GASIFICATION FOR 2nd GENERATION BIOFUELS

Bram van der Drift
ECN

Energy research Centre of the Netherlands

ECN mission: development of high-quality knowledge and technology for the transition to a sustainable energy supply, and bringing this to the market

~72 M€/y turnover
~600 employees
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ECN
business units

- Energy in the Built Environment
- Intelligent Grids
- Energy Efficiency in Industry
- Solar Energy
- Wind Energy
- Biomass, Coal & Environmental Research
- F-Cell
- Hydrogen & Clean Fossil Fuels
- Policy Studies
- Engineering & Services

energy saving
renewable energy
clean fossil
# FIRST AND SECOND GENERATION

<table>
<thead>
<tr>
<th>Biomass Fuel</th>
<th>1(^{st}) generation biofuels</th>
<th>2(^{nd}) generation biofuels</th>
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<td>methanol</td>
</tr>
<tr>
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<td></td>
<td>MA</td>
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*PPO: pure plant oil, VGO: straight vegetable oil, VPO virgin plant oil, FAME: fatty acid methyl ester, RME: rape seed methyl ester, ETBE: ethyl tertiary butyl ester, FT: Fischer-Tropsch, DME: dimethyl ether, MA: mixed alcohols, SNG: substitute natural gas*
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**gasification involved**

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RAPESEED
LIGNOCELLULOSE
WHAT IS GASIFICATION?

combustion:

fuel + air ($\lambda > 1$) $\rightarrow$ flue gas + heat
WHAT IS GASIFICATION?

**Combustion:**

`fuel + air (λ > 1) → flue gas + heat`

**Pyrolysis:**

`fuel + heat → gas + char`
WHAT IS GASIFICATION?

*combustion:*

fuel + air ($\lambda > 1$) $\rightarrow$ flue gas + heat

*pyrolysis:*

fuel + heat $\rightarrow$ gas + char

25%

75%
WHAT IS GASIFICATION?

combustion:
\[ \text{fuel} + \text{air (}\lambda > 1\text{)} \rightarrow \text{flue gas} + \text{heat} \]

pyrolysis:
\[ \text{fuel} + \text{heat} \rightarrow \text{gas} + \text{char} \]

\[ 25\% + 75\% \]

gasification:
\[ \text{fuel} + \text{air (}\lambda \sim 0.3\text{)} \rightarrow \text{gas} \]
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solid fuel is converted to gaseous fuel… for further processing
WHAT IS GASIFICATION?

**Combustion:**

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25%

**Pyrolysis:**

\[ \text{fuel} + \text{heat} \rightarrow \text{gas} + \text{char} \]

75%

**Gasification:**

\[ \text{fuel} + \text{air} \ (\lambda \approx 0.3) \rightarrow \text{gas} \]

~80% cold gas efficiency

solid fuel is converted to gaseous fuel… for further processing
WHY GASIFICATION?

- pre-treatment: gas is easier than solids
- back-end flexibility: power, chemicals, biofuels
- efficiency to power
- pre-combustion CO$_2$ capture
HOW?
many choices to make

- FICFB
- Biomass Engineering
- Choren
- Vølund
- ConocoPhillips
- Blaue Turm
- Lurgi
- Viking
- Foster Wheeler
- Pyroforce
- Heat pipe reformer
- AES
- TPS
- LT-CFB
- Carbona
- INC
- Viking
- Fluidyne
- Novel
- Cutec
- Entimos
- Nexterra
- MTI
- Taylor
- Hitachi
- SilvaGas
- Enerkem
- Chemrec
- General Electric
- Xylowatt
- CCM
- Dasagren
- TKE
- Siemens
- HoSt
- Page MaCrea
- Relax Umwelt
- Ebara
- PRME
- Compact Power
- Shell
- Enerkem
- Plasco
- JFE
- Dasagren
HOW?

many choices to make

- fixed bed or fluidized bed or entrained flow?
- small- or large-scale?
- methane or not in the gas?
- direct or indirect gasification?
- with or without coal?
- tar-free gas or not?
- dedicated or poly-generation?
- atmospheric or pressurized?
- fuel flexible or not?
- integrated or stand-alone?
- …
CHOICE: GASIFIER TECHNOLOGY

- **fixed bed updraft**
- **fixed bed downdraft**
- **circulating fluidized bed**
- **entrained flow**
CHOICE: DIRECT OR INDIRECT?

