Talk 3

Bio-based Gases, Scale-up and Utilization in Chemical Manufacturing

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Linde Engineering Dresden
Integral Part of The Linde Group

The Linde Group

Sales: 12.9 Billion EUR (2010)
Employees: > 50 000

Gases Division

Leading supplier of industrial gases

Engineering Division

Engineering & contracting specialist

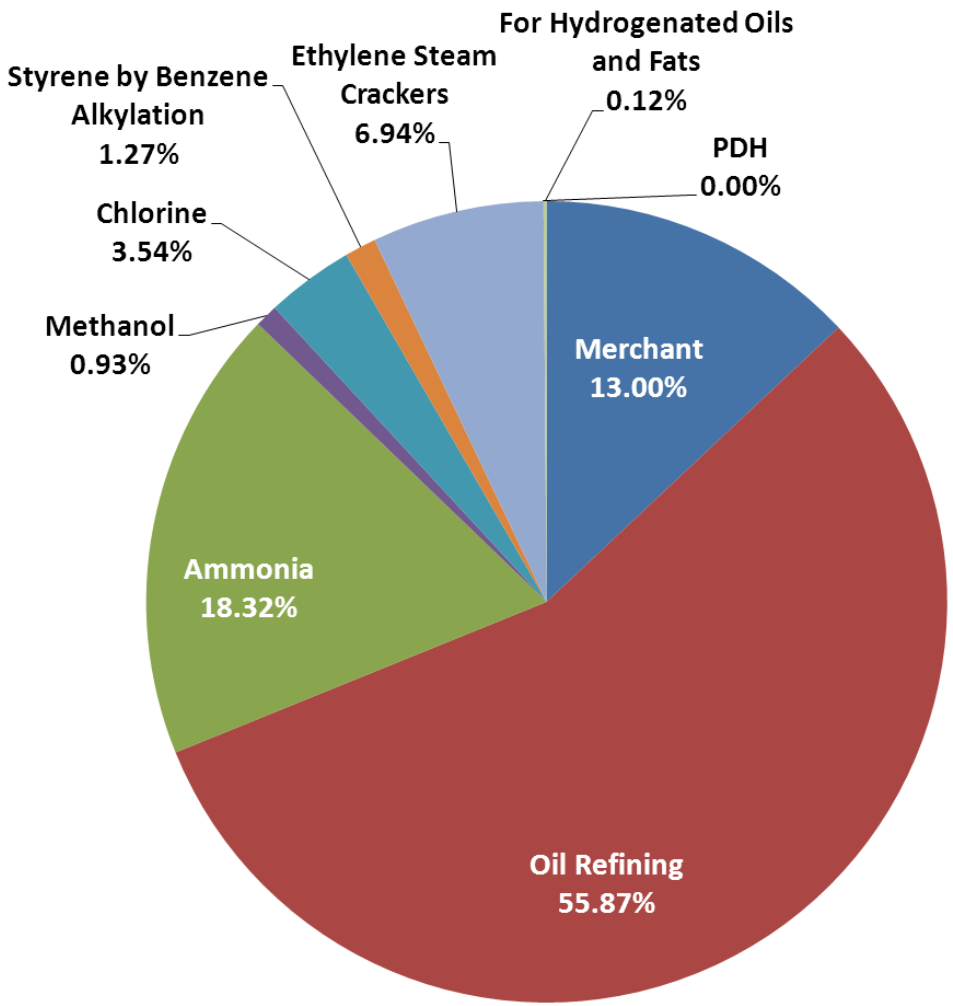
Linde Engineering Dresden

