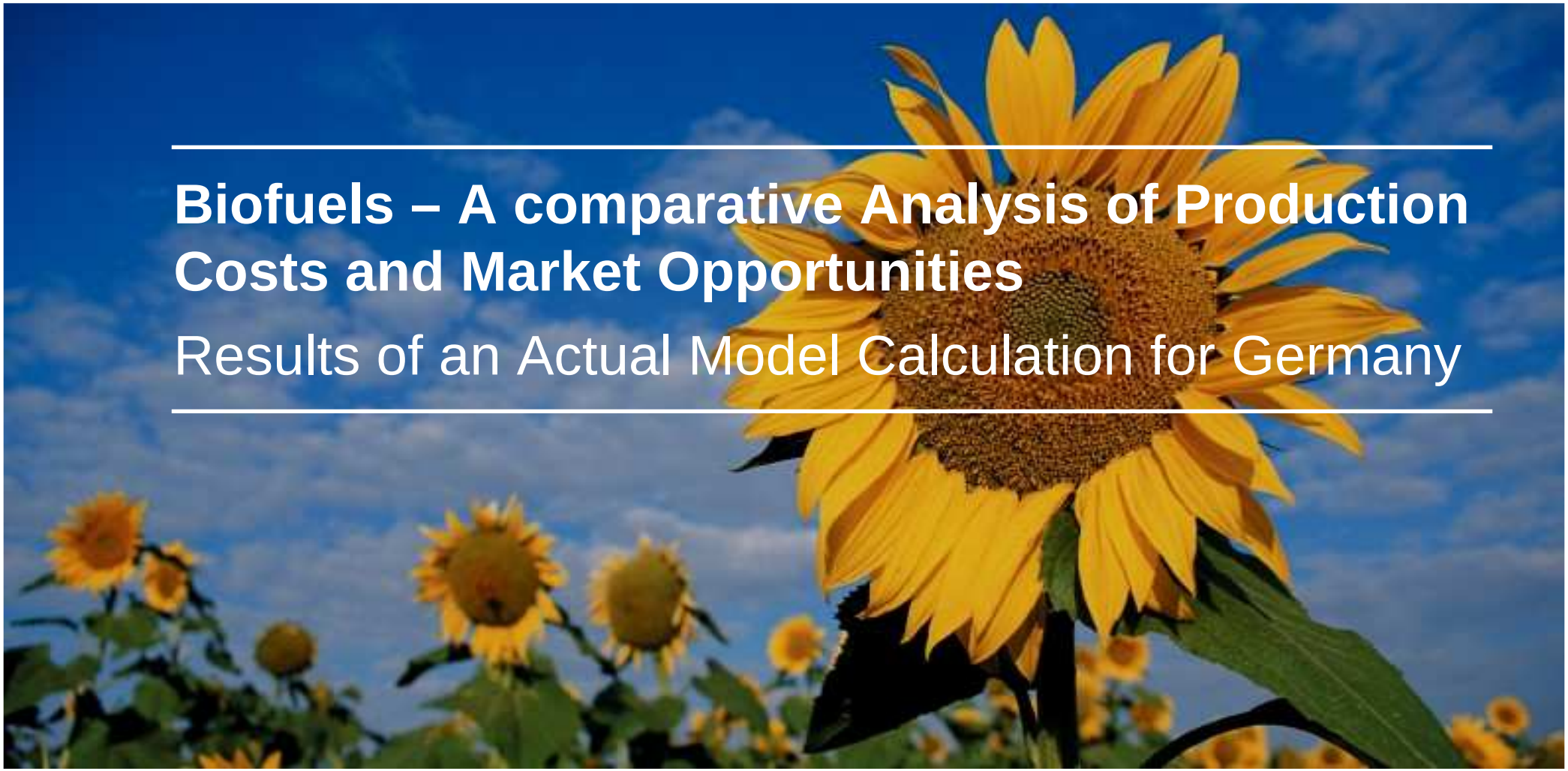


# Biofuels – A comparative Analysis of Production Costs and Market Opportunities

## Results of an Actual Model Calculation for Germany

GVC/Dechema-Jahrestagung 2006

Fokusthema "Nutzung nachwachsender Rohstoffe"

