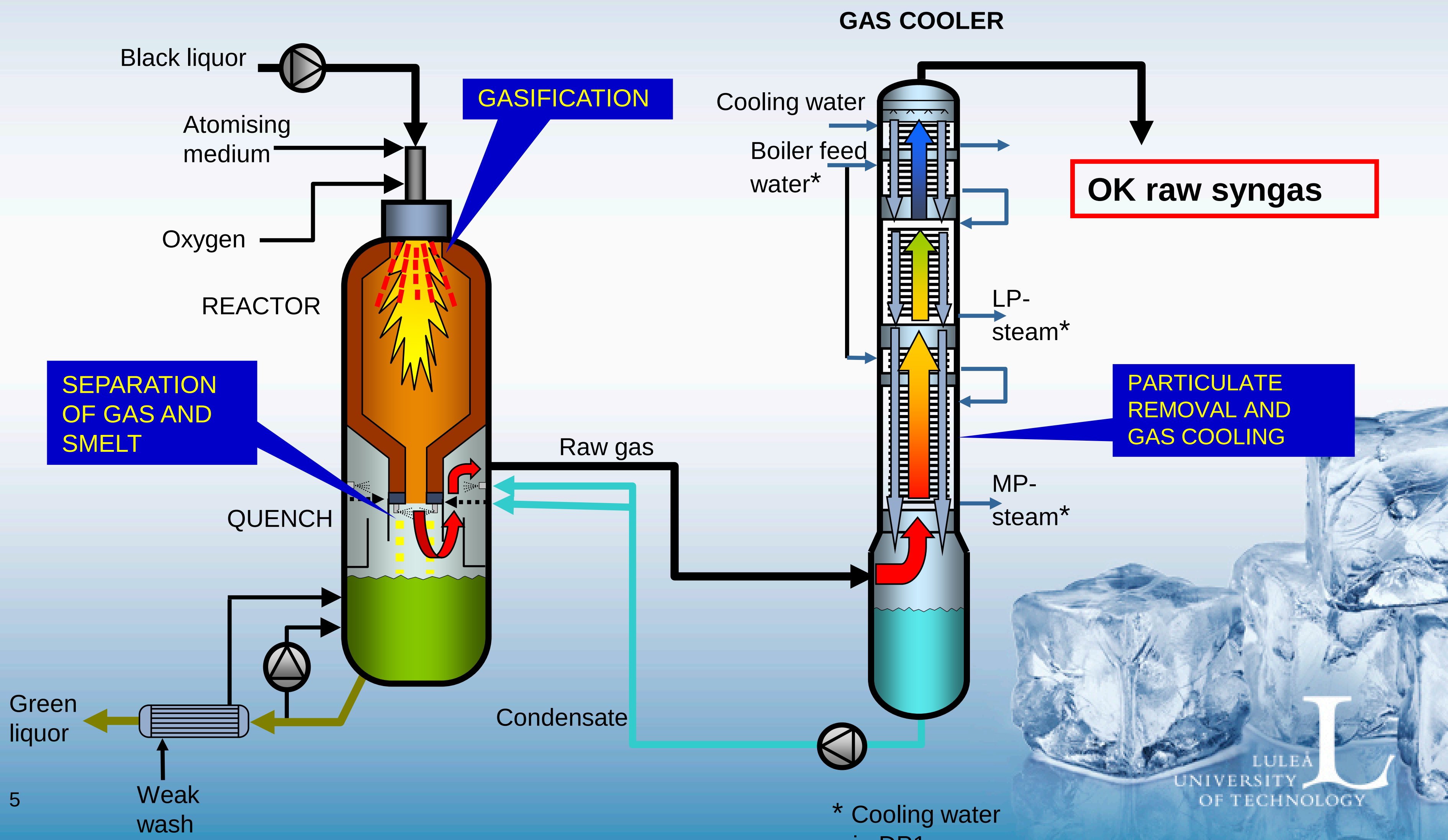


The Vision: Tomorrow's Biomass flow to the Forrest Industry

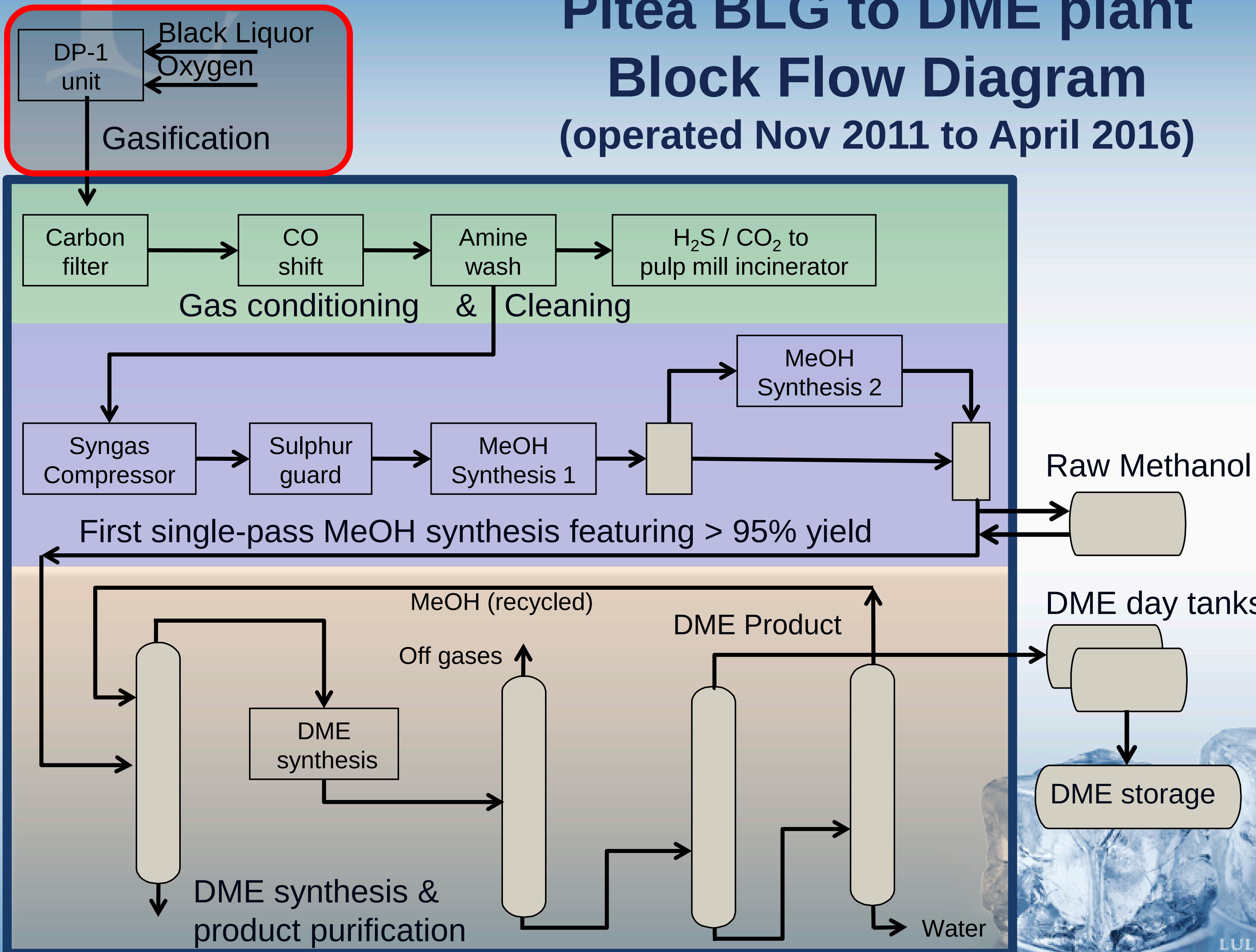


Chemrec technology generates good quality raw syngas with three main process steps: (1)Gasification, (2)Quenching and (3)Cooling

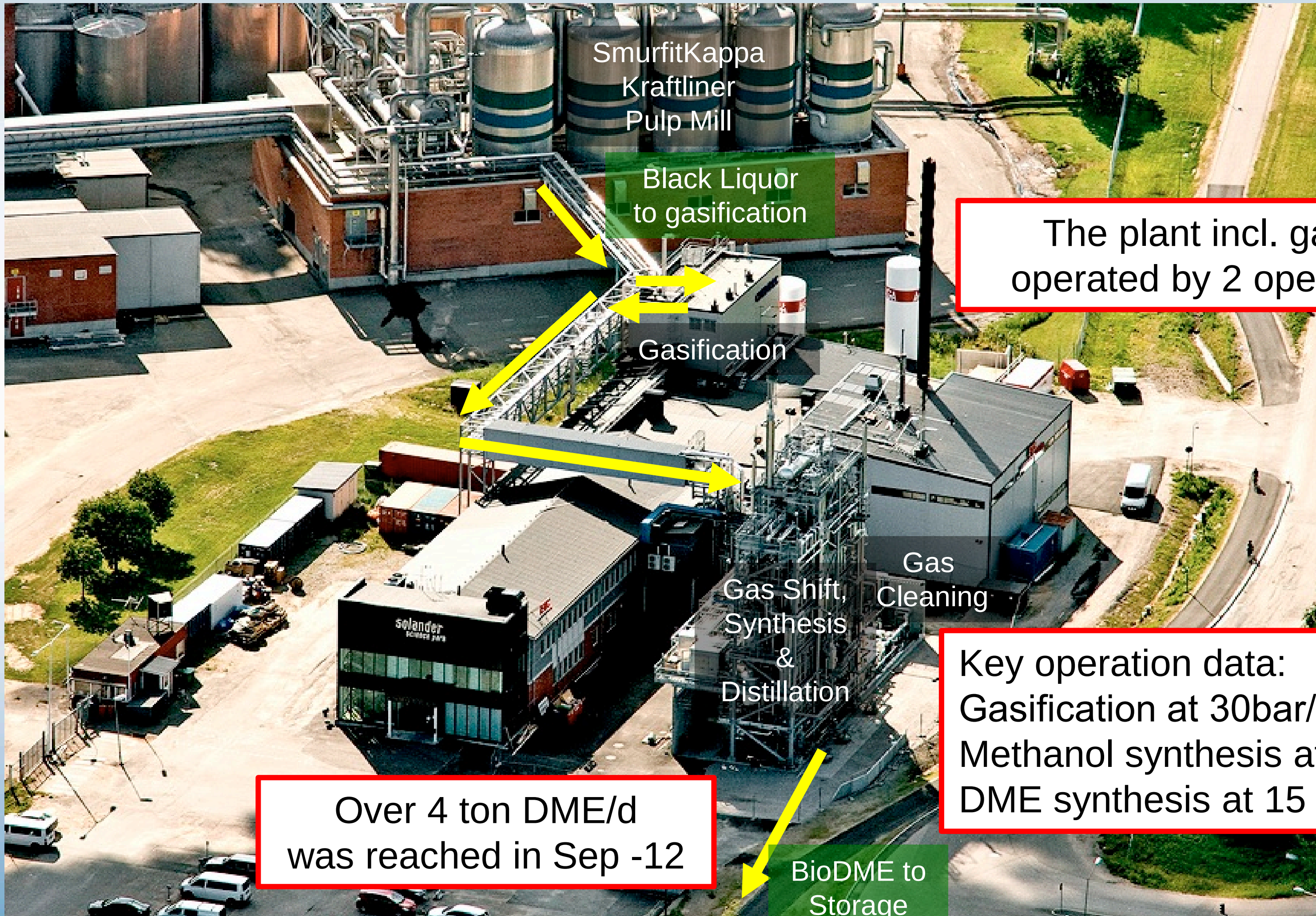
- Running as a gasification unit only Sep 2005 to June 2011 -



Piteå BLG to DME plant Block Flow Diagram (operated Nov 2011 to April 2016)



