Carbo-V® Biomass Gasification Technology.

Status after Application of Sound Engineering Practices.

IAE Workshop

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Agenda

1. Project background Carbo-V®
2. Project status Carbo-V®
   a) Identified areas for improvements
   b) Consolidation project - conclusion
   c) Examples
3. Actual status of Carbo-V®
4. Typical plant set up for "First of its Kind"
5. The new robust Carbo-V® process

1. Project Background Carbo-V®
Initial Situation

- Carbo-V technology was operated for short term, could not be put into **stable** operation but the operation of ~ 1200-2000 hrs. has shown the process principle
- 100% of HTG capacity was reached incl. endothermic quench (90%)
- Mechanical design problems led to repeated shut downs

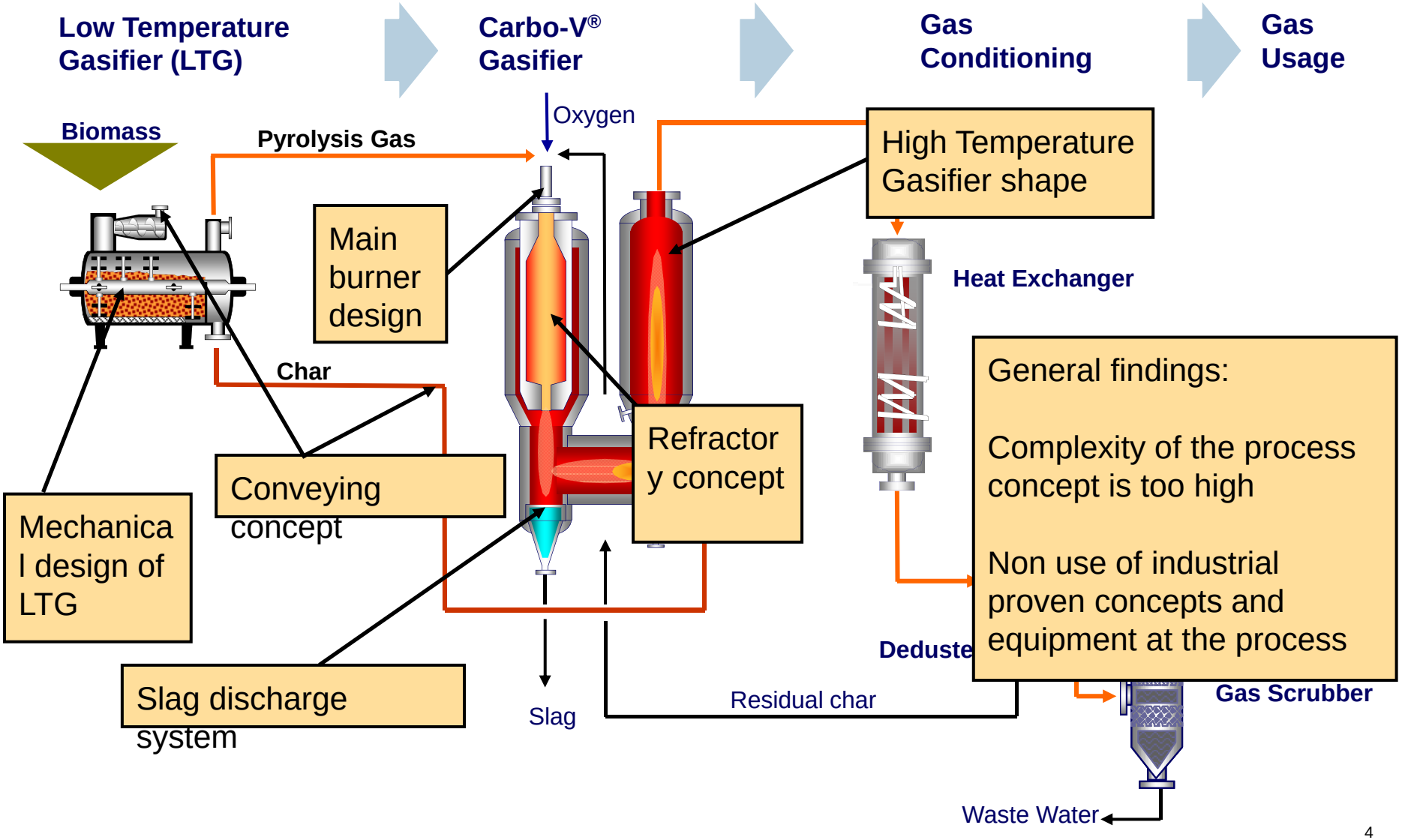
- Choren went into insolvency in July 2011 (Carbo-V® development since the early '90s)