- **Chemical, polymer, and gas plants**
- **Biotech & pharma plants**

Other Activities

Gist logistics solutions
Cleaning Enterprises

Example Hydrogen

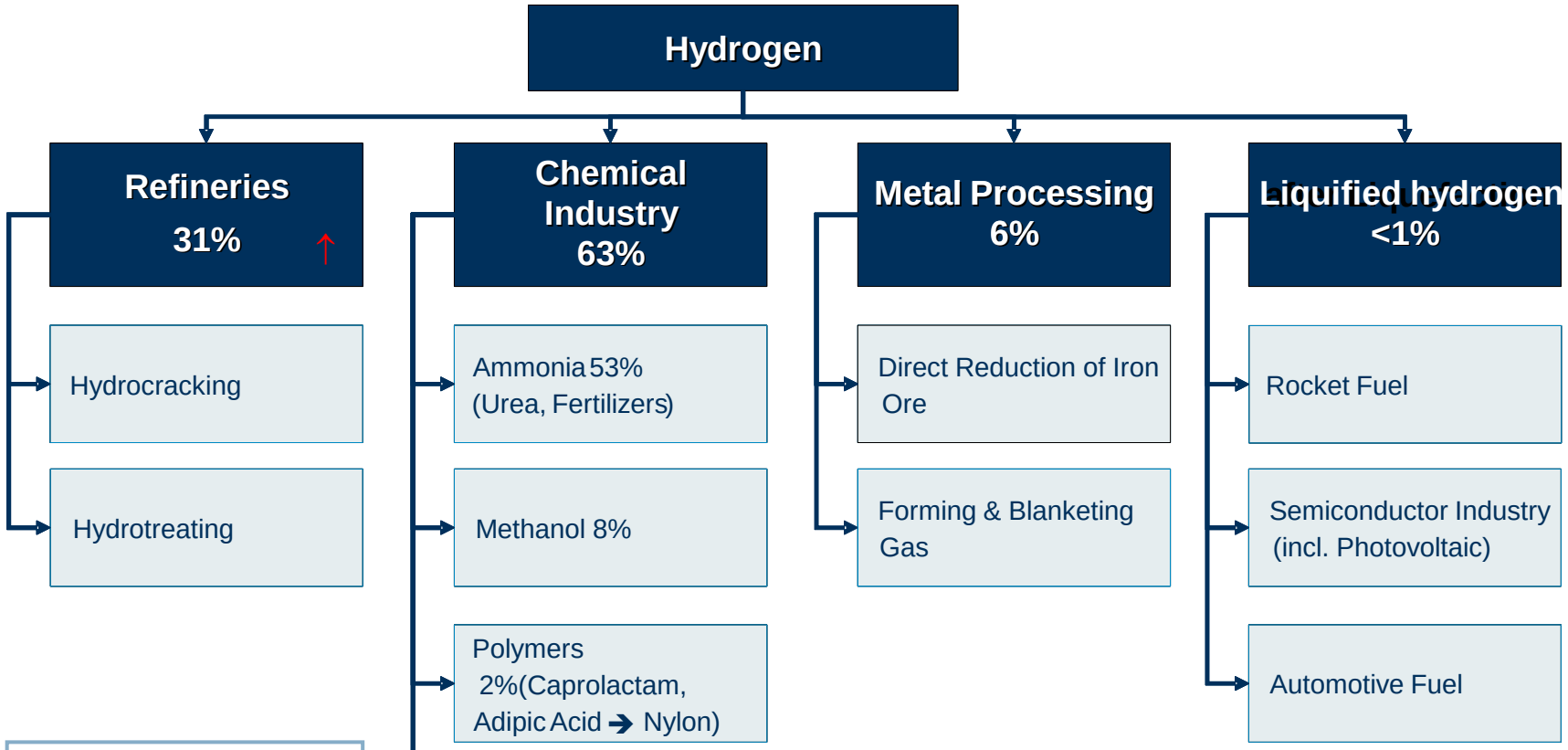


Source: NEXANT, 2010

2010 US Hydrogen Production

8.39 Mil. tons

Existing Hydrogen Markets and Applications



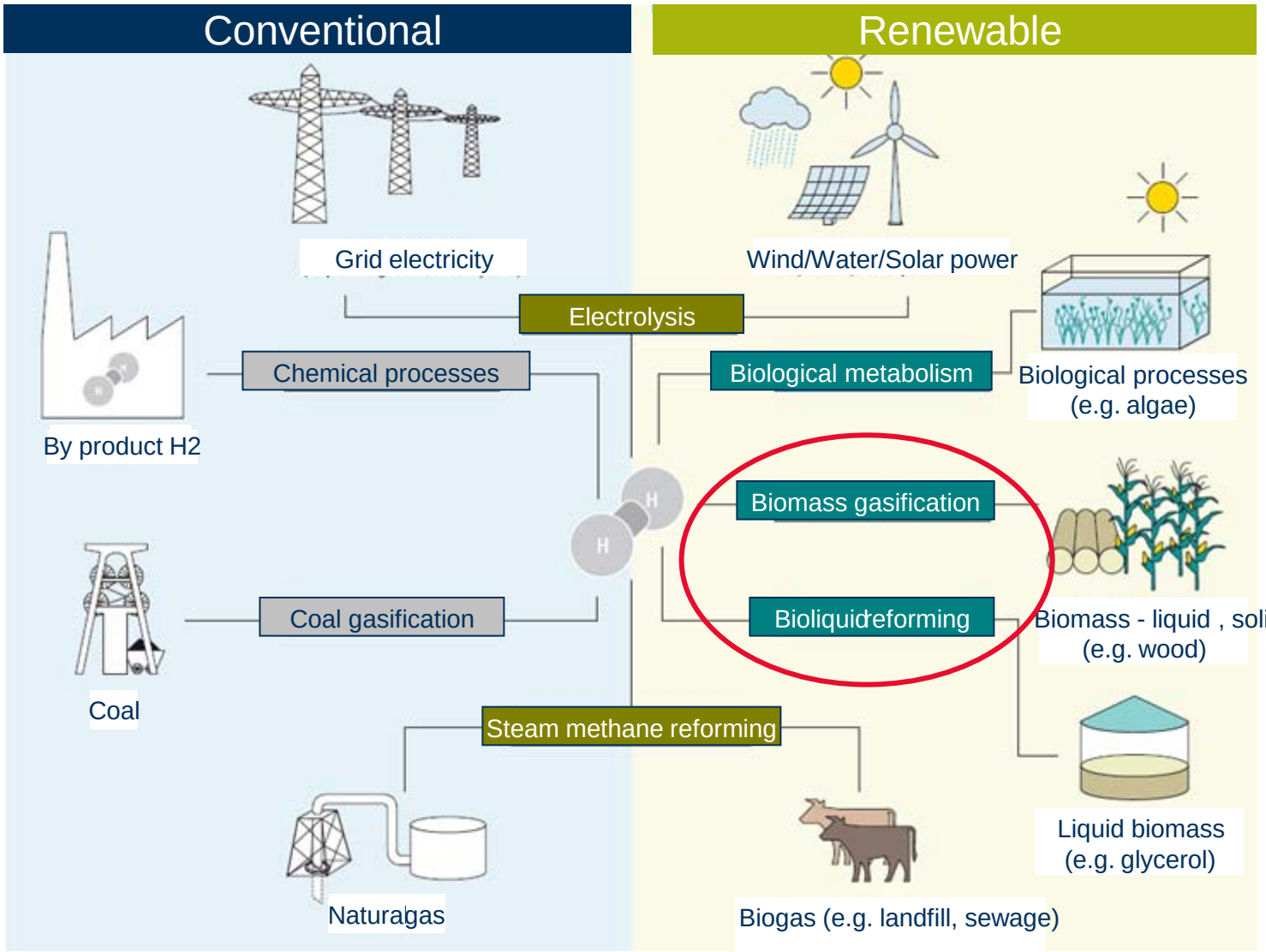
Other (<1.000 Nm^3/h): glass production, food (hydrogenation of fats), cooling of electric generators