• direct: one vessel, all reactions

• indirect: two coupled reactors, combustor supplies heat
CHOICE: DIRECT OR INDIRECT?

**gasification:**

fuel + air ($\lambda \approx 0.3$) → gas

**combustion:**

fuel + air ($\lambda > 1$) → flue gas + heat

**pyrolysis:**

fuel + heat → gas + char
**CHOICE: DIRECT OR INDIRECT?**

**gasification:**

fuel + air \((\lambda \approx 0.3)\) → gas

**combustion:**

fuel + air \((\lambda > 1)\) → flue gas + heat

**pyrolysis:**

fuel + heat → gas + char
CHOICE: WITH OR WITHOUT COAL?
CHOICE: WITH OR WITHOUT COAL?

- reasons for “with coal”:
  - available technology
  - large-scale

- reasons for “without coal”:
  - biomass is more reactive
  - coal is not accepted
EXAMPLE: WITH COAL

- Shell entrained flow gasifier
- gasifier, cooler, gas cleaning, gas/steam turbine (IGCC)
- $\sim 600 \text{ MW}_{\text{th}}$ coal capacity ($\sim 250 \text{ MW}_{\text{e}}$)
- co-gasification:
  - design: $\sim 120 \text{ MW}_{\text{th}}$ biomass
  - reality: $\sim 60 \text{ MW}_{\text{th}}$ biomass
CHOICE: DEDICATED OR POLY?
CHOICE: DEDICATED OR POLY?

- reasons for dedicated:
  - high efficiency to desired product
  - easy sales department

- reasons for poly-generation:
  - higher overall efficiency
  - easier process
EXAMPLE: DEDICATED

- Choren (Germany)
- 1 MW pilot, 45 MW demo
- entrained flow gasifier, char quench, cooler, scrubbers, filter, shift, CO$_2$-removal, quard beds, FT-synthesis
- maximum Fischer Tropsch products yields (cooperation with Shell)
EXAMPLE: POLY-GENERATION

- Dakota Gasification Company (US)
- updraft Lurgi gasifiers since 1984
- ~3000 MW coal input

- 54% SNG
- 9% tars
- 2% naphtha
- 1% phenols
CHOICE: ATMOSPHERIC OR PRESSURIZED?
CHOICE: ATMOSPHERIC OR PRESSURIZED?

- reasons for atmospheric:
  - simpler feeding
  - not needed for application (e.g. engine, boiler)

- reasons for pressurized:
  - higher efficiency
  - cheaper at large-scale
EXAMPLE: PRESSURIZED

- pressurized air-blown CFB (Foster Wheeler)
- 6 MW<sub>e</sub> IGCC
- Värnamo (Sweden)

- becomes: O<sub>2</sub>-blown, reformer, DME-production
CHOICE: METHANE OR NOT?
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- syngas: maximum $H_2$ and CO concentration, methane undesired
- producer gas: mixture of $H_2$, CO, CH$_4$, and other hydrocarbons
CHOICE: METHANE OR NOT?

- syngas: maximum $H_2$ and CO concentration, methane undesired
- producer gas: mixture of $H_2$, CO, $CH_4$, and other hydrocarbons

- reasons for methane:
  - higher efficiency
  - methane is desired product (e.g. SNG)

- reasons for methane-free gas:
EXAMPLE: METHANE

- Austrian Energy/TUV
- fluidized bed gasifier
- 2 MW$_e$ CHP
- gas engine
- Güssing (Austria)

- slip-stream production of SNG (Substitute Natural Gas)
EXAMPLE: METHANE-FREE

- VTT, Neste Oil, Stora Enso (Finland)
- CFB-gasifier, $O_2$-blown
- 12 MW gasifier and 5 MW gas cleaning demo for Fischer-Tropsch synthesis
- Varkaus (Finland)
SYNGAS PRODUCTION
BtL system layout

biomass → gasification → syngas → cleaning → synthesis → upgrading

2nd generation biofuels:
- FT products
- methanol
- DME
- mixed alcohols
- …
BtL system layout

biomass → gasification → syngas → cleaning → synthesis → upgrading

2nd generation biofuels:
- FT products
- methanol
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- ...