The integrated Black Liquor to DME plant in Piteå, Sweden

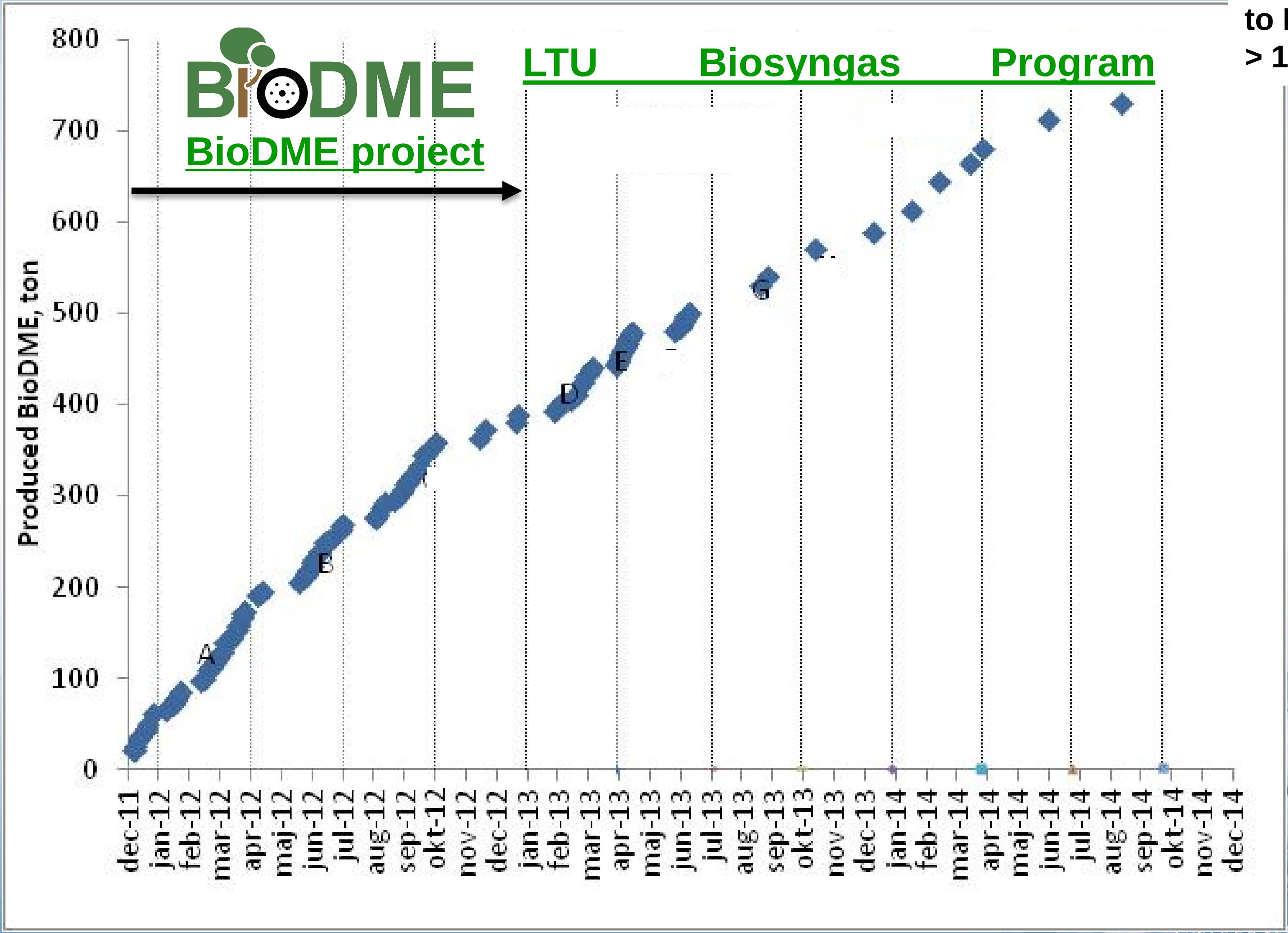


The plant incl. gasification is operated by 2 operators per shift

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



to May 2016
> 1000 ton

Fuel Distribution

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

200 m³ storage tank in Piteå

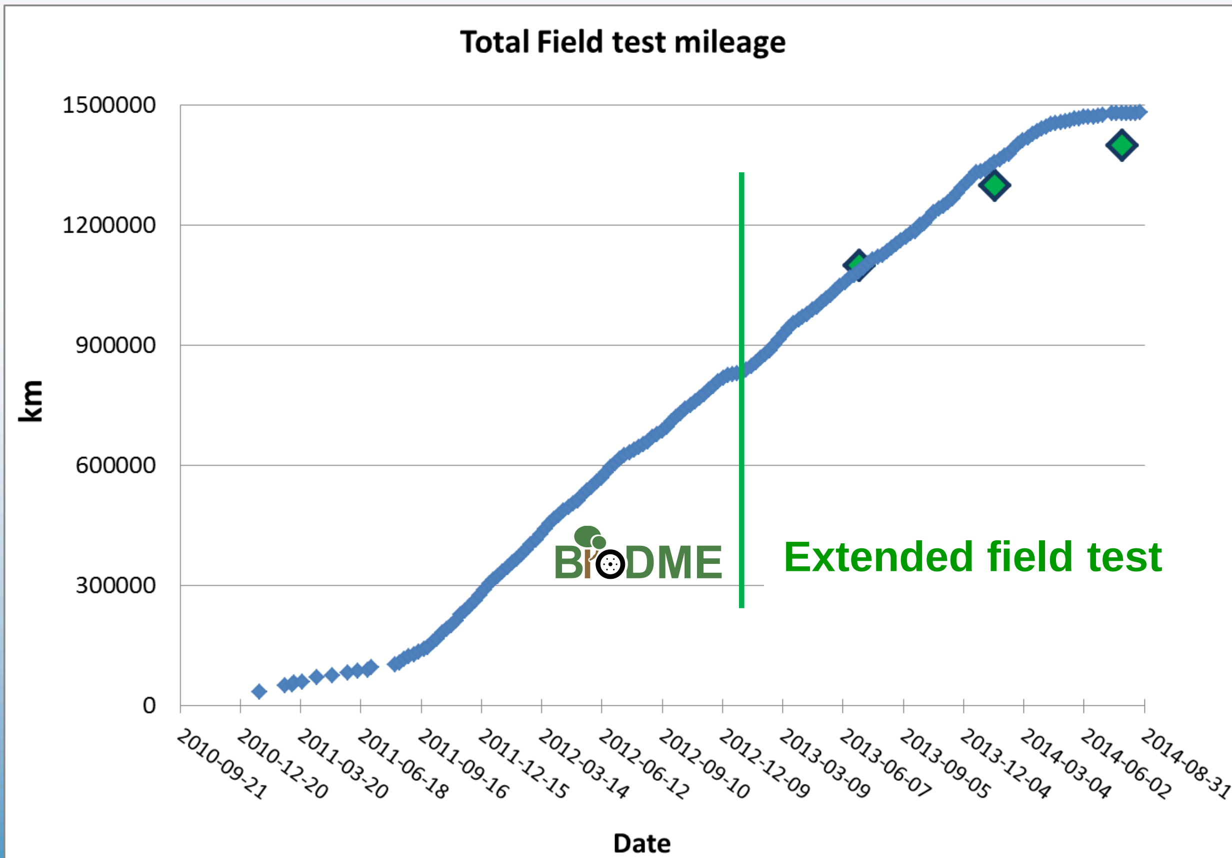
34 m³ trailer

Four filling stations

Goals achieved for the Volvo field tests

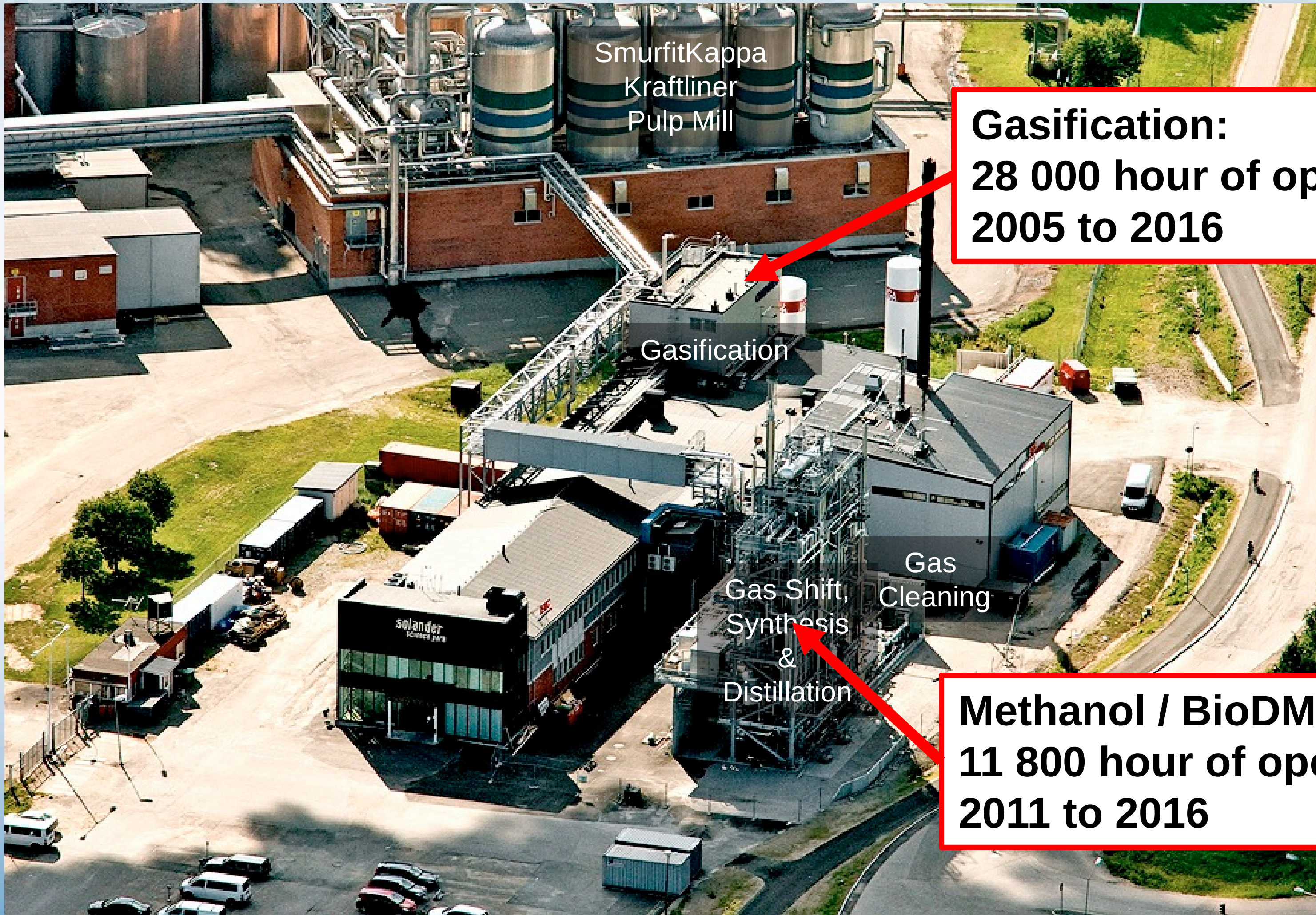
8 trucks, 2013-01-01 to 2014-06-30

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



LULEÅ UNIVERSITY OF TECHNOLOGY

Total operating hours for the Piteå development plant



Gasification:
28 000 hour of operation
2005 to 2016

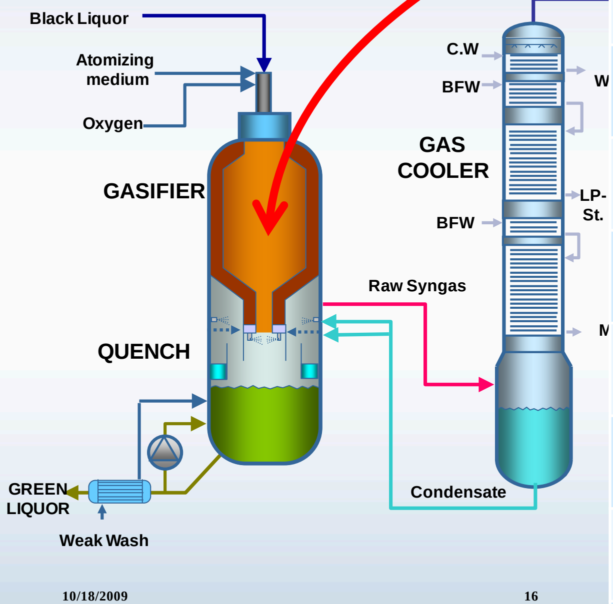
Methanol / BioDME Plant:
11 800 hour of operation
2011 to 2016