Wiesbaden, September 27, 2006

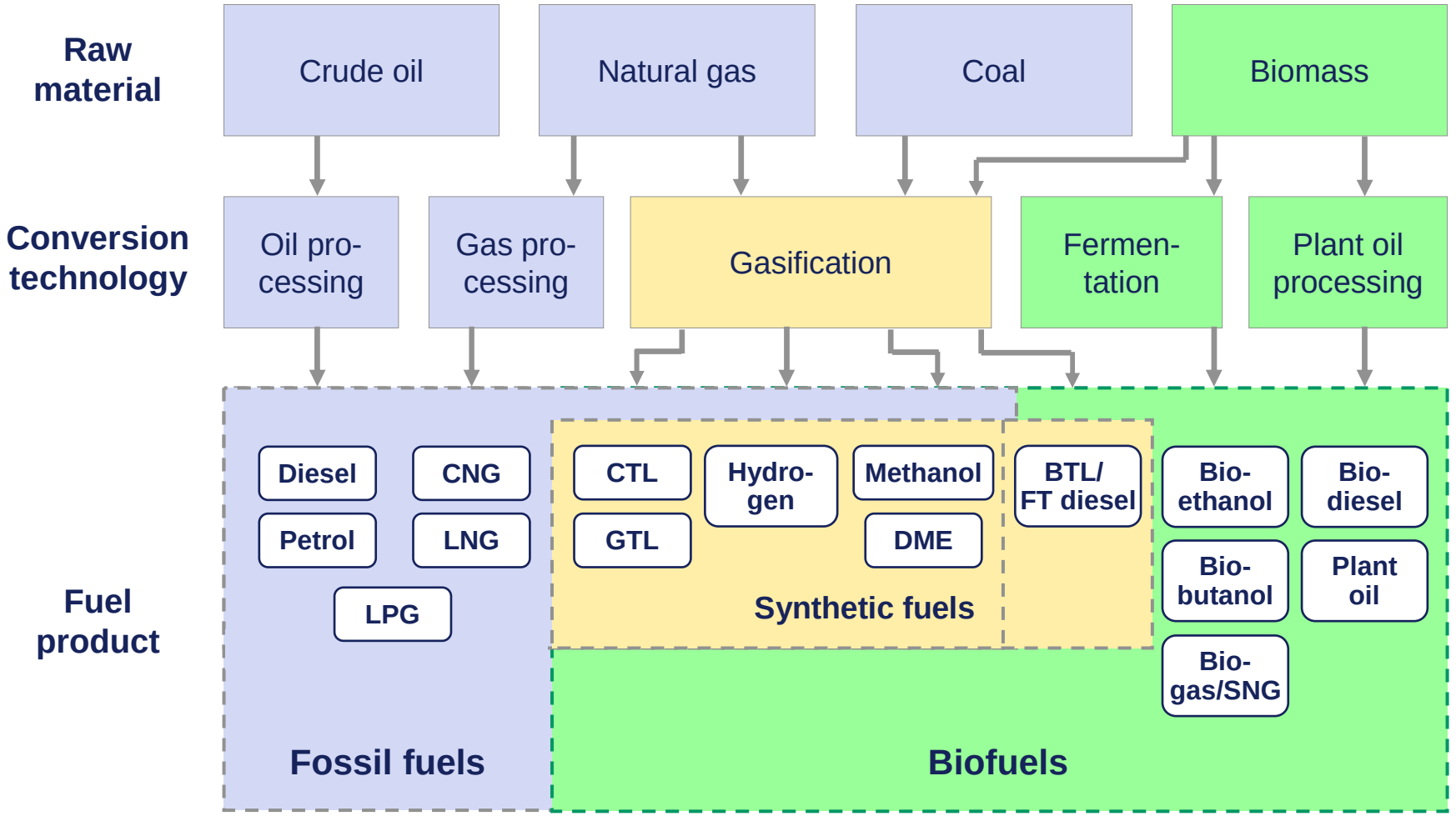
FESTEL CAPITAL

Creating a Better Future

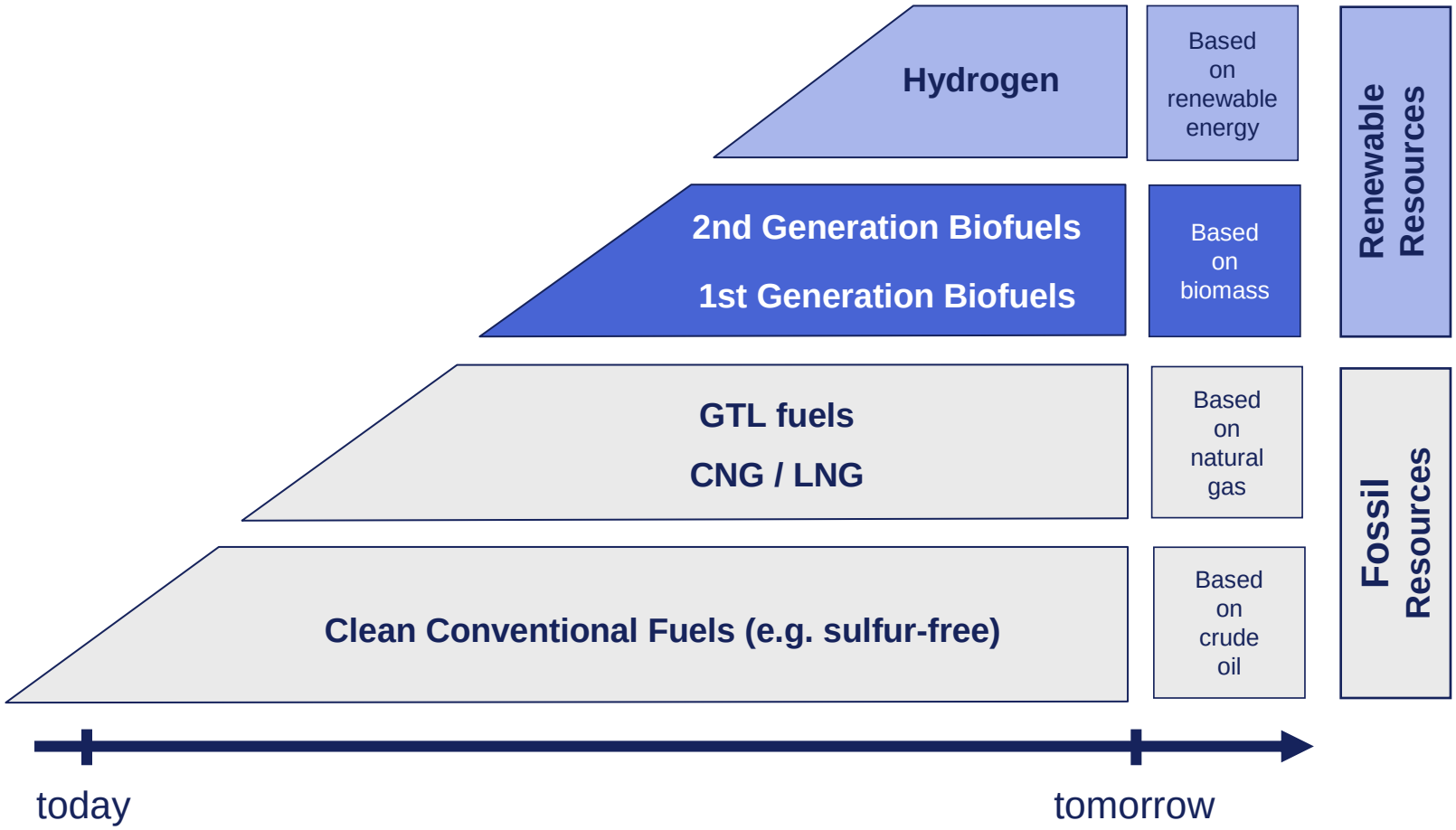
## Contents

FESTEL CAPITAL
Creating a Better Future

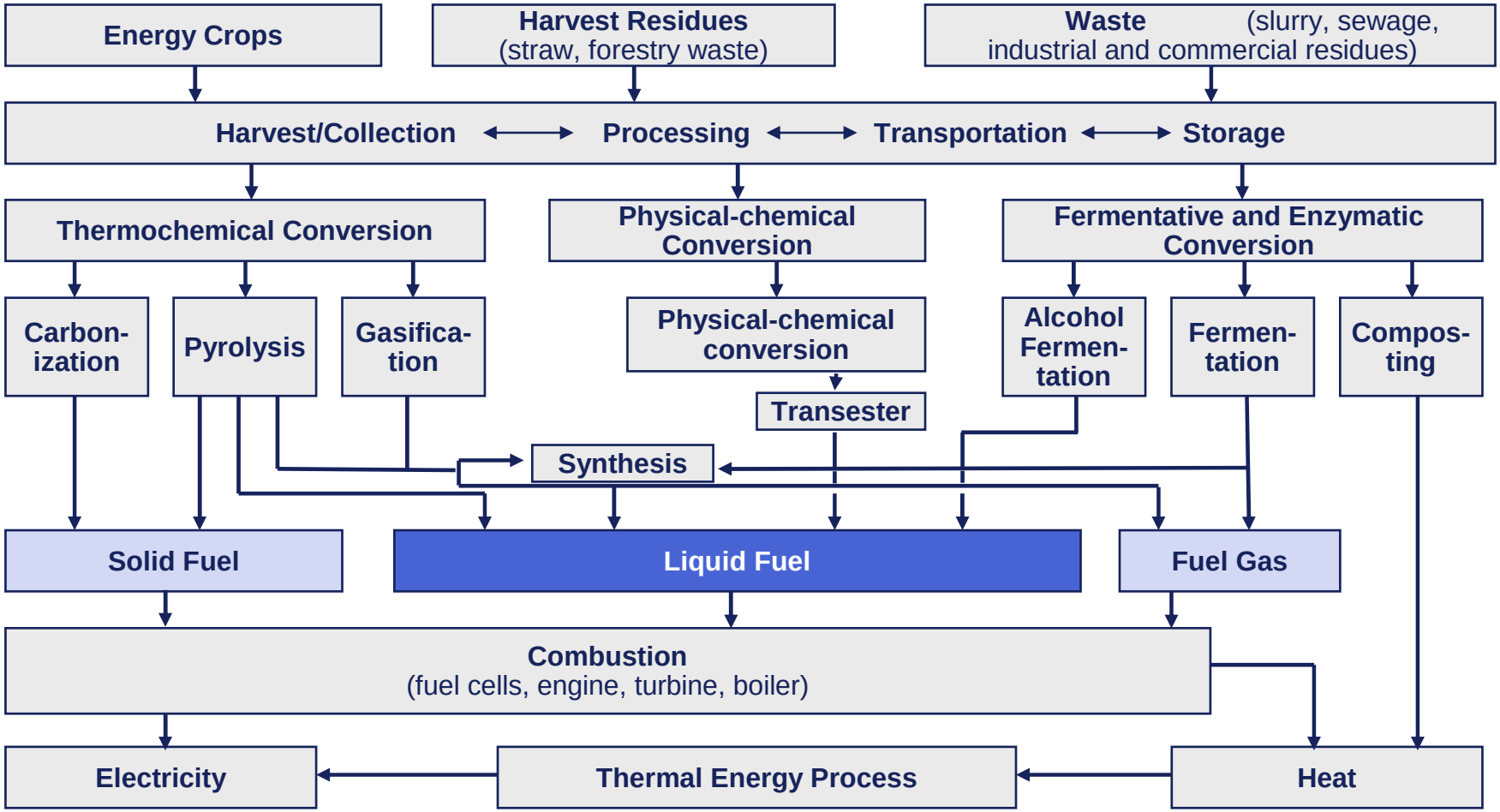
# Fuel types can be categorized based on raw materials and main conversion technologies



# Different generations of modern fuels deriving from fossil and renewable resources exist



# There are many pathways for the energetic utilisation of the different kinds of biomass




Source: Fraunhofer Institute for Environmental, Safety and Energy Technology