focus of this presentation
OPTION 1: ENTRAINED FLOW GASIFICATION

- high temperature (typically 1300-1500°C)
- pure oxygen
- the ashes melt: slag
- conversion: over 99%
- conventional technology for coal on large-scale
- implementation: from coal to biomass
OPTION 1: ENTRAINED FLOW GASIFICATION

- high temperature (typically 1300-1500°C)
- pure oxygen
- the ashes melt: slag
- conversion: over 99%
- conventional technology for coal on large-scale
- implementation: from coal to biomass

but: small fuel particles needed
Freiberg, Germany

[Shell]

Buggenum, Netherlands

[Siemens]
OPTION 2: FLUIDISED BED GASIFICATION

- low temperature (typically 800-900°C)
- pure oxygen, steam needed as moderator
- no melting: dry ash
- conversion: typically 95%
- hardly any fuel size restrictions
- technology in development
- implementation: from small- to large-scale
OPTION 2: FLUIDISED BED GASIFICATION

- low temperature (typically 800-900°C)
- pure oxygen, steam needed as moderator
- no melting: dry ash
- conversion: typically 95%
- hardly any fuel size restrictions
- technology in development
- implementation: from small- to large-scale

but: gas contains too much methane, gas needs after-treatment
VTT pilot plant, Finland

Värnamo, Sweden

GTI pilot plant, USA
OPTIONS SUMMARY

- Entrained flow gasifier
- Fluidised bed gasifier
- Syngas
OPTIONS SUMMARY

- Biomass
  - Pre-treatment
  - Entrained flow gasifier
  - Fluidised bed gasifier
  - Syngas
OPTIONS SUMMARY

biomass → pre-treatment → entrained flow gasifier → syngas

biomass → fluidised bed gasifier → syngas
OPTIONS SUMMARY

1. **Biomass** → **Pre-treatment** → **Entrained Flow Gasifier** → **Syngas**

2. **Biomass** → **Fluidised Bed Gasifier** → **Catalytic Reformer** → **Syngas**
OPTIONS SUMMARY

subject of case study

biomass → pre-treatment → entrained flow gasifier → syngas

biomass → fluidised bed gasifier → catalytic reformer → syngas
PRE-TREATMENT OPTIONS

for entrained flow gasifier

- milling
  + easy technology
  - high energy demand
- torrefaction
  + low energy demand
  + biomass becomes like coal
  - new technology
- pyrolysis
  + low energy demand
  + easy feeding/pressurizing
  - new technology

- “advanced”
INTERMEZZO

torrefaction: roasting

- “roasting” at 250-300°C
- biomass becomes brittle and hydrophobic like coal
- ECN technology for >90% efficiency

torrefaction facility, 50-100 kg/h
INTERMEZZO

torrefaction: easy pulverizing

source: ECN-reports ECN-C-05-013, ECN-05-067, ECN-05-073
INTERMEZZO

torrefaction: the process parameters

Temperature [°C]

Residence time [min]

10’  300°

10’  200°

10’  residence time [min]  60’
INTERMEZZO

torrefaction: the process parameters

![Graph showing the relationship between temperature and residence time. The graph illustrates the grindability of materials at different temperatures and residence times.](image)
INTERMEZZO

torrefaction: the process parameters

![Graph showing the relationship between temperature (°C), residence time (min), grindability, and energy efficiency.](image)
INTERMEZZO

*torrefaction*: the process parameters

- Temperature [°C]: 200°, 300°
- Residence time [min]: 10', 60'
- Grindability
- Energy efficiency
- Size/economy
**INTERMEZZO**

*torrefaction: the process parameters*

- Temperature [°C]
  - 200°
  - 300°

- Residence time [min]
  - 10'
  - 60'

- Grindability
- Energy efficiency
- Size/economy
- Gas combustability
INTERMEZZO

torrefaction: the process parameters

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- **Grindability**
- **Energy Efficiency**
- **Size/Economy**
- **Gas Combustability**
- **Feedability**
INTERMEZZO

*torrefaction: the process parameters*

Temperature [°C] vs. residence time [min].