BioDME Plant Non-availability Jan-June, 2012
(total calendar time: 4368h)

Variable	Total downtime Jan-June 2012	Planned downtime	Unplanned downtime caused by			
			Gasifier unit	BioDME plant	Support system	Mill
Gasifier + BioDME plant not in operation	1527 h	737	252	433	26	80
% of total time (4368 h)	35 %	17	6	10	<1	2
% of total downtime		48	17	28	2	5

On stream factor, PLANNED: 50% of calendar time
On stream factor, ACHIEVED: approx. 65% of calendar time
On stream factor, ACHIEVED: approx. 78% of planned operation time
Longest run: 26 days followed by a planned stop

Gas composition for a typical case (p = 27 bar, λ = 0.3, T = 1050 ºC)

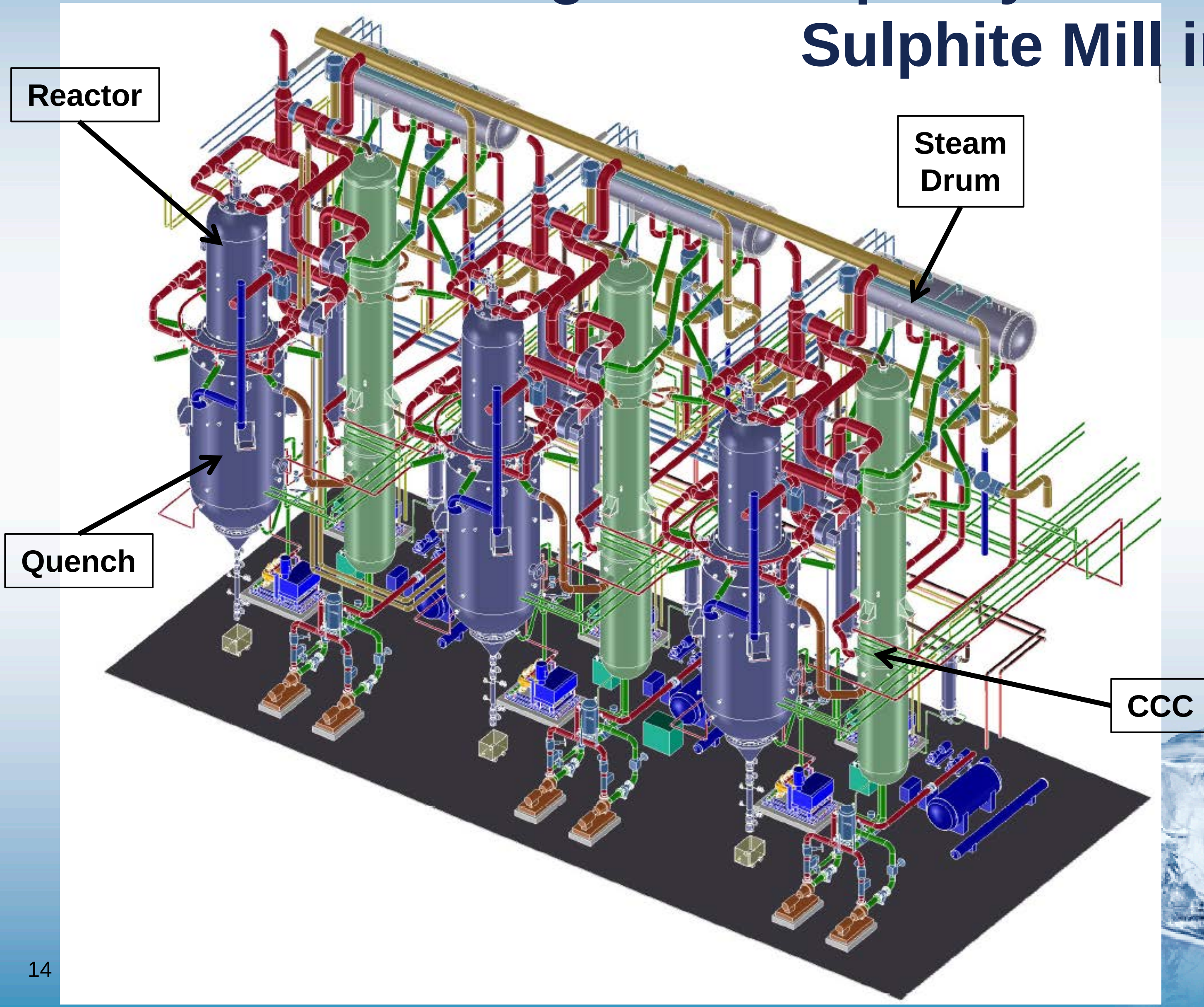


	Inside reactor (%)	Cooled syngas (%)
CO_2	33.9 ±0.3	33.6 ±0.2
H_2S	1.65 ±0.04	1.71 ±0.02
CH_4	1.36 ±0.07	1.44 ±0.07
CO	28.7 ±0.2	28.5 ±0.2
H_2	34.3 ±0.2	34.8 ±0.1
COS	468 ±22 ppm	122 ±5 ppm
H_2/CO	1.19 ±0.01	1.22 ±0.01
H_2/CO_2	1.01 ±0.01	1.04 ±0.01
CO/CO_2	0.85 ±0.01	0.85 ±0.01

* Average of ten samples per sample point

Data by the BLG Program,
R. Gebart et al, TCBiomass 2009

2011: Time for full scale demonstration. 3 x 50% gasifier capacity for the Domsjö Sulphite Mill in Sweden



Approx. 90 MW Feedstock per gasifier

Why was the Domsjö project not completed?

1. **Secured funding**

   200 million EUR, more than half of 350 million EUR total project funding, arranged as follows:

   55 million EUR Swedish Energy Agency Grant, approved by DG Comp.

   145 million EUR Pledged by mill owner, EPC Contractor and Int. Oil & Gas major

2. **Missing funding**

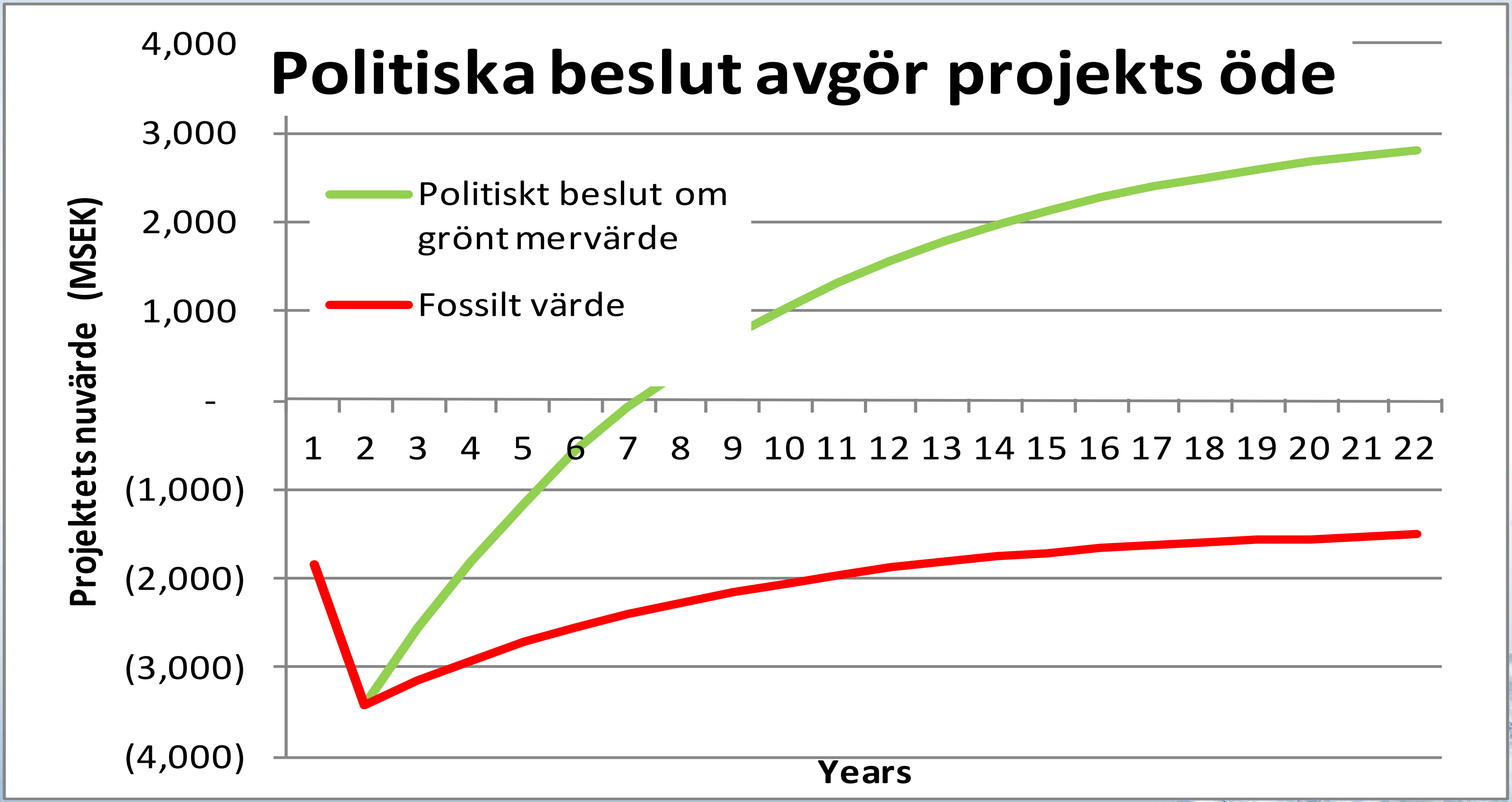
   Debt financing of the remaining 150 million EUR prevented mainly due to lenders assessment of political risk:

- Swedish CO2 & Energy tax exemption for Biofuels only applicable 1 year at a time. Project finance requires min 3+10=13 year stable legal framework.
- Letter of Comfort required from Swedish Government did not provide clarity on long term regulations.

Summary: Lack of stable regulatory framework stopped the project!!