FESTEL CAPITAL
Creating a Better Future

# There are numerous evaluation systems for the comparison of the different fuel types

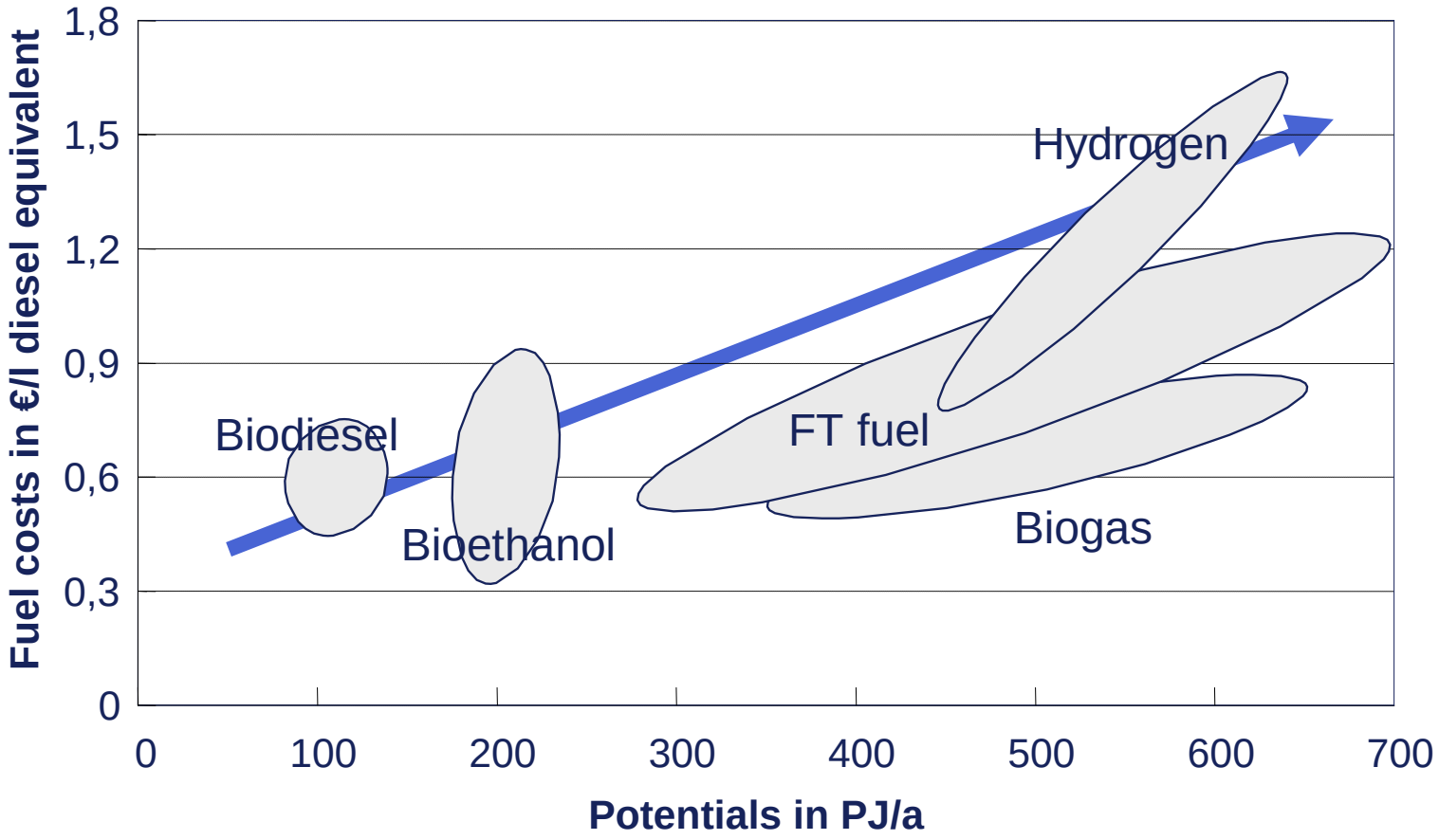
| Kind / Criteria | Biofuel production | | Biofuel suitability concerning | |
|---|---|---|---|---|
| | Overall thermal effciency[a] | Technical effort[b] | Current fuel distribution | Current vehicle fleet |
| FT diesel | → | ↘ | ↗ | ↗ |
| MeOH | → | → | ↘ | ↘ |
| DME | → | ↘ | → | → |
| SNG | ↗ | ↗ | → | → |
| $H_2$ | ↗ | ↗ | ↘ | ↘ |