2010 US Production: 8.39 Mil. tons

Approx. 500 bil. Nm^3/yr worldwide:
~ 1.500 TWh/yr or ~ 300 Mio. fuel cell vehicles

Source: DOE, Fair-PR

Hydrogen Production Pathways



Pathways to "Green" Hydrogen from Biogenic Feedstock

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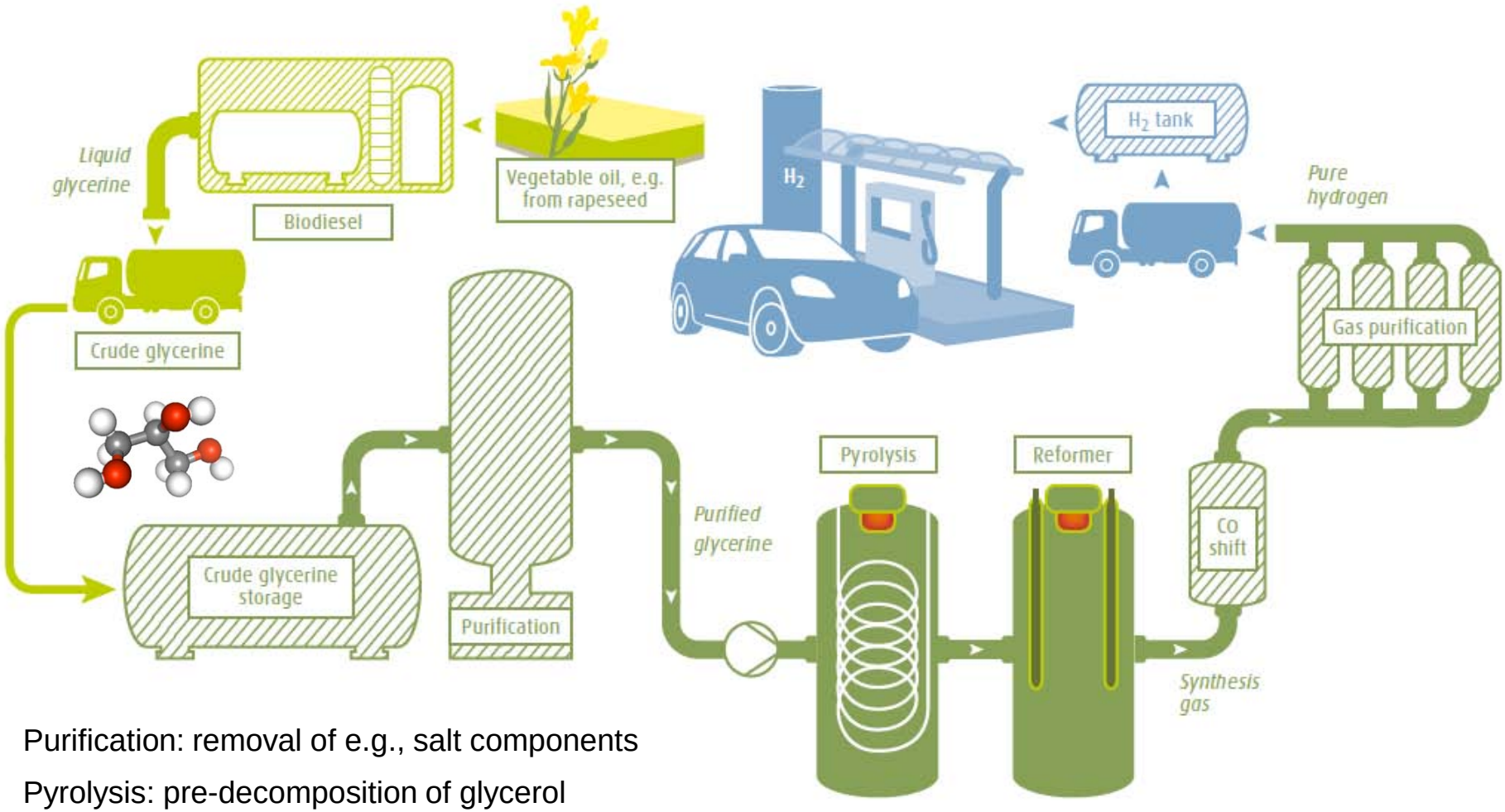
Biomass conversion approaches

1. Pyro-reforming of liquid biomass, e.g., glycerol
2. Gasification of solid biomass, e.g., wood residues

Goals

- Cost competitiveness compared to conventional SMR
- Utilization of biomass that is not used for food or feed
- Versatile technology for decentralized use

1. "Green" Hydrogen from Glycerol Pyro-reforming



Purification: removal of e.g., salt components

Pyrolysis: pre-decomposition of glycerol

Reformer: conversion of pyrolysis gas into synthesis gas, i.e. hydrogen

CO shift: maximizing hydrogen yield

Glycerol Pyro-reforming – Pilot Plant, Leuna

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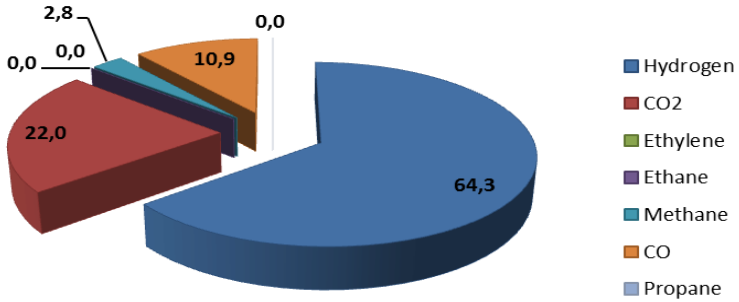
- Approx. 140 kg H_2/t (1,6 Nm/kg) Glycerol
- 50 Nm^3/hr H_2
- Sustainable CO_2-footprint
- Cost-competitive Linde technology
- Range of liquid biogenic feedstocks
- Scale-up under way