LULEÅ UNIVERSITY OF TECHNOLOGY

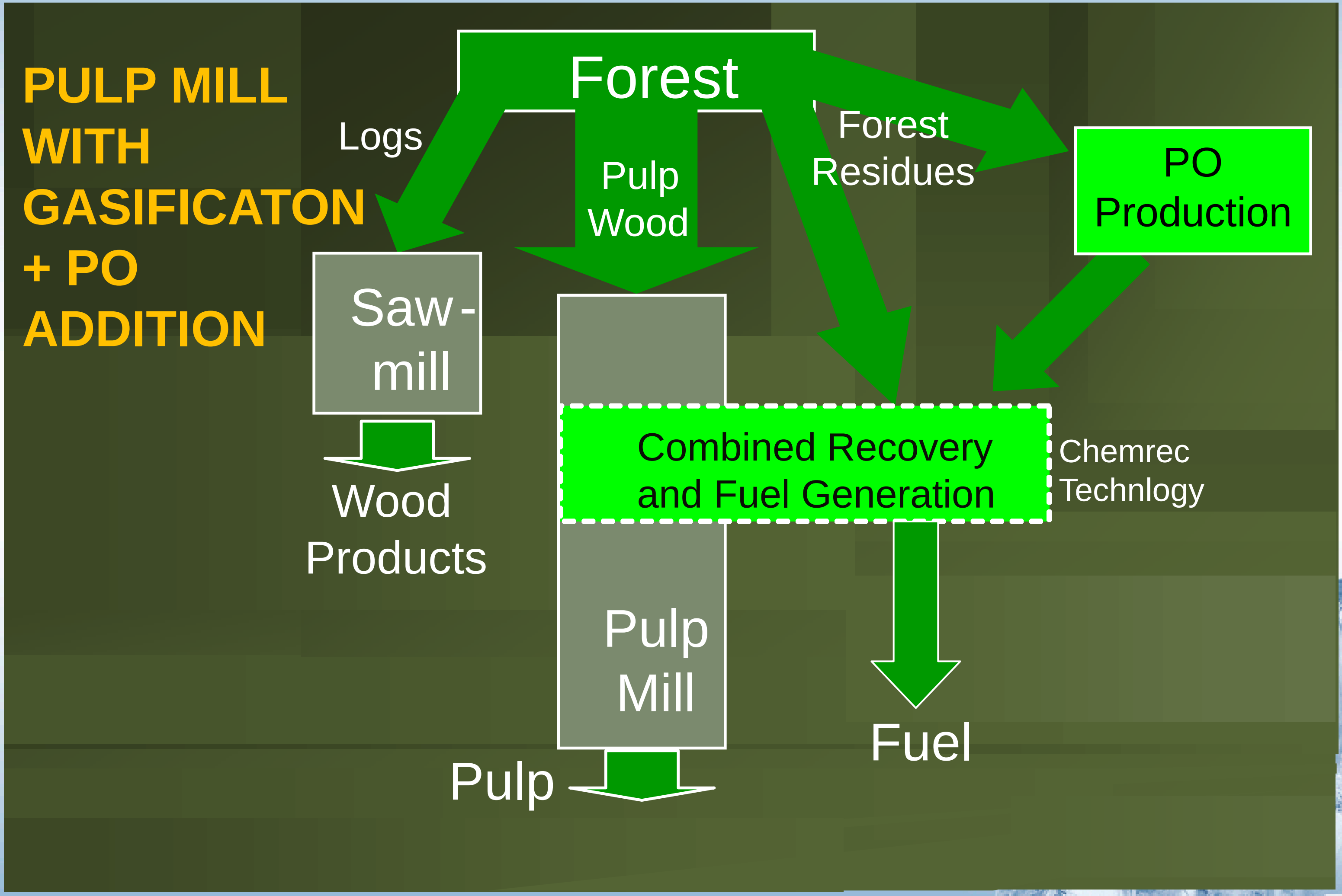
Lawmakers did not understand that political decisions ultimately and irrevocably determine the fate of Biofuel production projects.



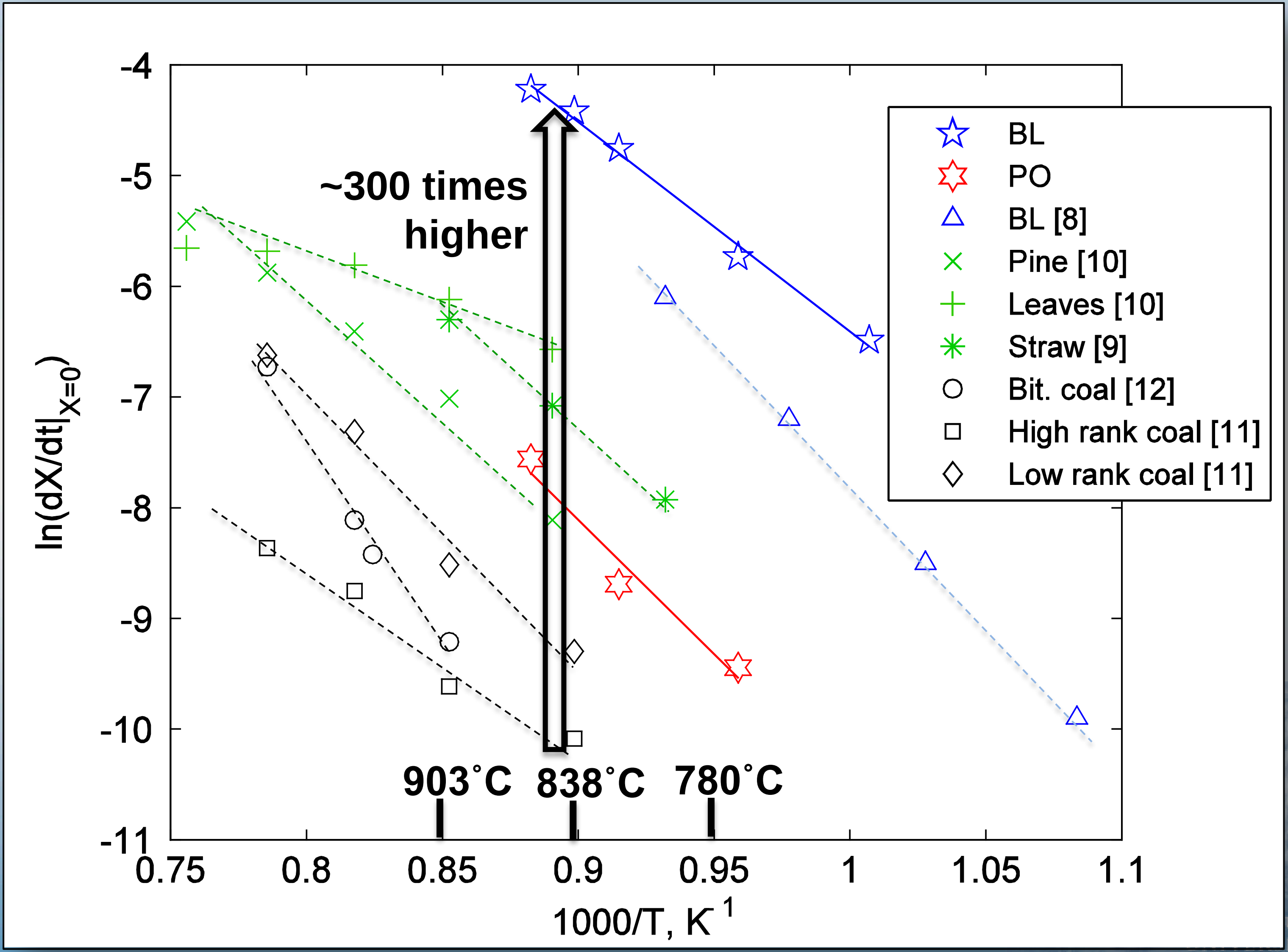
Note: 1st plant NPV (MSEK)

Investment ~ 350 MEUR

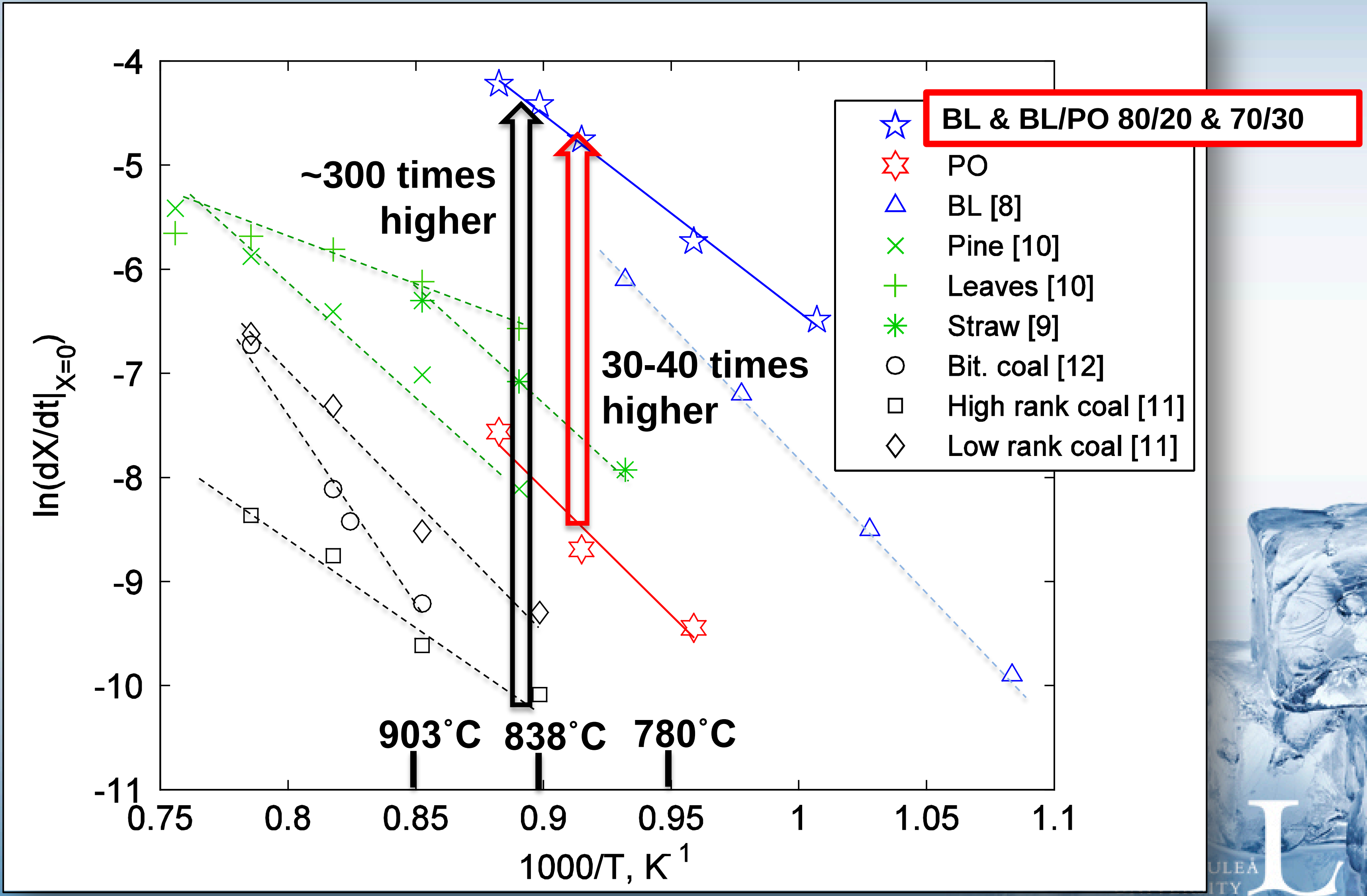
Biomass flow from the forest can be increased adding pyrolysis oil to the black liquor flow



Black liquor char has a very high reactivity compared to chars of other origin



When BL and PO are mixed the char from the mix gets the reactivity of BL



With about 25% of PO in the BL/PO mix syngas production is doubled

Capacity can be increased up to 100% by adding about 25% PO to the BL (by weight)