Legend: ↗ very promising → promising ↘ less promising

Evaluation of biofuels in relation to each other in context of present frame conditions
[a] based on selected refererences
[b] in terms of system complexity

Source: Institute for Energy and Environment Leipzig

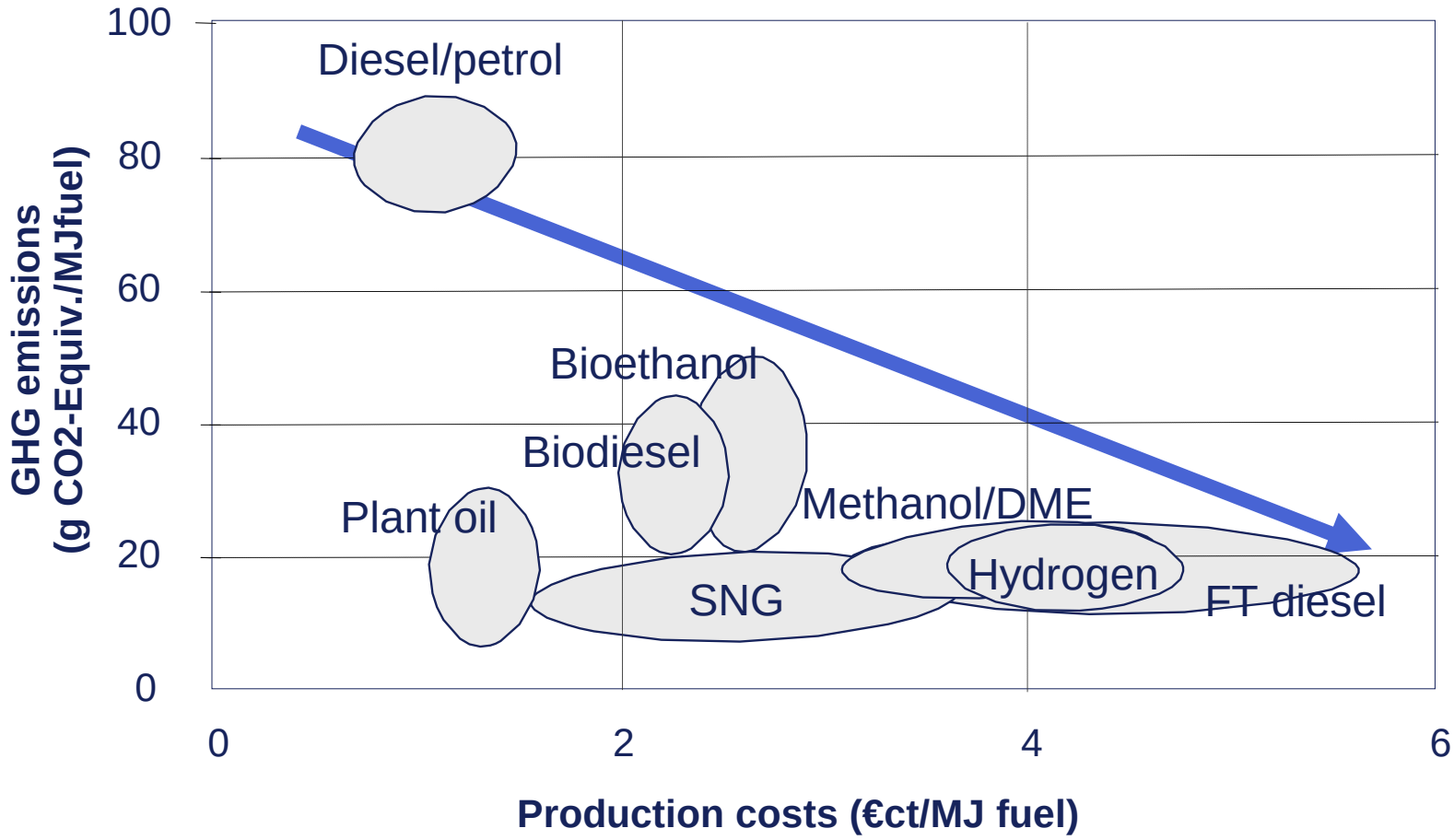
## Alternative Fuels with high potentials are correlated with high fuel costs at the moment so that thechnological improvements are required




Source: Institute for Energy and Environment Leipzig

FESTEL CAPITAL
Creating a Better Future

# Low GHG emissions are correlated with high production costs based on current technology




Source: Institute for Energy and Environment Leipzig

FESTEL CAPITAL
Creating a Better Future

## Biofuels are an extremely complex topic due to the high number of different influencing factors

### Biofuels influencing factors

| Technical factors | Economical factors | Ecological / political factors |
|---|---|---|
| • Raw material supply | • Fuel costs (incl. subsidy and tax aspects) | • GHG emissons and reduction costs |
| • Conversion technologies | • Engine modification costs | • Support of local farmers |
| • Engine / powertrain technologies | • Infrastructure / availability costs | • Efficient land use / food vs. fuel usage |
| • Infrastructure requirements / investments | • Trade balance impact | • Reduced dependency on crude oil |

**How can interesting technological opportunities be identified without getting lost in these details?**

FESTEL CAPITAL
Creating a Better Future

## There are some fundamental hypotheses regarding biofuel usage over the next 10 to 15 years

### Hypotheses regarding biofuel usage

#### Customer acceptance

- Lower prices compared to fossil fuels (without tax subsidy!)
- Normal usage of existing cars
  - No loss of power and range
  - No modification costs
- High availability and easy handling (similar to existing fuels)