- Linde (LEDD) bought Carbo-V® Technology in Q1 2012 because synergies and add on´s for other Linde technologies identified (ASU, Rectisol, CO2, H2, etc.) including all related know how, operation records, trade marks and patents

- Linde (LEDD) established a consolidation project (successfully completed)

  → **As final step, Linde to demonstrate stable operation of Carbo-V technology and its successful integration in biofuel / biochemical production**

2. Project Status Carbo-V®
Identified Areas for Improvement

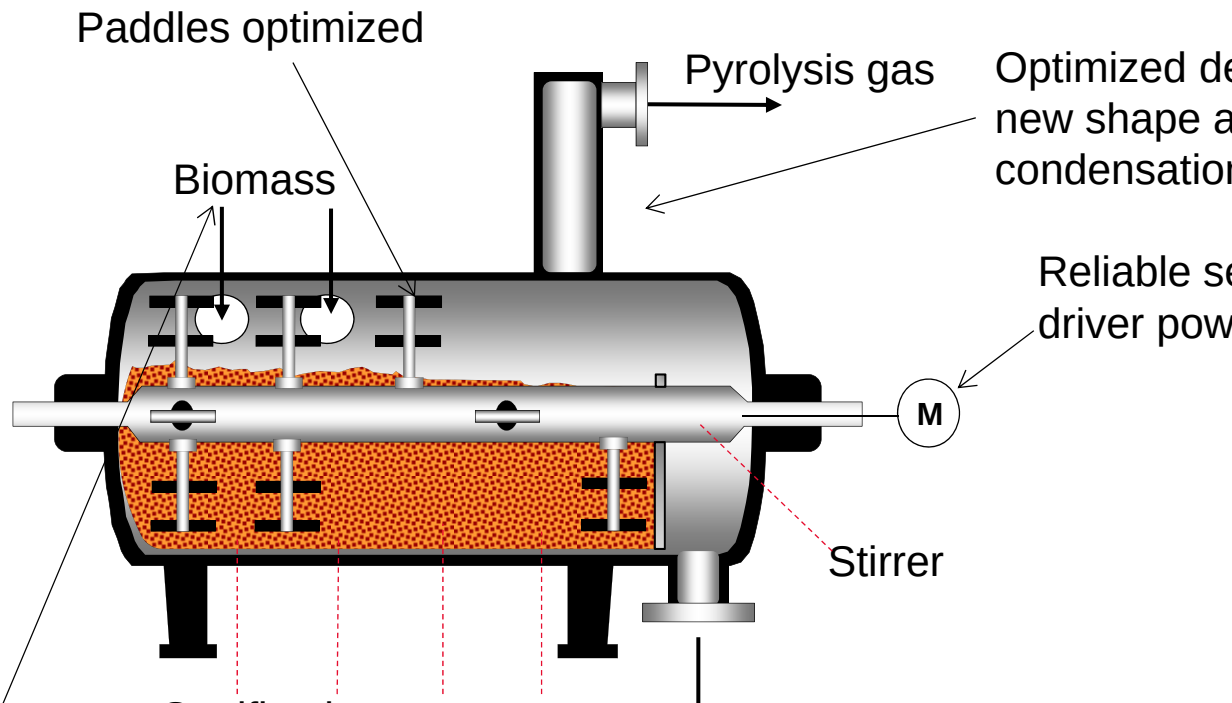


2. Project Status Carbo-V®– Results Consolidation Project – Conclusion

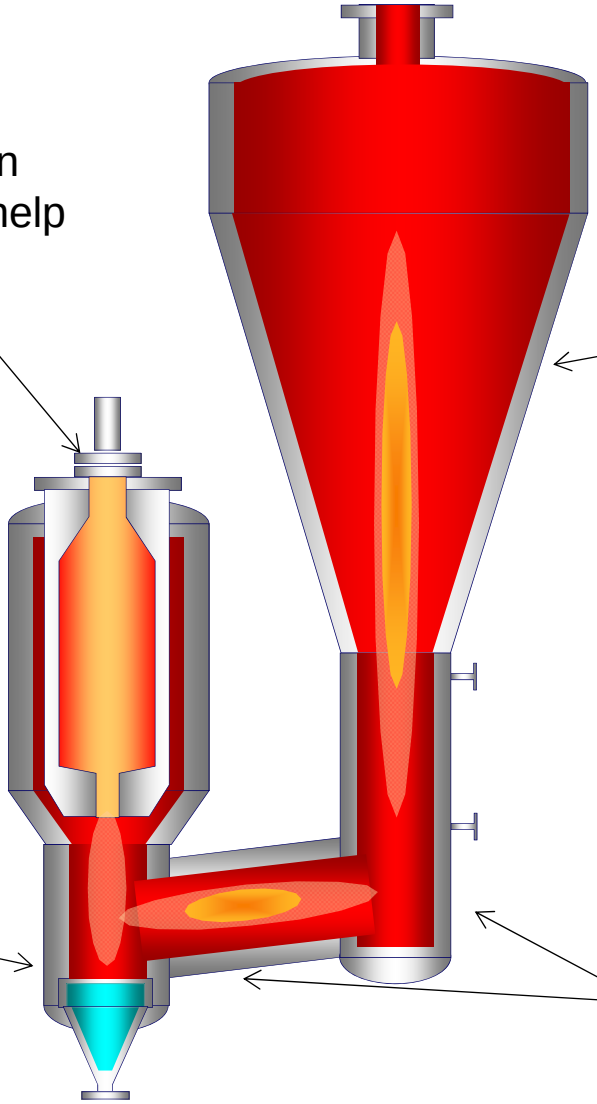
- Carbo-V ® technology is a driver regarding cold gas efficiency, syngas quality and carbon conversion rate compared to other technologies available for woody biomass gasification
- The consolidation confirmed that problems at the demo plant envisaged are not related to the technology and its principles
- The consolidation confirmed that problems at the demo plant envisaged are rather shortcomings in the selection of the right equipment type and consequently engineering professionalism
- Systematic investigations and tests at universities and with vendors provided appropriate explanations for the problems found and sound solutions for the future design
- Kinetic and fluid dynamic modeling and simulations calibrated with operational results from the previous operating period provide a sound basis for the design modifications undertaken

➔ **The Carbo-V® Technology is ready to be built and tested to mitigate the main uncertainty related to missing long term running experience despite challenging process implementation due to its "First of its Kind" character**