Pyroreforming Unit

Glycerine Purification Unit

Glycerol Pyro-reforming – Sustainability

ZERTIFIKAT ◆ CERTIFICATE ◆ 認証証書 ◆ СЕРТИФИКАТ ◆ CERTIFICADO ◆ CERTIFICAT

TÜV SÜD Industrie Service

ZERTIFIKAT

Die Zertifizierstelle „klima und energie“
der TÜV SÜD Industrie Service GmbH
bescheinigt, dass das Unternehmen

Linde Gas

Linde Gas Produktions-
gesellschaft mbH & Co. KG
Seitner Str. 70
82049 Pullach

für den Geltungsbereich

Erzeugung von grünem Wasserstoff (GreenHydrogen)
die Voraussetzungen erfüllt, entsprechend dem

TÜV SÜD Standard CMS 70: Erzeugung von grünem Wasserstoff (12/2011)
Wasserstoff aus Glyzerin als Nebenprodukt der Biodieselproduktion zu erzeugen, der ein Treibhausgas-Minderungspotenzial von mindestens

- 35 % gegenüber dem Vergleichswert für fossile Kraftstoffe aus der Biokraft-NachV, sowie von mindestens
- 50 % gegenüber konventionell hergestellem Wasserstoff besitzt.

Durch ein Audit, Bericht-Nr. **1 458 887**
wurde der Nachweis erbracht, dass diese Anforderungen erfüllt sind.
Das Zertifikat ist nach Ausstellungsdatum drei Jahre gültig.