#### Biofuel requirements

- Low raw material and production costs
- No additional distrubution / infrastructure costs
- Problem-free mixing with existing fuel types
- Same chemical/physical properties as existing fuels (e.g. energy content)

**Important are economical factors and not ecological aspects - the deciding factor for market success are the costs for the car owner at the filling stations**

FESTEL CAPITAL
Creating a Better Future

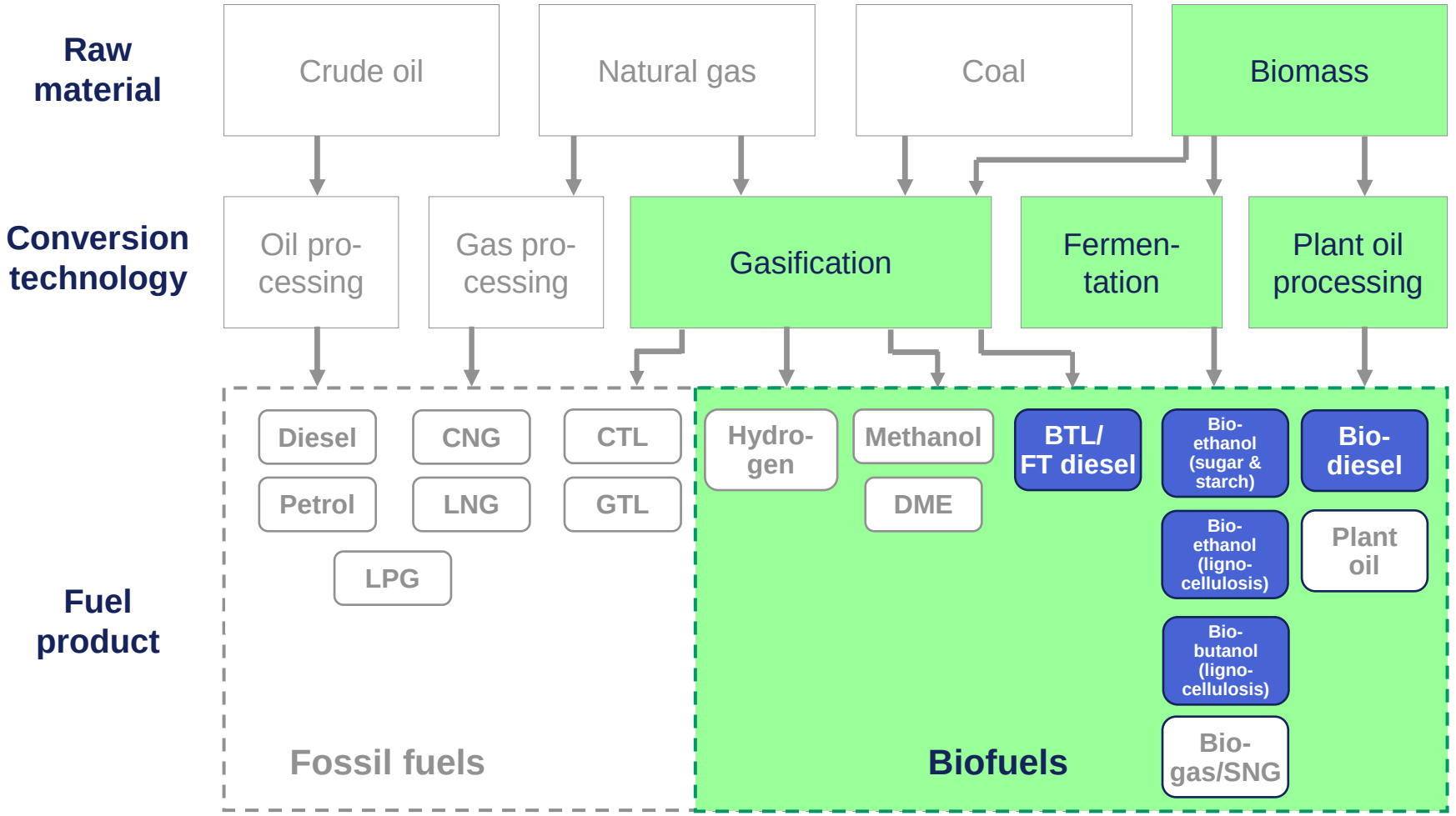
## The high complexity of biofuels can be reduced significantly by following these hypotheses

### Biofuels influencing factors

| Technical factors | Economical factors | Ecological / political factors |
|---|---|---|
| • **Raw material supply** | • **Fuel costs** (incl. subsidy and tax aspects) | • GHG emissons and reduction costs |
| • **Conversion technologies** | • Engine modification costs | • Support of local farmers |
| • Engine / powertrain technologies | • Infrastructure / availability costs | • Efficient land use / food vs. fuel usage |
| • Infrastructure requirements / investments | • Trade balance impact | • Reduced dependency on crude oil |

**Regarding success probability only fuel costs based on raw material supply and conversion technologies are of importance**

## Due to our selection criteria only BTL fuel, bioethanol, biobutanol and biodiesel were analysed in detail with regard to production costs



## Contents

FESTEL CAPITAL
Creating a Better Future

# A model calculation for Germany shows the competitiveness of the different biofuel types (1/2)

**Numbers are based on a "bottom-up" calculation model**

| Biofuel | Raw Material | Region | Scenario | Plant Size (kt/year) | Plant Investment (mn Euro) | Production Costs (Euro/l fuel) | Profit Margin (Euro/l) | Price at Filling Station (Euro/l) |
|---|---|---|---|---|---|---|---|---|
| **Petrol** | Crude oil | Europe | **60 USD/barrel** | 10,000 | 2,600 | 0.37 | **0.05** | 1.30 |
| **Biobutanol** | Corn | USA | Large scale 2008 | 200 | 240 | 0.33 | **0.02** | 1.30 |
| **Biobutanol** | Straw | USA | Large scale 2008 | 200 | 240 | 0.30 | **0.05** | 1.30 |
| **Biobutanol** | Straw | Europe | **Large scale 2008** | 200 | 240 | 0.35 | **0.09** | 1.30 |
| **Bioethanol** | Straw | USA | Small scale 2008 | 50 | 90 | 0.45 | **-0.13** | 1.30 |
| **Bioethanol** | Straw | USA | Large scale 2008 | 200 | 240 | 0.30 | **0.02** | 1.30 |
| **Bioethanol** | Straw | USA | Large scale 2012 | 200 | 240 | 0.27 | **0.05** | 1.30 |
| **Bioethanol** | Straw | Europe | Large scale 2008 | 200 | 240 | 0.36 | **0.01** | 1.30 |
| **Bioethanol** | Wheat | Europe | **With tax** | 200 | 200 | 0.48 | **-0.11** | 1.30 |
| **Bioethanol** | Wheat | Europe | **Without tax** | 200 | 200 | 0.48 | **0.54** | 1.30 |