2. Project Status Carbo-V® – Results
LTG Design - Modified



2. Project Status Carbo-V® - Results
HTG Design - Modified



Proper burner design developed with the help of Linde experts

Combustion chamber with optimized cooling and refractory concept

New slag discharge system

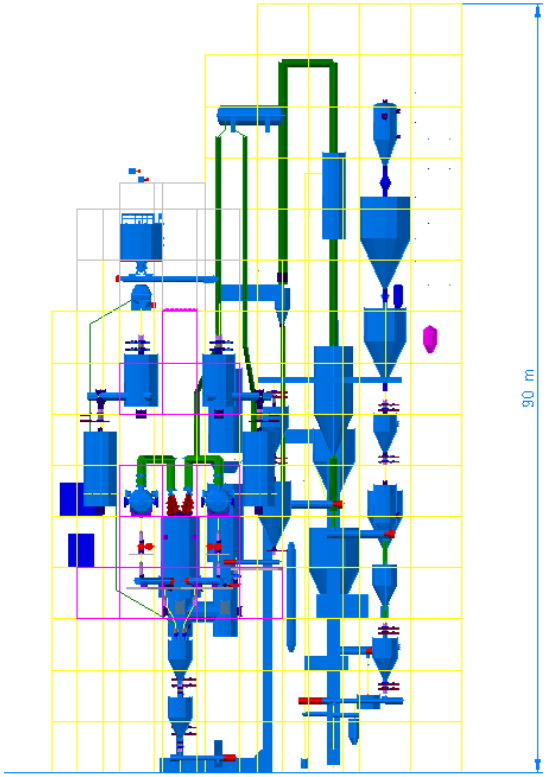
Optimized design of endothermic part for max. coke conversation to push up cold gas efficiency to 73% by lab tests and CFD simulations

Modified design of deflections chambers and transfer pipe

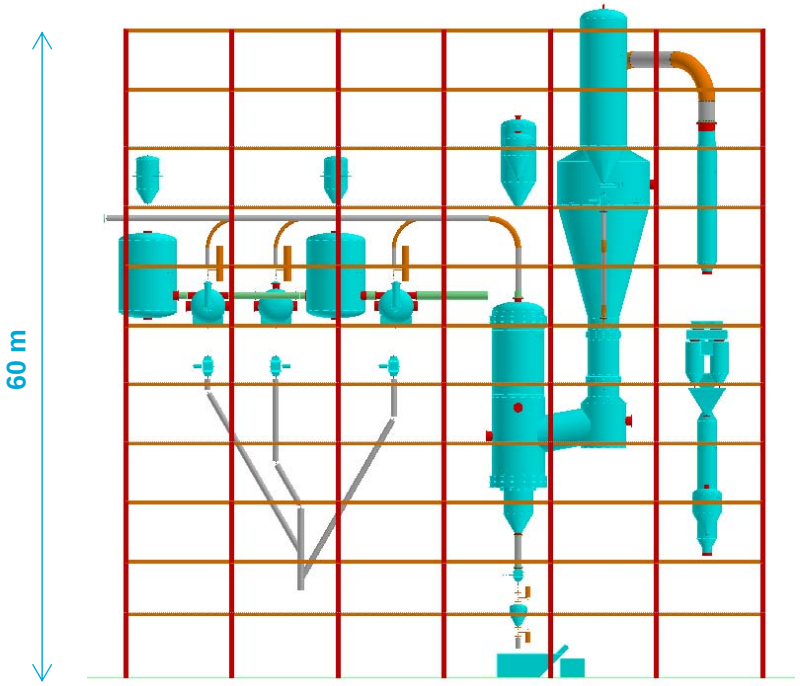
2. Project Status Carbo-V® - Results
Equipment Quantity and Layout