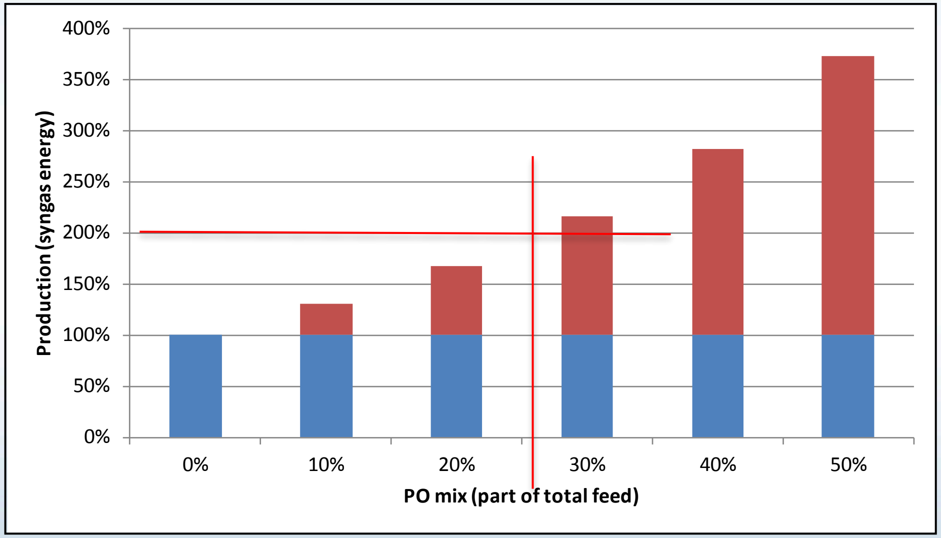


Figure shows simulated increased production of final liquid biofuel product at fixed BL feed (i.e. for specific mill)

Energy efficiency for gasification of added PO is 80-85%

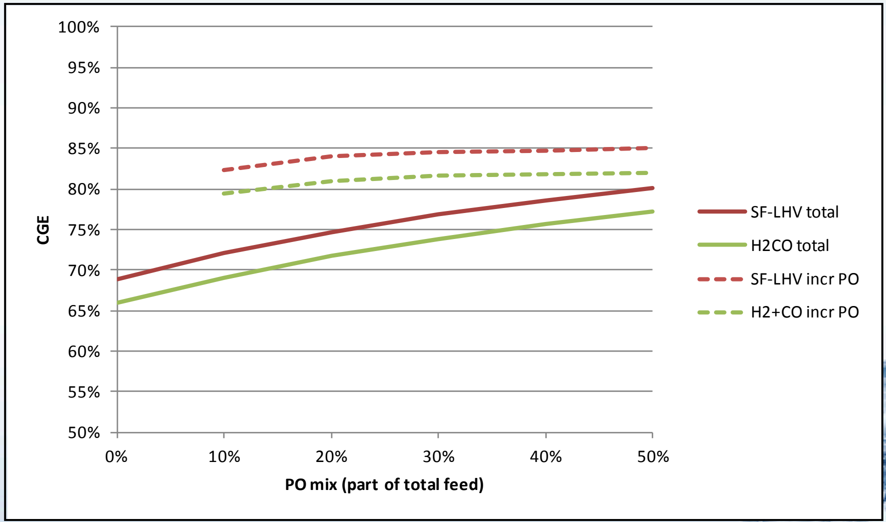
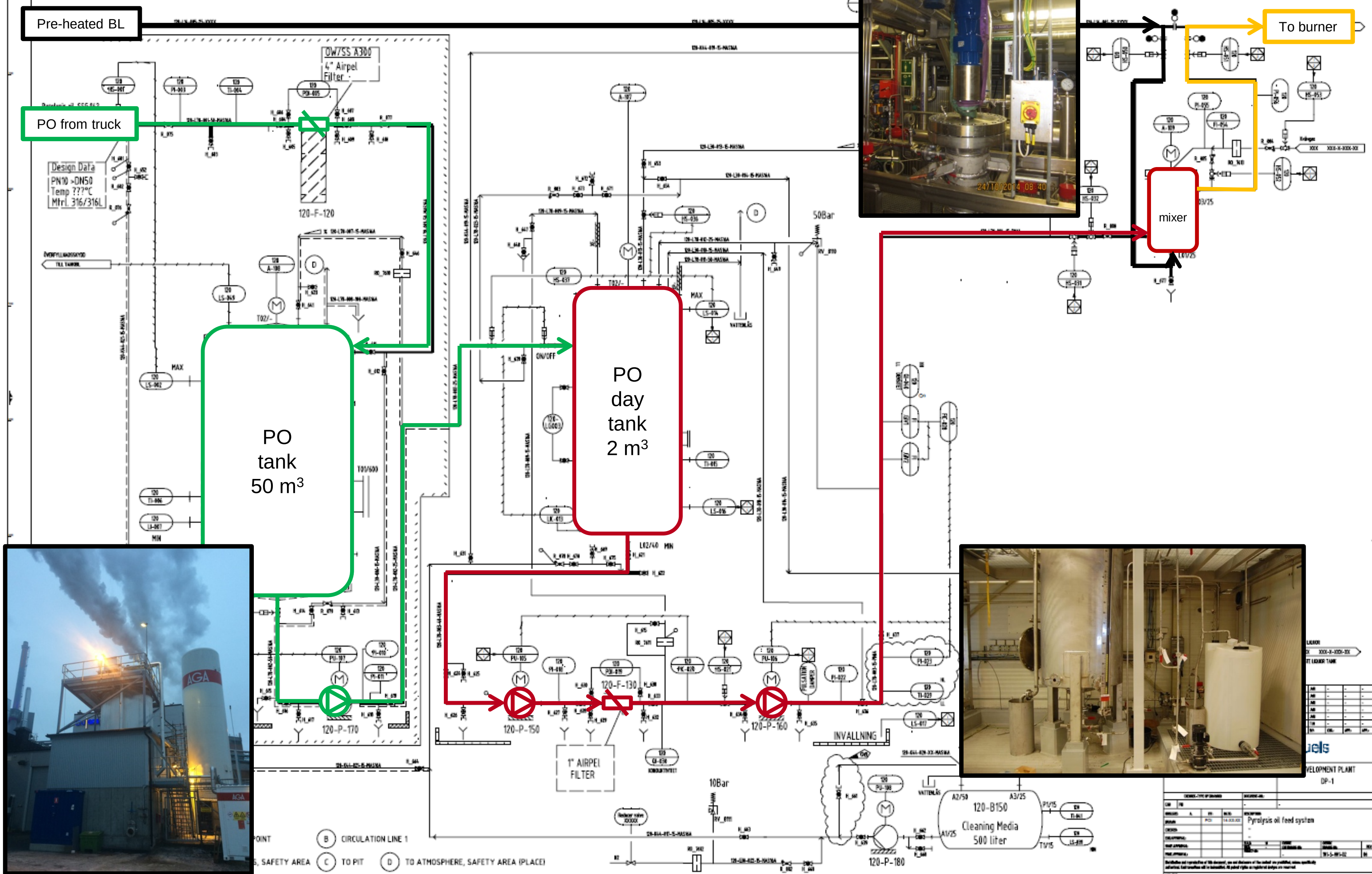


Figure shows simulated gasifier energy efficiency of total mixed feed (solid) and for added PO (dashed)