Source: FESTEL CAPITAL analysis

FESTEL CAPITAL
Creating a Better Future

# A model calculation for Germany shows the competitiveness of the different biofuel types (2/2)

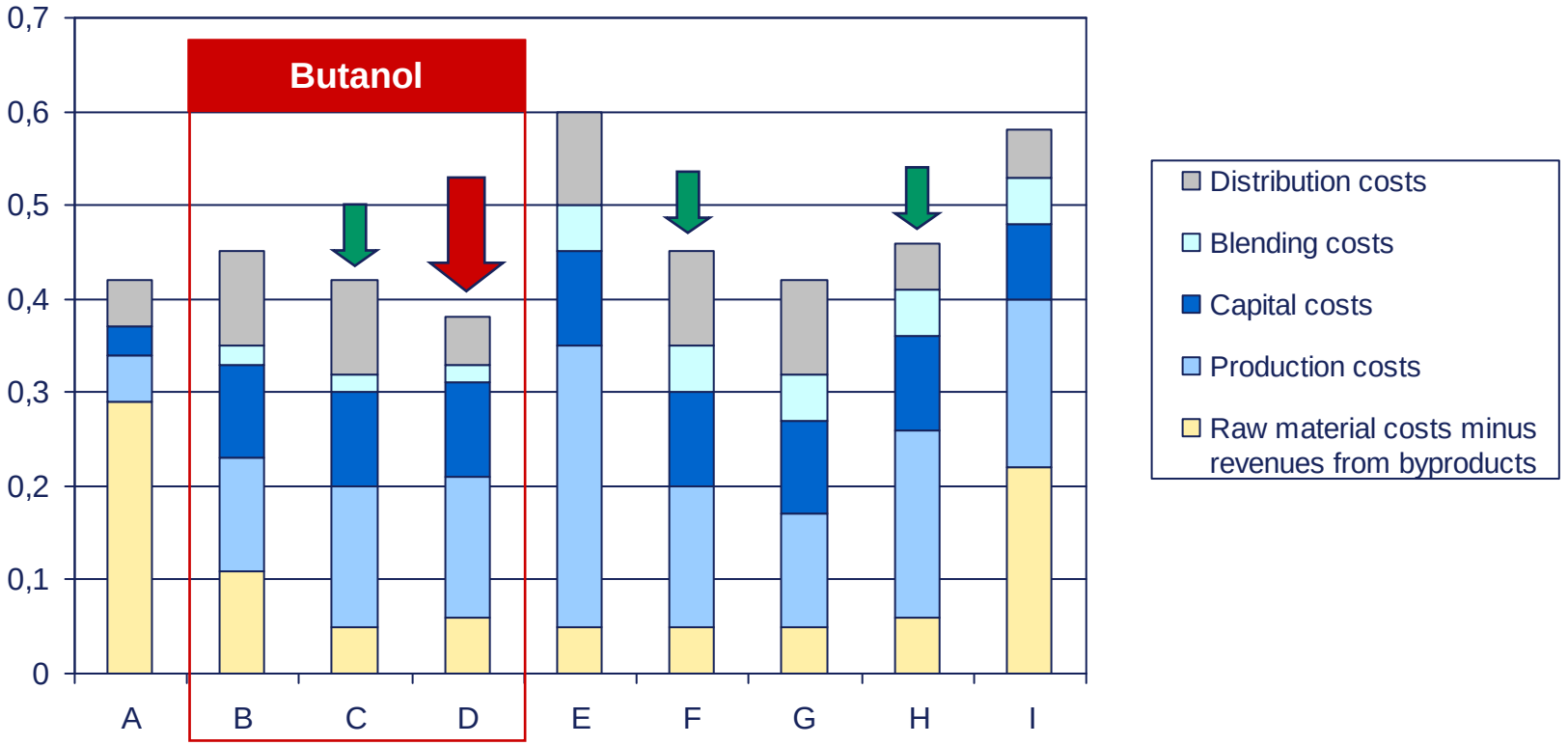
**Numbers are based on a "bottom-up" calculation model**

| Biofuel | Raw Material | Region | Scenario | Plant Size (kt/year) | Plant Investment (mn Euro) | Production Costs (Euro/l fuel) | Profit Margin (Euro/l) | Price at Filling Station (Euro/l) |
|---|---|---|---|---|---|---|---|---|
| **Diesel** | Crude oil | Europe | **60 USD/barrel** | 10,000 | 2,600 | 0.37 | **0.06** | 1.10 |
| **Biodiesel** | Rape seed | Europe | **With tax** | 200 | 40[1)] | 0.54 | **-0.13** | 1.10 |
| **Biodiesel** | Rape seed | Europe | **Without tax** | 200 | 40[1)] | 0.54 | **0.34** | 1.10 |
| **BTL** | Wood | Europe | Small scale with tax | 120 | 180 | 1.02 | **-0.61** | 1.10 |
| **BTL** | Wood | Europe | **Large scale with tax** | 1,200 | 1,800 | 0.82 | **-0.41** | 1.10 |
| **BTL** | Wood | Europe | **Large scale without tax** | 1,200 | 1,800 | 0.82 | **0.06** | 1.10 |