Zertifikats-Nr.: **70.0004.12**

München, 25.01.2012

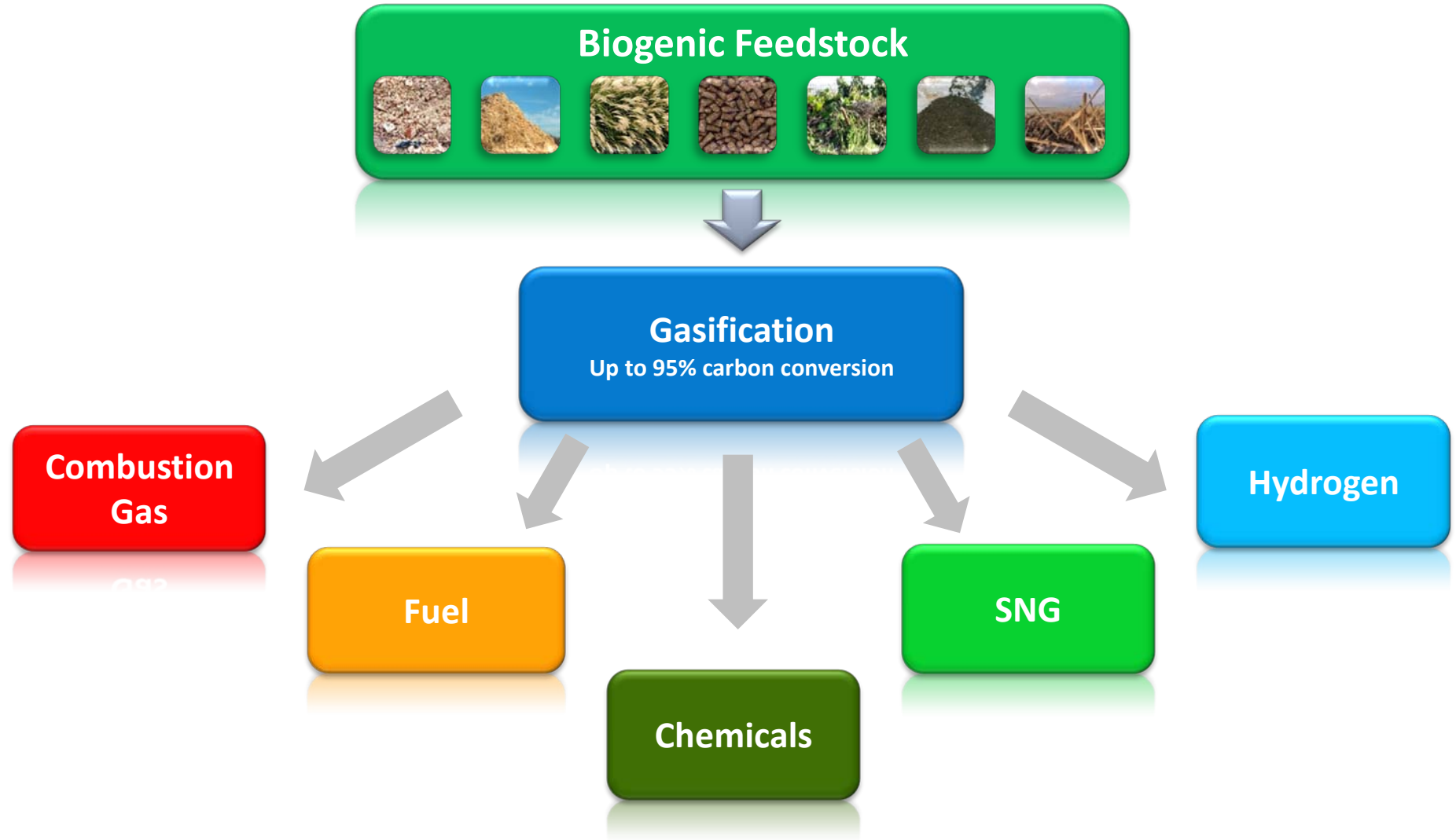
Zertifizierstelle „klima und energie“

TÜV SÜD

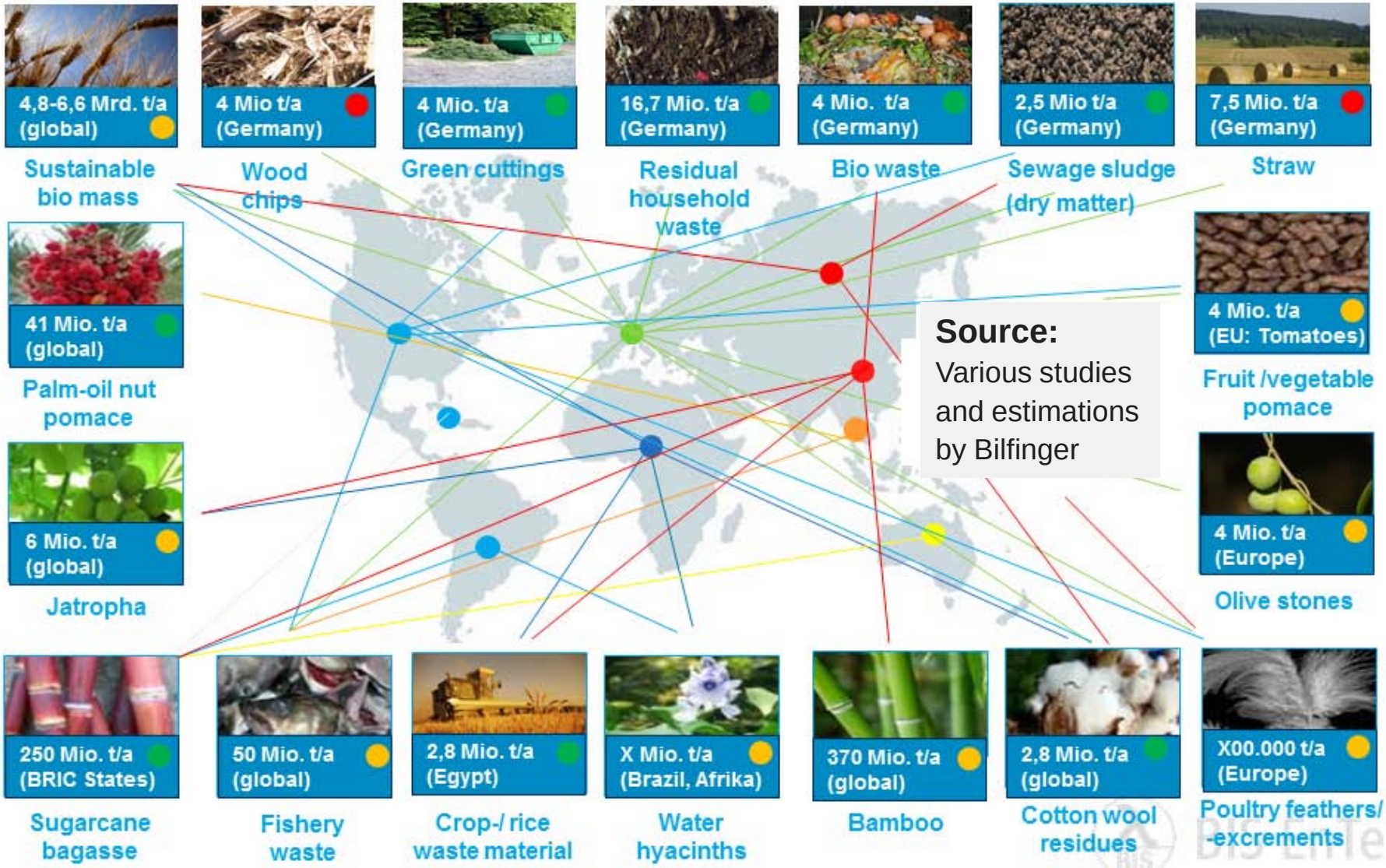
TÜV®

- CO_2-Footprint: European Union sustainability criteria fulfilled
- The certification "green" hydrogen has been granted by TÜV Süd in November 2011