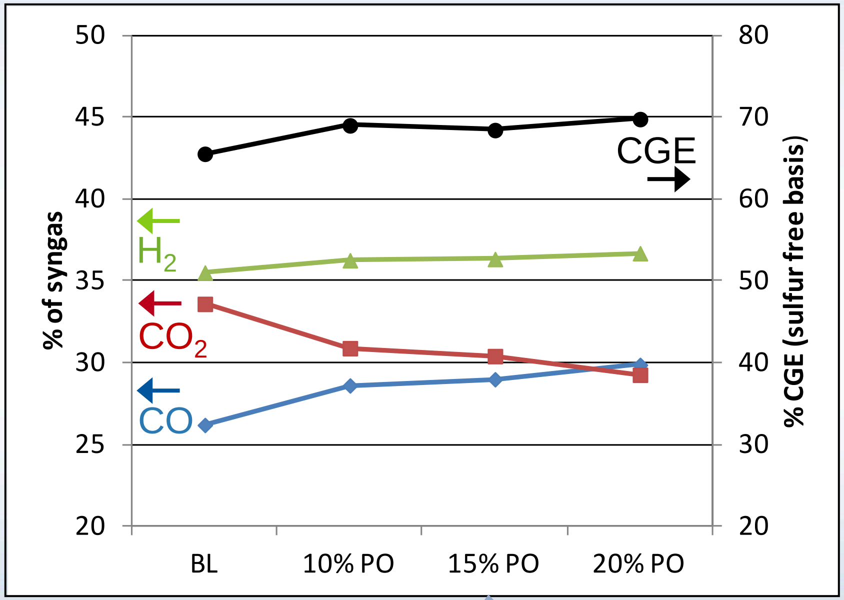
LULEÅ UNIVERSITY OF TECHNOLOGY

Pilot plant modifications



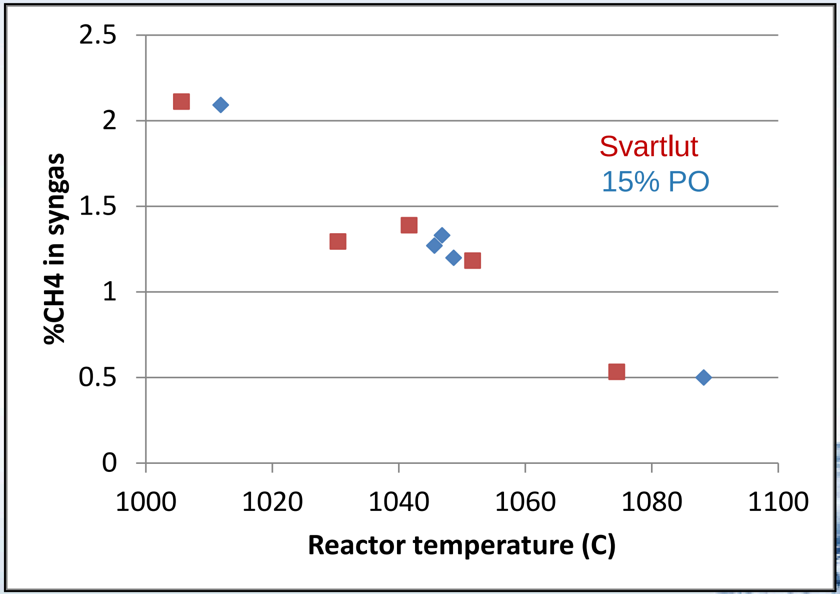
Pilot plant performance

Efficiency increases



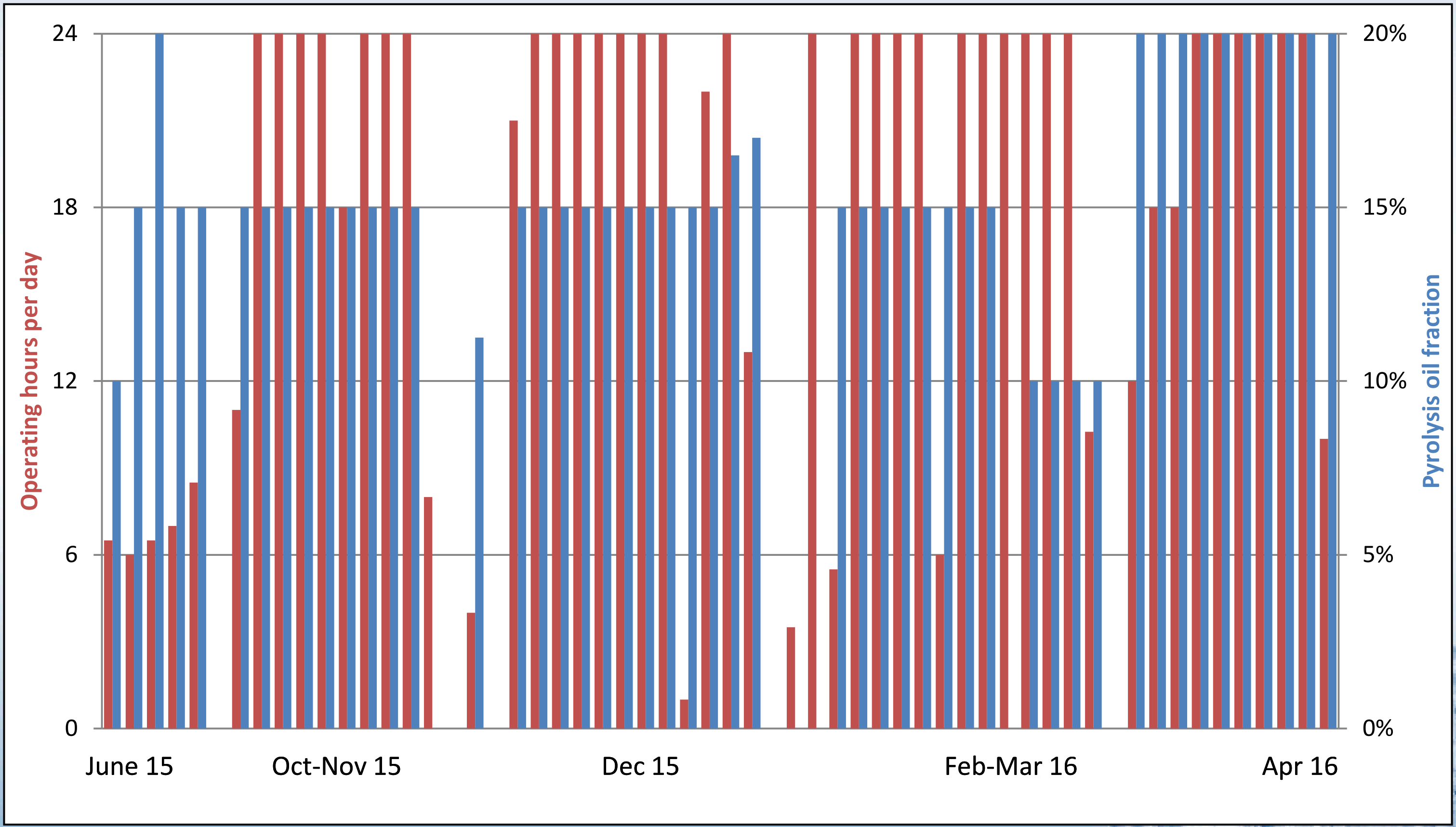
1.3% CH_4
1.5% N_2
1.4% H_2S
114 ppm C_6H_6
11 ppm C_2-C_3

Very similar temperature

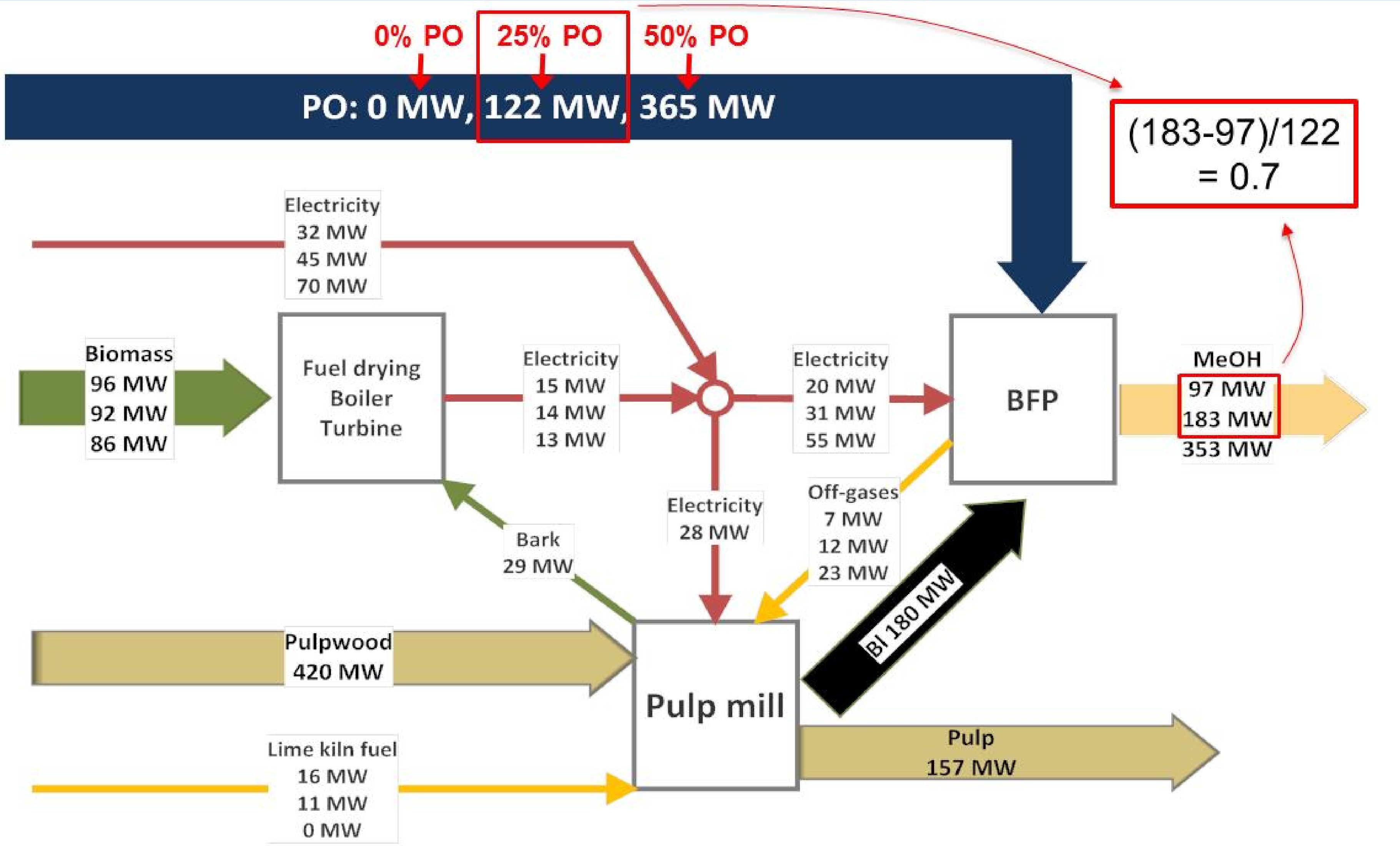


Pilot plant demonstration

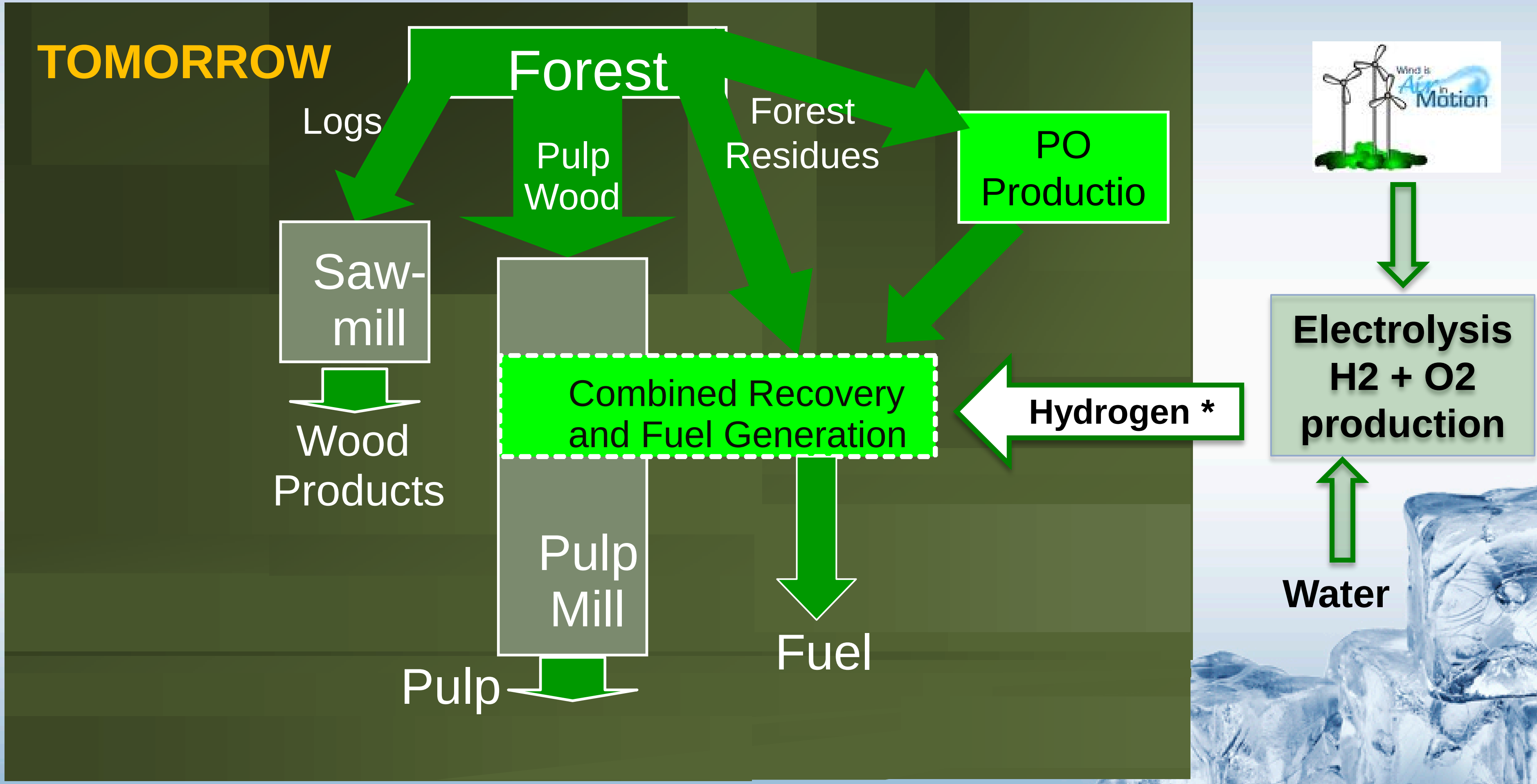
Total: ~1100 h (900 h with MeOH/DME), 170 ton PO