1) Including oil mill

Source: FESTEL CAPITAL analysis

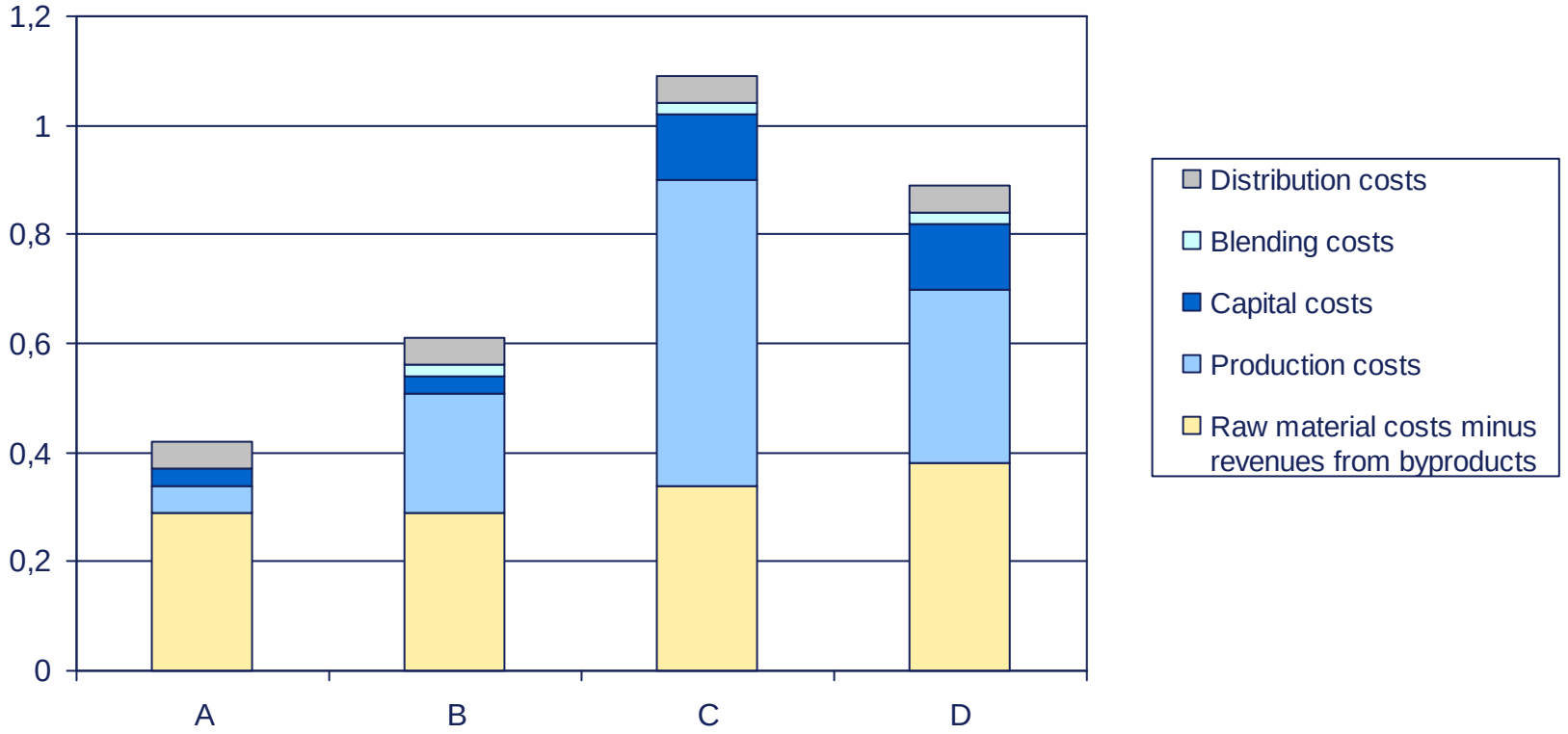
# The most competitive biofuel type for the German market is European bio-butanol made from straw (1/2)




A - Petrol (crude oil, 60 USD/barrel)
B - Biobutanol (corn, USA, large scale 2008)
**C - Biobutanol (straw, USA, large scale 2008)**
**D - Biobutanol (straw, Europe, large scale 2008)**
E - Bioethanol (straw, USA, small scale 2008)
**F - Bioethanol (straw, USA, large scale 2008)**
G - Bioethanol (straw, USA, large scale 2012)
**H - Bioethanol (straw, Europe, large scale 2008)**
I - Bioethanol (wheat, Europe)

Source: FESTEL CAPITAL analysis

# The most competitive biofuel type for the German market is European bio-butanol made from straw (2/2)




A - Diesel (crude oil, 60 USD/barrel)
B - Biodiesel (rape seed, Europe)
C - BTL (wood, Europe small scale 120 kt)
D - BTL (wood, Europe large scale 1,200 kt)

Source: FESTEL CAPITAL analysis

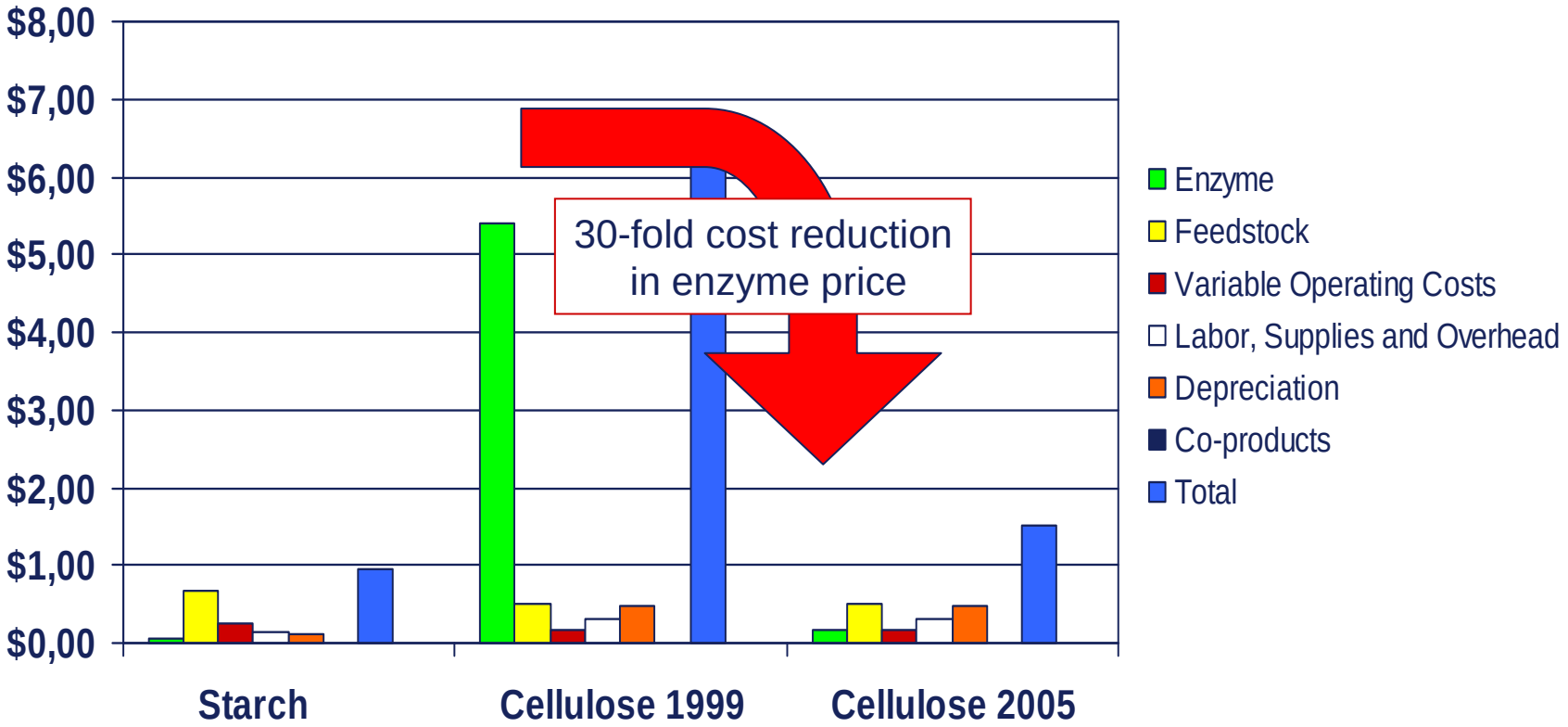
## Contents

## Butanol is being seen as a more superior alternative fuel than ethanol due to its more favourable chemical / physical properties