2. Hybrid Biomass Gasification



Global Biomass Potential - Examples

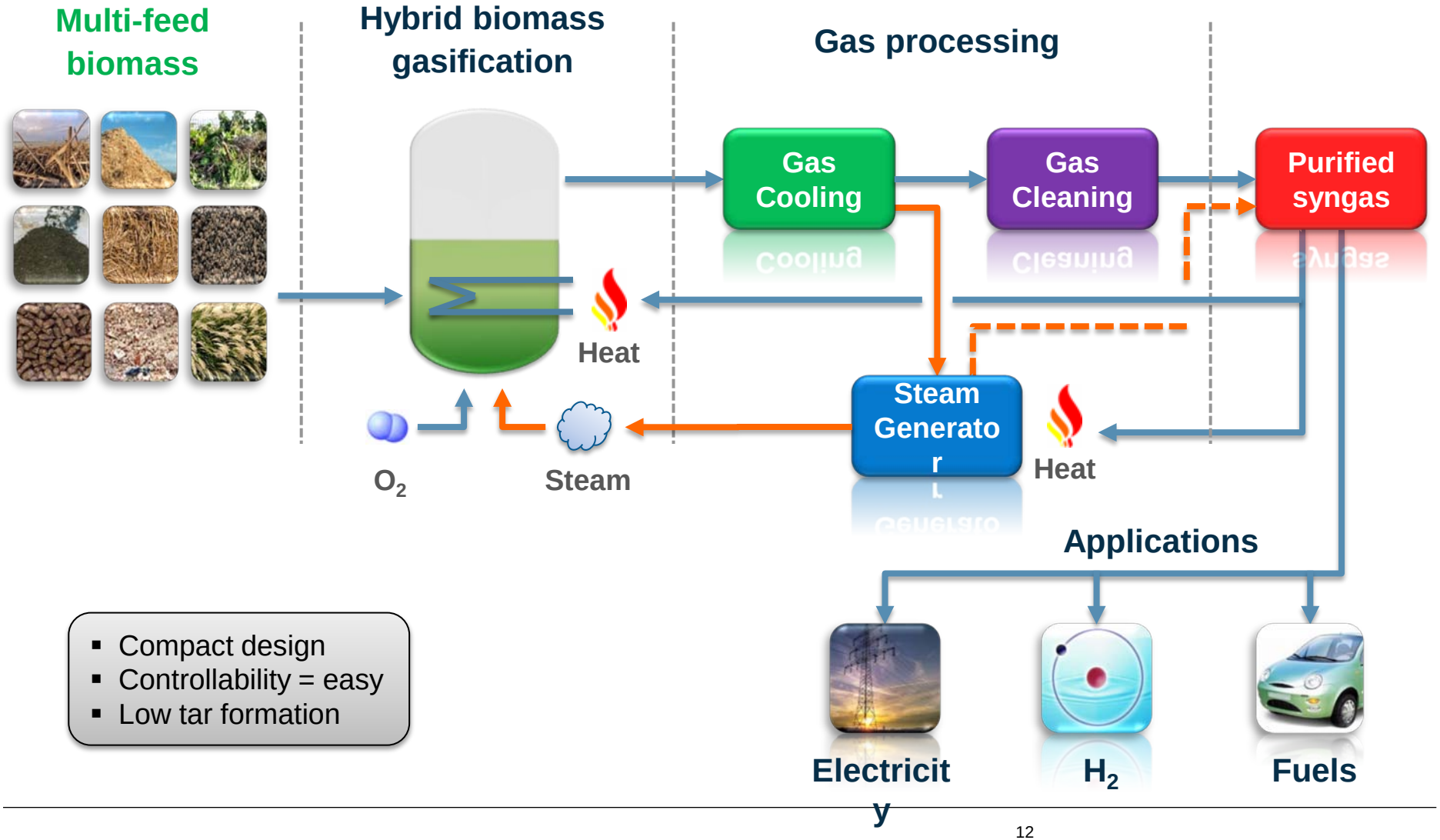


Source: Bilfinger – Hybrid Biomass Gasification

Hybrid Gasification Technology Joint Development with Bilfinger

BILFINGER BERGER Industrial Services

THE LINDE GROUP Linde



- Compact design
- Controllability = easy
- Low tar formation

Development Stages

BILFINGER BERGER Industrial Services

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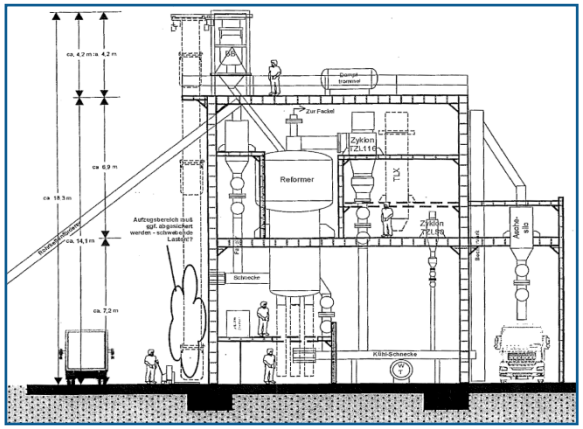
Laboratory

- Cold model
- Properties of fluidized bed
- Theoretical estimations
- Geometry of reactor
- Verification of model and parameters