Material and energy balances

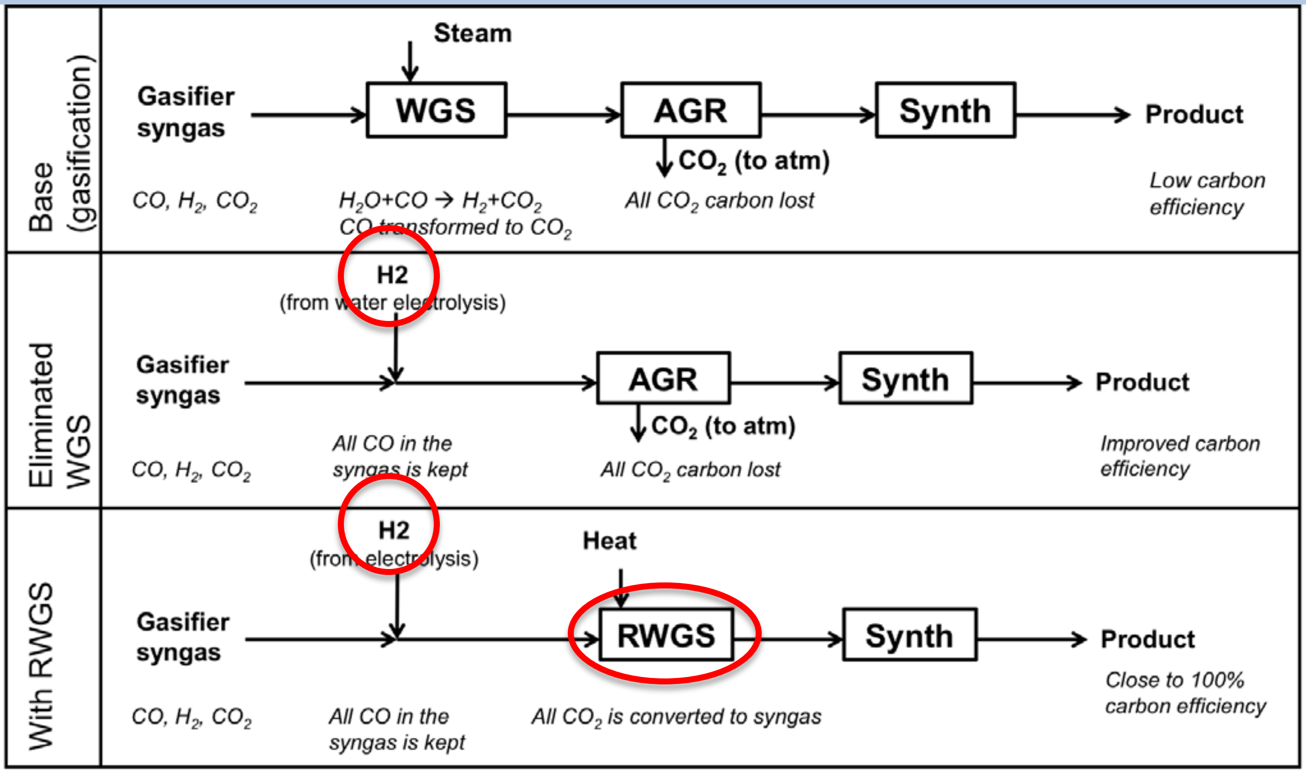


Biomass flow from the forest can be increased adding hydrogen from renewable power
(*true for any type of gasification based process*)



*** Plus Oxygen for gasification**

Power-to-liquids in a biorefinery

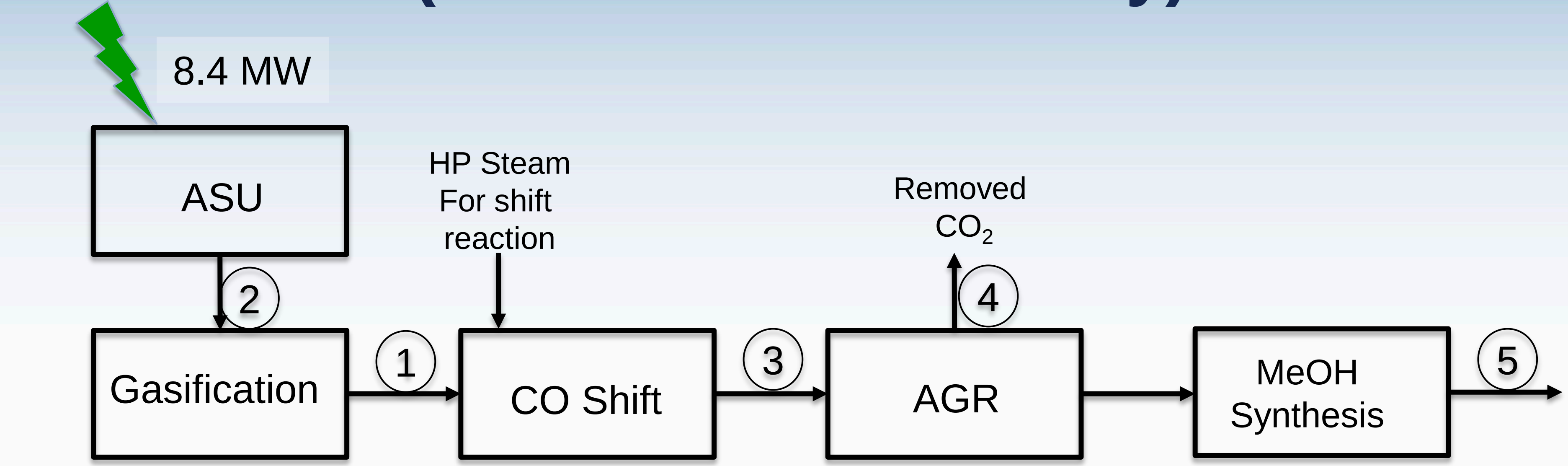


Base case

Hydrogen addition
60% improvement

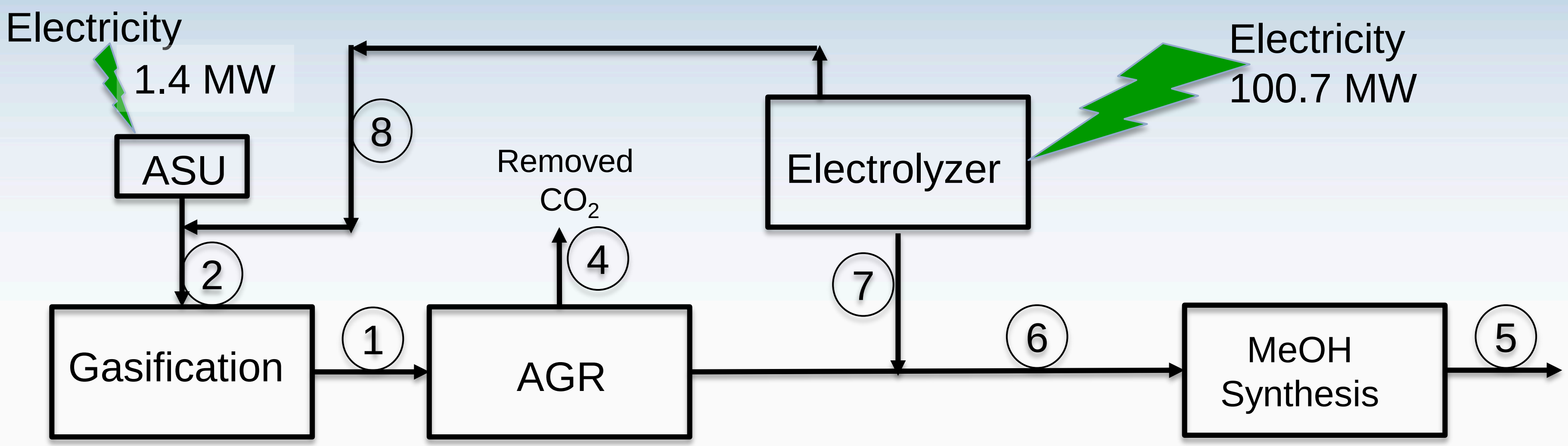
Reverse shift
150% improvement

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

Key conclusions

- **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) / 64,2 = **88%**

Cost of power in the Hydrogen cost

Power price 60 €/MWh

Cost of power in the hydrogen production cost then becomes 60 / 0.685 = **88€ / MWh ***

Power price 45 €/MWh

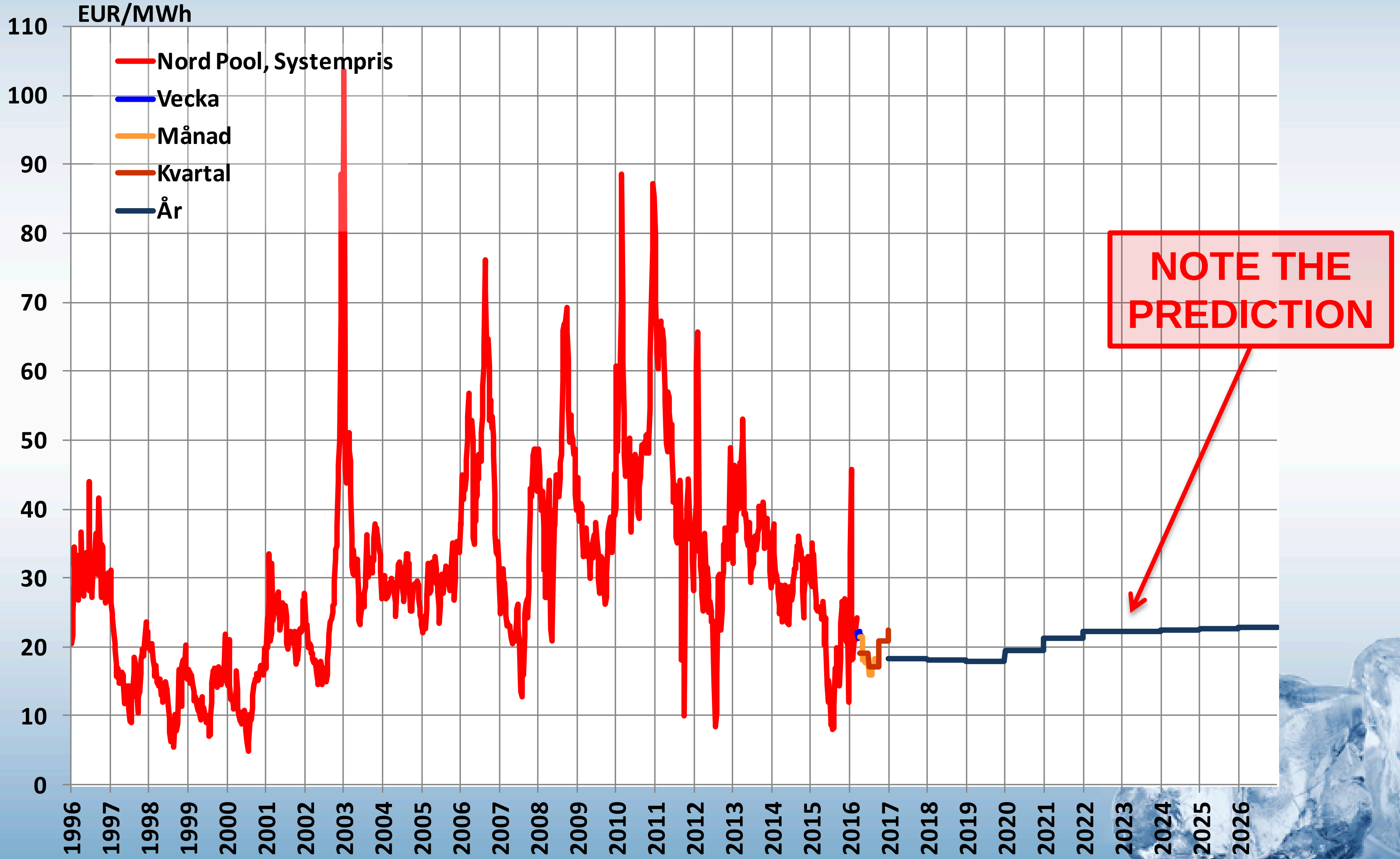
*If average power price is 45€ / MWh the corresponding cost element is **66 €/MWh ****