- Butanol has a **high flashpoint** of 35°C compared to ethanol with 13℃ (this is an advantage with regard to fire safety)
- Butanol has a **lower vapour pressure** and is less miscible with water than ethanol
- Butanol can replace fossil fuels **up to 100% without modifying the engine** (some sources say only 40%!) whereby ethanol can only be blended up to 85% and here modifications to the engine are required (FFV = Flexible Fuel Vehicle)
- Butanol is **far less corrosive** than ethanol and it can be shipped and distributed through existing pipelines and filling stations
- Besides using butanol as a straight substitute for petrol, butanol can be blended with diesel or biodiesel and **burned in diesel engines**
- **Disadvantages:** Butanol has a lower octane rating than ethanol (it has research octane numbers of 96 compared to 130 ethanol) and a higher viscosity

# Enzyme cost no longer dominates the bioethanol/biobutanol cost picture but the hydrolysis step is not yet feasible in large scale

## Cost comparison after recent achievements: strach vs. cellulose (USD/gallon ethanol)

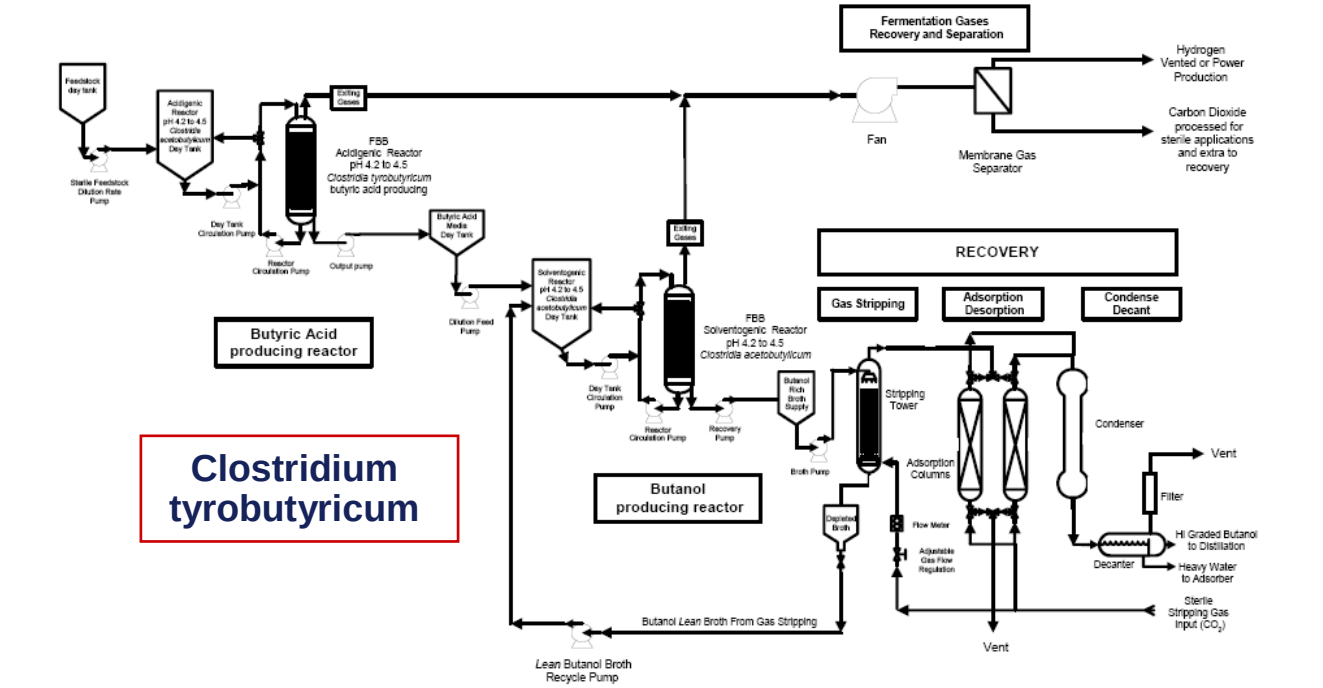



Source: "Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks", NREL/TP-580-28893 joint USDA, NREL study released in October 2000

## Normally the ABE (acetone, butanol, ethanol) or Weizmann process is used to produce butanol

- **Clostridium acetobutylicum** and many other Clostridiums can digest whey, sugar, starch, lignin, cellulose fiber and other biomass directly into butanol, propionic acid and other substances
- In the **ABE or Weizmann process** these bacteria begin with butyric acid fermentation, but, when the pH drops below 5, they switch into butanol and acetone production in order to prevent further lowering of the pH (two molecules of butanol are formed for each molecule of acetone)
- The **yield of butanol** from the ABE process may be substantially increased by using a coculture of at least two different Clostridium species
  - Researchers have discovered that by using a coculture of a Clostridium species where one produces butyric acid (e.g. C. pasteurianum or C. butyricum) and one for the conversion of butyric acid to butanol (e.g. C. butylicum or C. acetobutylicum), at least 20% more butanol can be yielded from the conventional ABE Process
  - It is reported that the two different species could not only be used in a multiple stage system but also concurrently in the same reaction vessel whereas, at equilibrium, the number ratio of the butyric acid forming species to butanol conversion species should range between about 1:3 and about 3:1

# Environmental Energy Inc. (EEI) has developed dual immobilized reactors with continuous recovery process




1. Dry or wet milling
2. Conversion of biomass into usable sugars
3. **Butyric acid and hydrogen fermentation** (acidiogenic)
4. **Butanol fermentation** (solventogenic)
5. High grading: gas-stripping/adsorption/ desorption/condensing/ decantation
6. Distillation: high purity
7. By-product recovery

Source: Environmental Energy Inc.