No. of equipment reduced by more than 40%

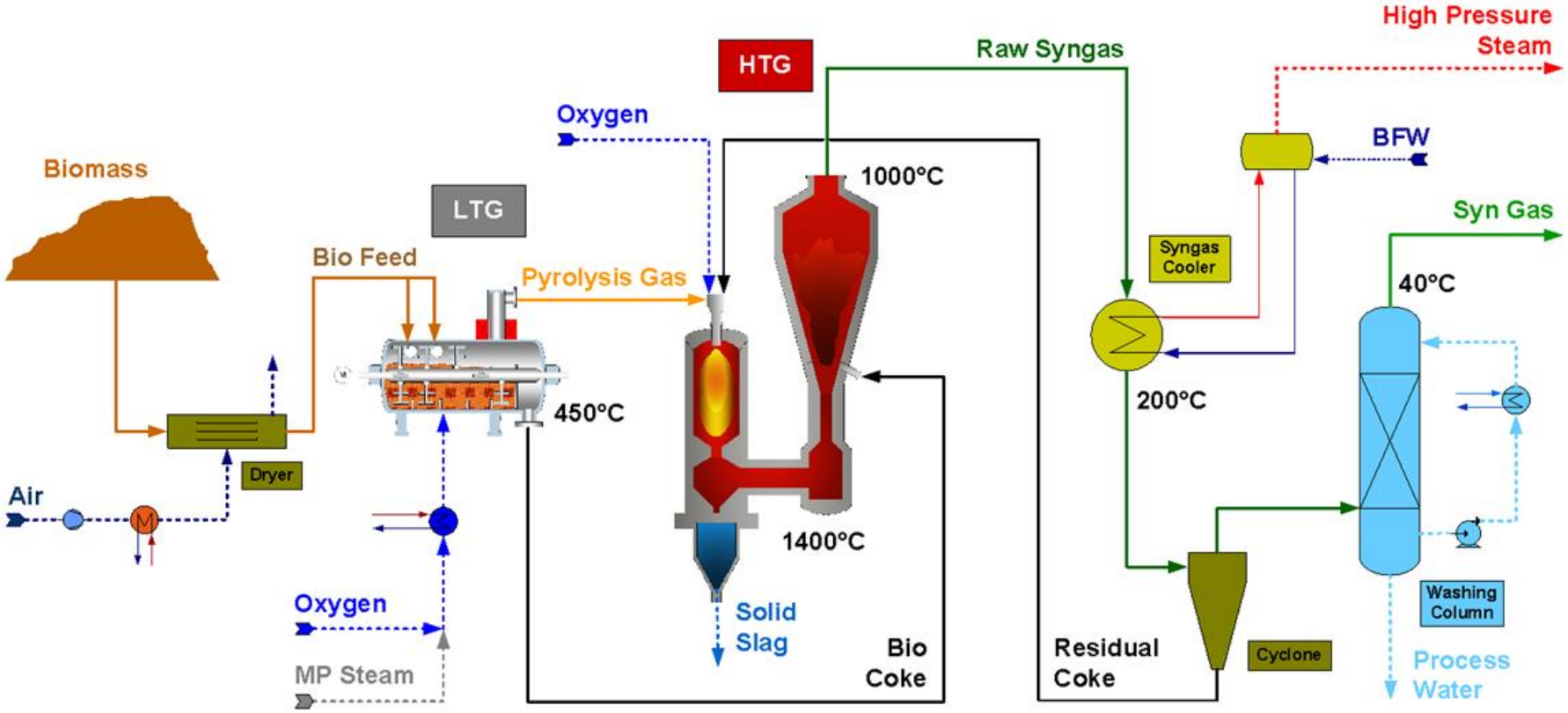
Previous Choren plant layout



New plant layout
→ reduction of plant height by 30m



3. Actual Status of Carbo-V®
The Carbo-V® Process



Three-stage process

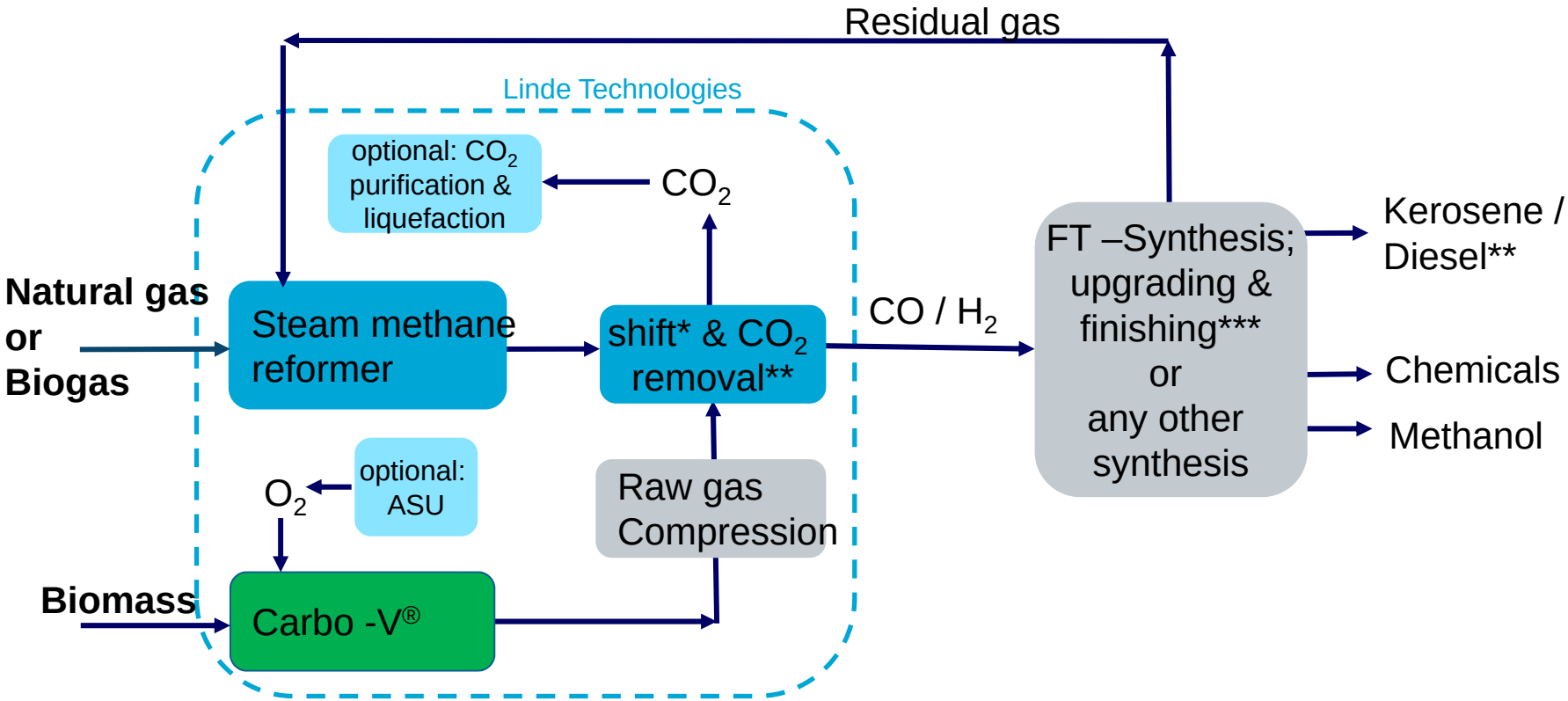
- 1st stage: Low temperature gasification (LTG)
- 2nd stage: High temperature gasification (HTG)
- 3rd stage: Endothermic Fluidized bed Gasification

3. Actual Status of Carbo-V®
Technology Features - Highlights

- Cold gas efficiency more than 73%
- Tar-free and methane-lean raw syngas → unique feature of Carbo-V technology
- Highest possible carbon conversion rate (> 99.5 % by mass)
- No biomass pretreatment necessary (except drying and chipping)
- Plants with high installed capacity possible (scale up)

Syngas	Vol. %
CO	38…41
CO_2	24…27
H_2	31…33
CH_4	0.1…0.2
N_2	1…2
H_2S/COS	0.01

4. Typical Plant set up for "First of its Kind" GtL/BtL Process SMR Boosted



* shift reaction only in case it is required to adjust the H2/CO ratio
** CO2 removal only in case CO2 is not of use in downstream process
*** product split depends on FT technology, to be up dated / confirmed by FT Licensor

5. Carbo-V® Improvement Summary

Technology improvement by Linde (compared to bought technology status)

- Simplification and optimization of process
- Reduction of number of equipment items by 1/3
- Less mechanical feeding devices
- New main burner
- Self-flowing slag additive and new slag discharge system
- Improved robustness and availability by
  - Usage of standard equipment as far as possible
  - Shifting of critical equipment from main process stream to side streams
  - Considerable reduction of mechanical feeding and sluicing devises
  - Reasonable buffer volumes
  - Reasonable redundancies / easy replacement concepts at critical parts
- Optimization of layout, reductions of plant heights by 30m
- Safety compliant instrumentation concept

Thank you for your attention.