***** Regarding Oxygen***

Hydrogen costs are credited for the oxygen supplied to gasification

Spot Price Power in Nord Pool

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

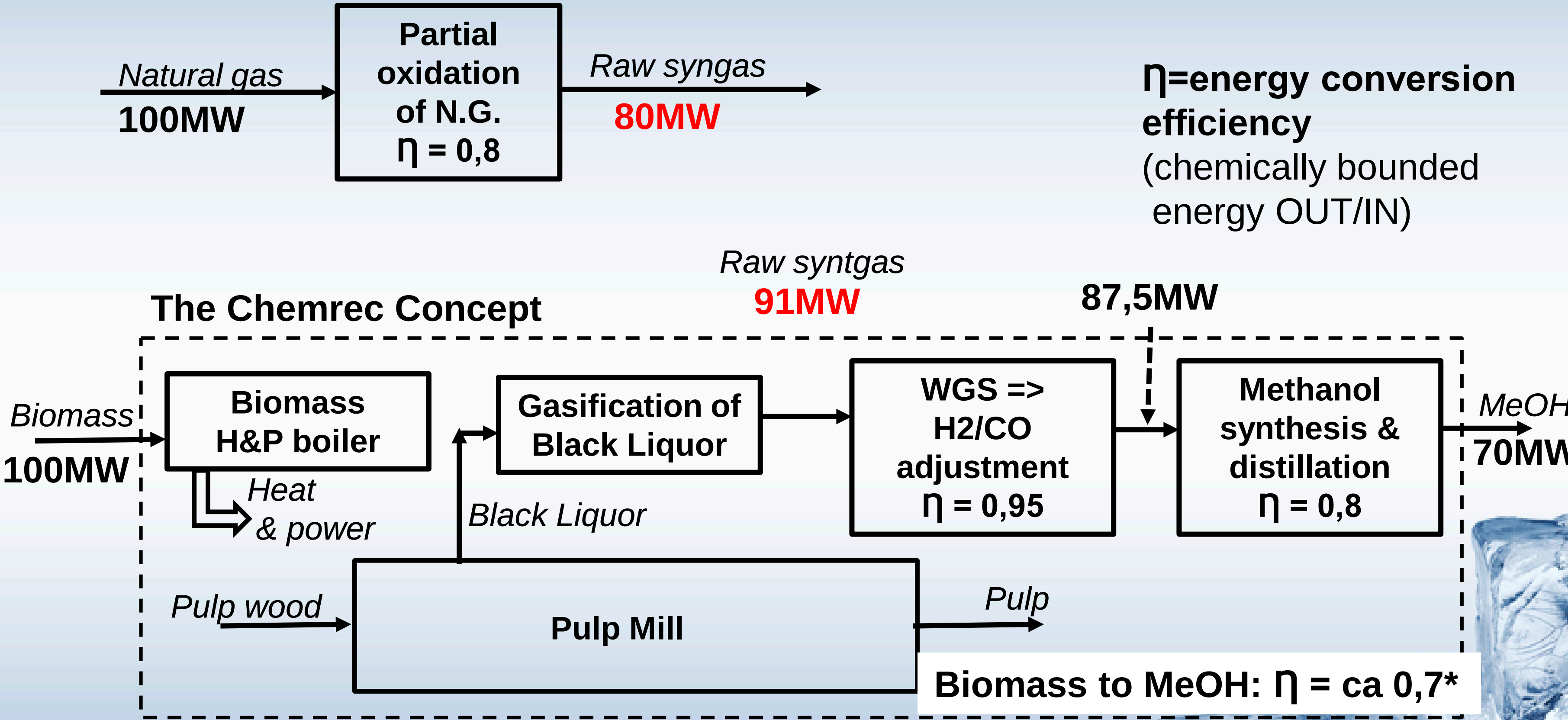


LULEÅ UNIVERSITY OF TECHNOLOGY

Cost of power in the methanol production cost

- 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.**
- If Power price average is 25€ / MWh then the cost of power in the methanol production cost is 25 / 0.685 / 0.8 = **46 € / MWh.**

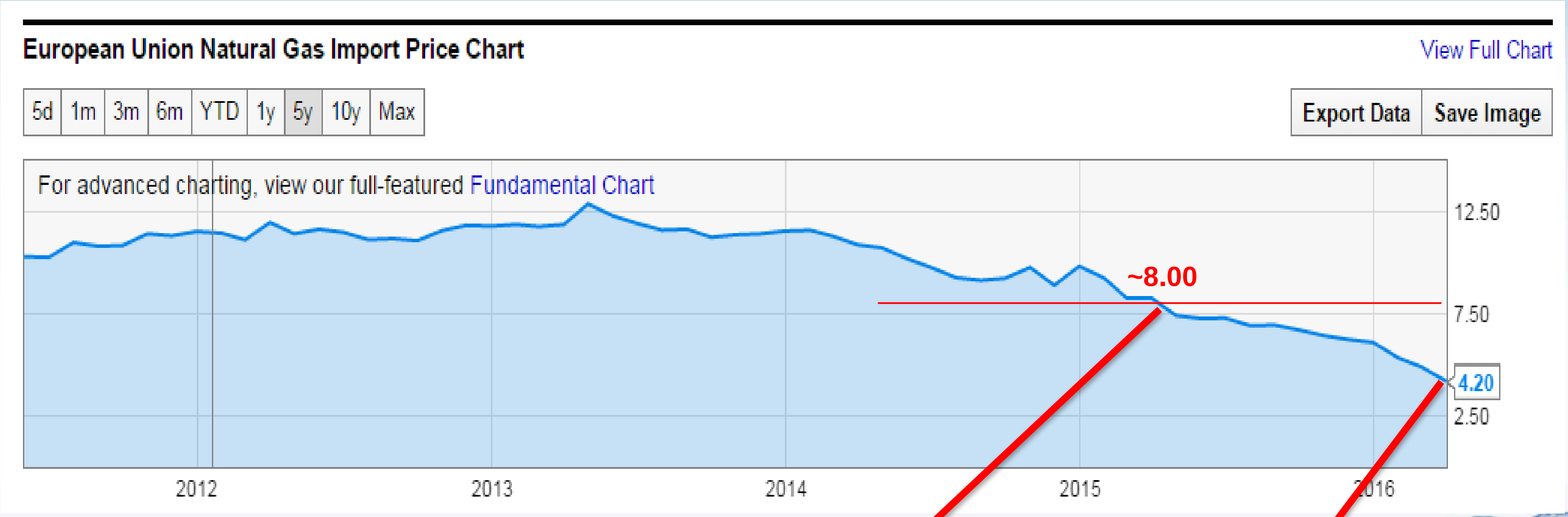
Raw syngas from natural gas and biomass respectively utilizing black liquor in pulp mills (energy balances)



- 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

European Union Natural Gas Import Price

(USD/MMBtu)



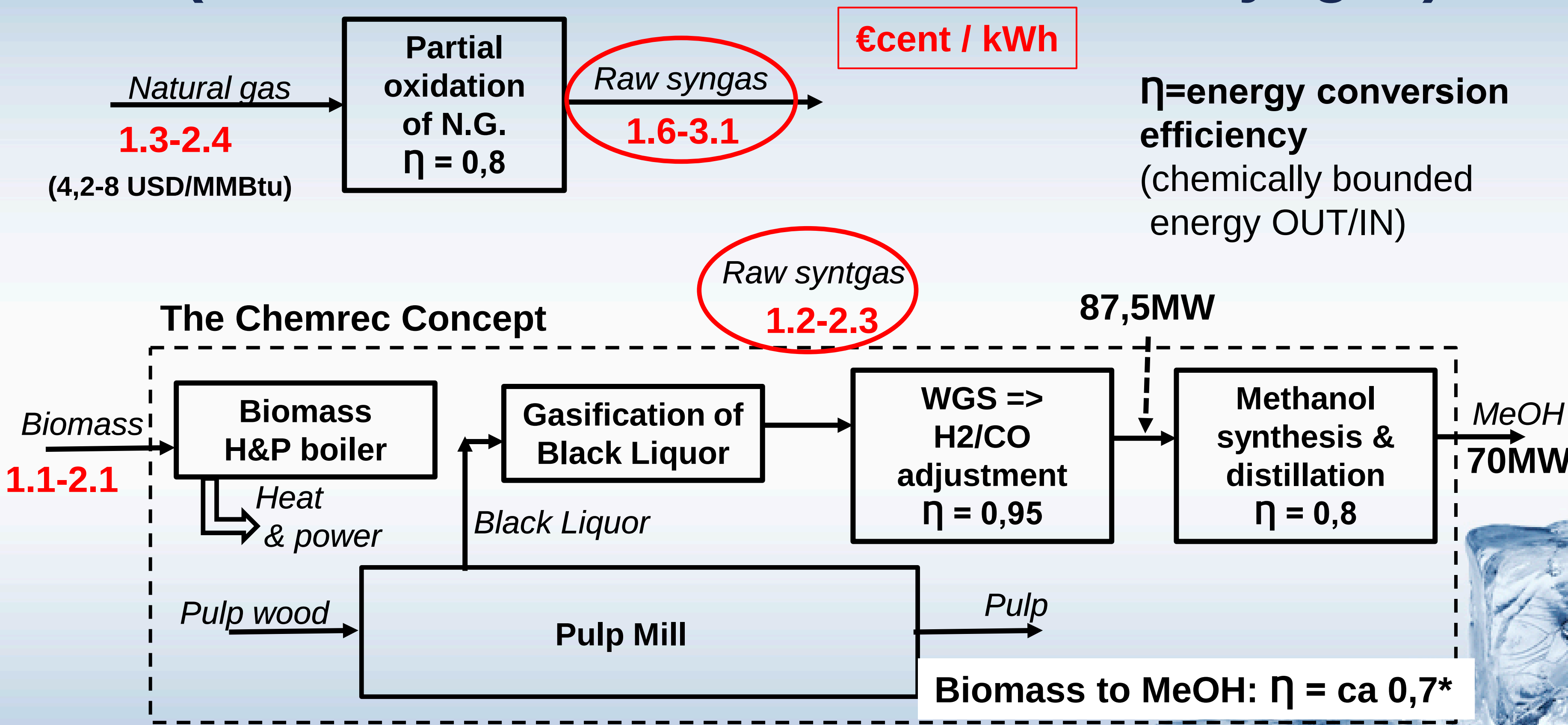
1 MWh = 3,4095 MMBTU
EUR/USD = 1.12

2.4 €cent/kWh

1.3 €cent/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

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

	TWh/y	Toe/y	% of EU estimate* of transport fuel in 2030 (350 Mtoe)	Biomass required TWH/y
BL in Europe	140	--	--	---
MeOH fr BL in Europe	77	6,7	1.9	110
PL part 25% in BL + PL: Production x 2	155	13,4	3.8	240
PL part 50% in BL+PL: Production x 3	230	20	5.7	365
Add H2 instead of WGS shift process	370	32	9.1	365
Add H2 and use reversed WGS	580	50	14.3	365

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

The best way to make renewable fuels happen would be to ….

(from Keynote EU BC&E conf. 2013 in Copenhagen)

1. Accept that renewable fuels cannot be introduced without a long term incentive (> 10 years)

2. Agree on support level on an energy basis e.g.

- Advanced Biofuels will be priced double cost of fossil (a minimum fossil price level needed) for the first demonstration like 100 €/MWh when fossil price is 50 €/MWh

With these two requirements in place

- there will be plants built.

- The risks associated with new technologies will be carried by the investors.

- Technology barriers will be resolved / removed!

If nothing happens:

(from Keynote EU BC&E conf. 2013 in Copenhagen)

If the above does not materialize the risk is big that developers and their financers leave the green fuels business for an indefinite time period. This has major consequences like

- **Built up knowledge disappears**
- **Key individuals change work focus**
- **IPR portfolios loose value**
- **Time to get up and running again will be long**
- **Etc**

This scenario is a not unlikely and a real threat to continued R&D efforts.

Research partners and sponsors from 2005 until today

ETC

Umeå Universitet

CHEMREC

Luleå University of Technology

Haldor Topsøe – Catalysing your business

Volvo

preem

W2C waste2chemicals

KTH Vetenskap och Konst

Chalmers

Innventia

Total

Delphi

IVAB Infjärdens Värme AB

Swedish Energy Agency

Seventh Framework Programme

Länsstyrelsen Norrbotten

MISTRA

Smurfit Kappa Kraftliner Piteå

Sveaskog

Södra

SCA

THANK YOU!