Pilot-plant

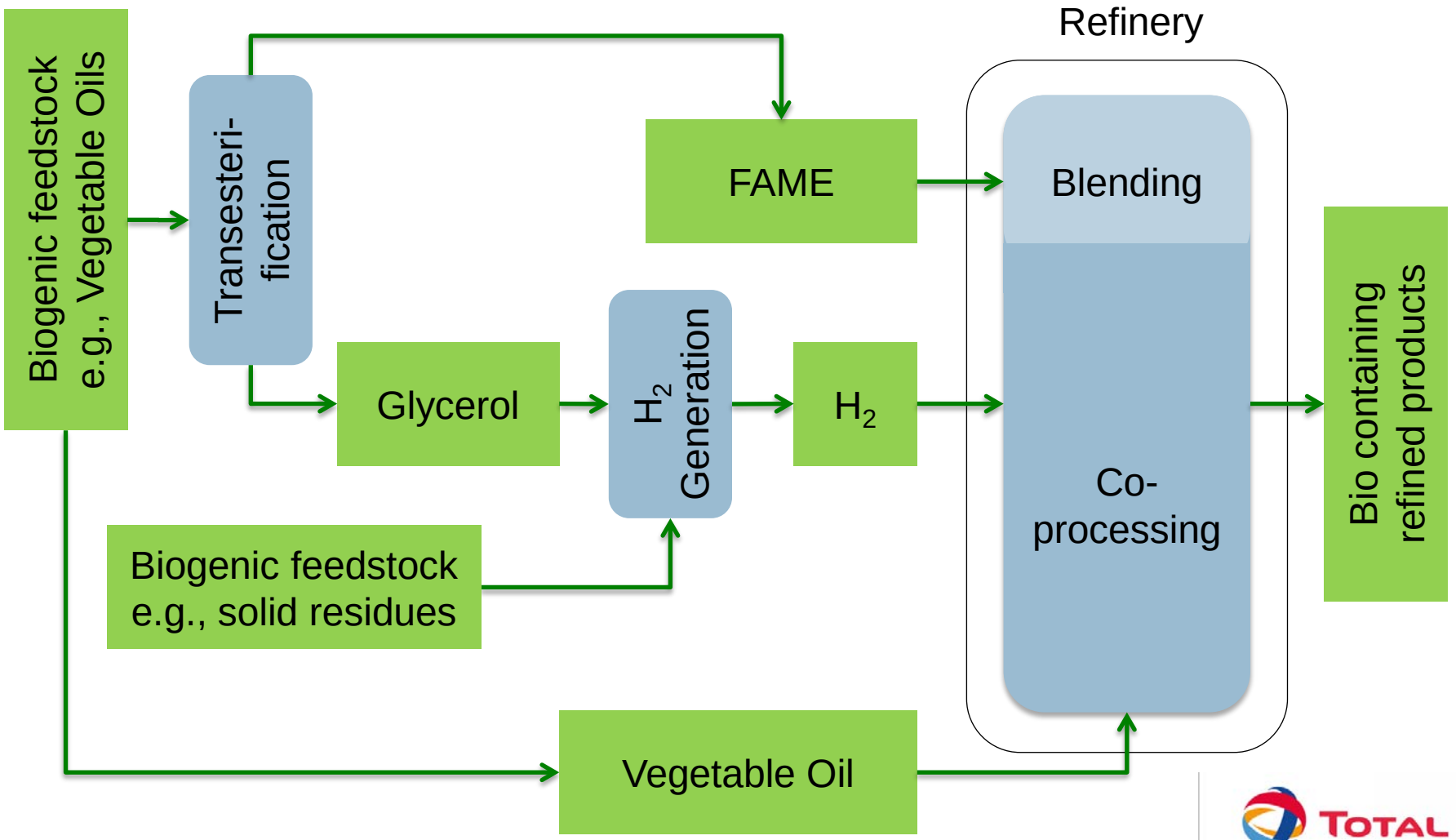
- Throughput: 10-15 kg/h biomass
- Proof of principle
- Extended feedstock tests
- Test of critical components, materials
- Verification of process steps:
  - gasification
  - gas quality
  - gas composition
  - entire process chain up to gas-cleaning

Demo "BL 1000"

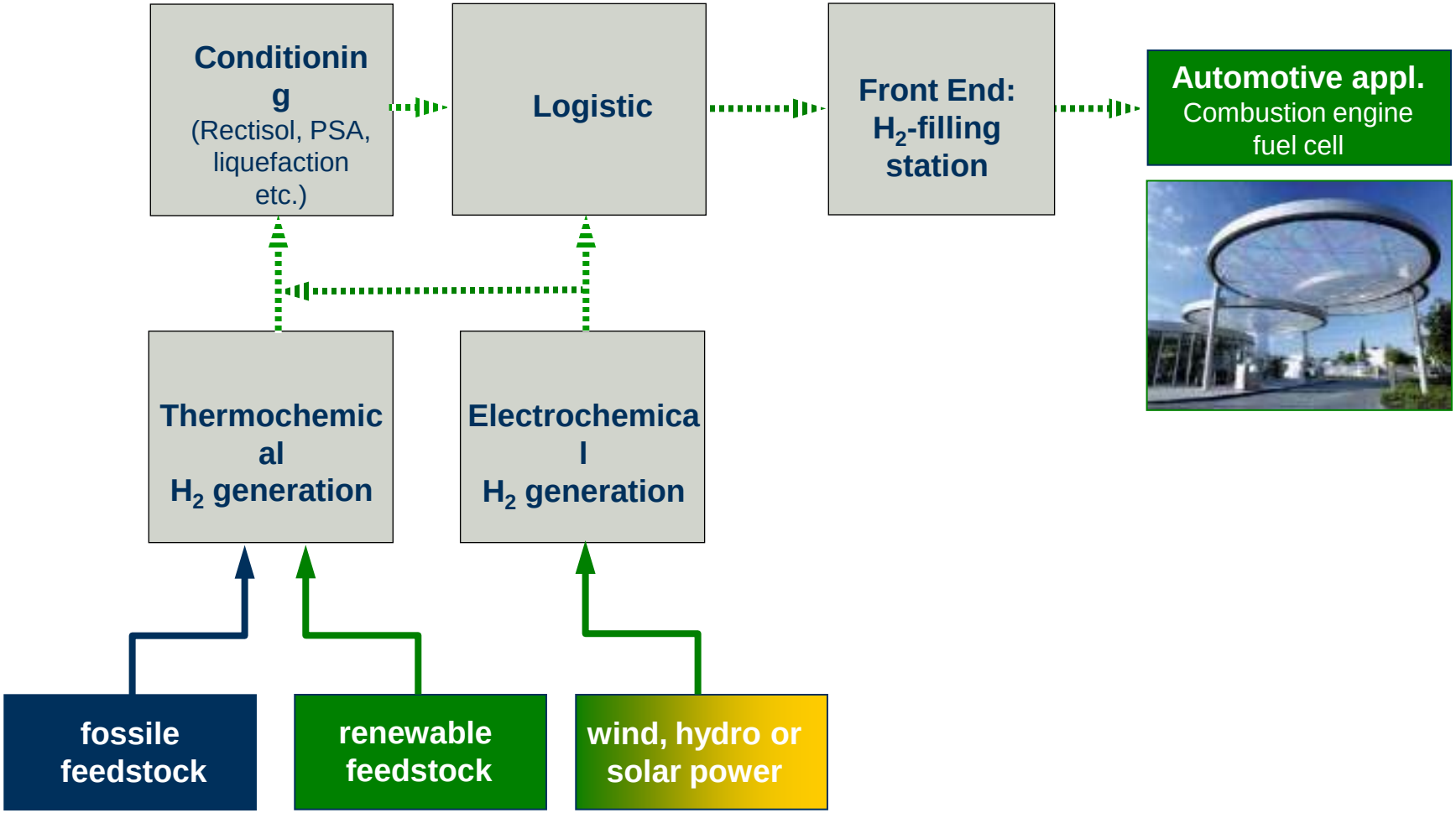


- Throughput: 1.500 kg/h of biomass
- Proof of concept / function of entire process chain
- Energetic optimization/heat recovery
- Long-term stability, seasonal fluctuations of feedstock
- Identification of optimization potential
- Feedstock pre-treatment und waste disposal
- Overall optimization of operation
- Demo for customers

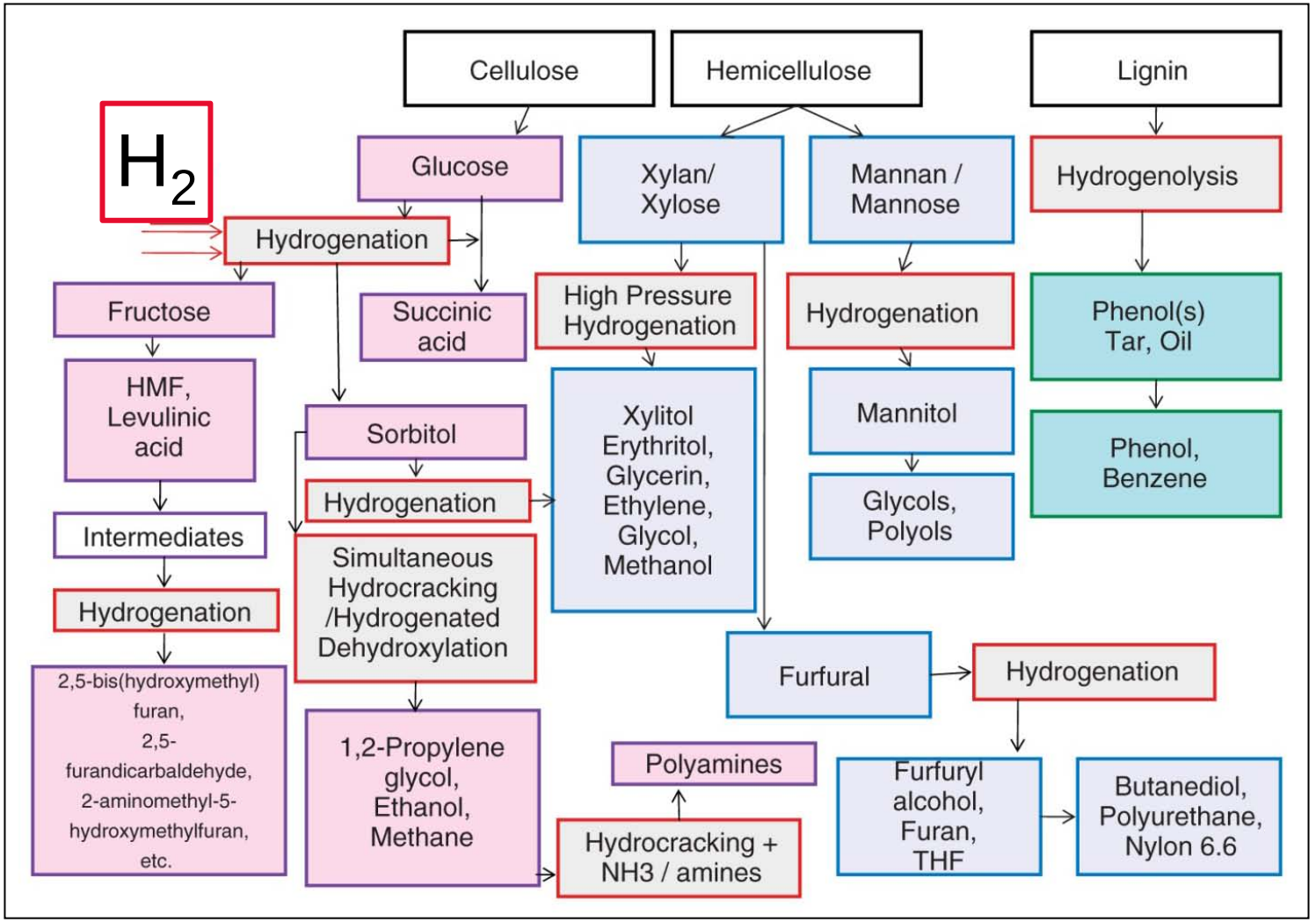
"Green" Hydrogen Applications (I)
Hydrogenation Processes in Refining



"Green" Hydrogen Applications (II)
Mobility



"Green" Hydrogen Applications (III)
Possible Utilization Pathways in Biorefineries



Source: A. P. Borole, Oak Ridge National Laboratory, Biofuels, Bioprod. Bioref. 5:28-36 (2011)

Form Concept to Industry

Chemical – Biotechnological Process Center Leuna, Germany

- Heart of the “Integrated Biorefinery” concept at the chemical site Leuna
- Development and scale-up of sustainable industrial biotech processes
- Inauguration October 2nd 2012, by German Chancellor Angela Merkel
- Owned and operated by Fraunhofer-Gesellschaft
- Linde Engineering Dresden General Contractor technology

Form Concept to Industry

Thank you for your attention.

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