- Grindability
- Energy efficiency
- Size/economy
- Gas combustability
- Feedability
**INTERMEZZO**

*torrefaction: the process parameters*

- temperature [°C]
- residence time [min]
- grindability
- energy efficiency
- size/economy
- gas combustability
- feedability

but depends on: fuel size, fuel moisture, fuel type, integration
INTERMEZZO

*pyrolysis (1)*

- based on flash pyrolysis (~500°C)
- FZK (Karlsruhe) development with Lurgi twin-screw mixer reactor
- high energy efficiency due to mixing char and oil into a slurry (~90%)
- 10 kg/h and 500 kg/h facility available at FZK
- focus on straw
INTERMEZZO

*pyrolysis (2)*

2008: pyrolysis/slurry production
2009: gasifier
CASE STUDY

boundary conditions and assumptions (1)

- oxygen-blown entrained flow gasification, 40 bar
- Fischer-Tropsch process:
  - $C_{5+}$ hydrocarbons are assumed to be upgraded to products
- power production/consumption included in cost calculations
CASE STUDY
boundary conditions and assumptions (2)

200 PJ/y = 2% of EU15 fuel consumption = ~7 GW_\text{th}
requires ~23 million ton/y biomass

~200 PJ/y Fischer-Tropsch
products in Rotterdam

wood chips in collection
facility 4 €/GJ

wood-rich region

sea

the Netherlands

collection facility (80x)

hub/harbour (8x)

Rotterdam (1x)
### CASE STUDY

**wood chips pre-treatment**

<table>
<thead>
<tr>
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<th>pulverizing</th>
<th>other pre-treatment</th>
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<td>--</td>
<td>torrefaction, pulverizing, pelletizing</td>
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CASE STUDY

transport

- wood chips
- wood pellets
- wood oil/char slurry
- torrefied wood pellets (TOP)
- Fischer-Tropsch products
CASE STUDY
10 cases

4 €/GJ wood chips

~200 PJ/y FT products
CASE STUDY

Fischer-Tropsch products costs

$14/\text{GJ}_{\text{diesel}} = 0.50/\text{ltr}_{\text{diesel}}$ (crude oil $80/\text{barrel}$)
CASE STUDY

**Fischer-Tropsch products costs**

- **chips sea transport**
- **slurry**
- **TOP**
- **ADV**
- **ADV**

**Slurry:** pyrolysis oil/char-slurry feeding
**TOP:** torrefied biomass powder feeding
**ADV:** “advanced”

14 €/GJ_{diesel} = € 0.50/ltr_{diesel} (crude oil $ 80/barrel)
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**CASE STUDY**

*Fischer-Tropsch products costs*

- **chips sea transport**
  - slurry
  - TOP
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  - slurry
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CASE STUDY

Fischer-Tropsch products costs

- Chips sea transport
- Wood pellets sea transport
- Other sea transport

FT-products

- Slurry: pyrolysis oil/char-slurry feeding
- TOP: torrefied biomass powder feeding
- ADV: “advanced”
**CASE STUDY**

*costs breakdown*

typical cost breakdown of FT-products from large-scale BtL on imported wood:

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<td>40%</td>
<td>45-50%</td>
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<td>transport/storage</td>
<td>30%</td>
<td>10%</td>
</tr>
<tr>
<td>capital and O&amp;M</td>
<td>30%</td>
<td>40-45%</td>
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<tr>
<td>net power production</td>
<td>-5%</td>
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CONCLUSIONS ON BIO-SYNGAS
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- large-scale bio-syngas has two main technology options:
  - entrained flow gasification of pre-treated biomass
  - fluidised bed gasification with subsequent reforming
- the implementation path:
  - entrained flow: from coal to biomass (large-scale)
  - fluidised bed: from small to large (100% biomass)
- the main technological challenges:
  - entrained flow: pre-treatment
  - fluidised bed: catalytic reforming
CONCLUSIONS ON BIO-SYNGAS
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- the entrained flow case study:
CONCLUSIONS ON BIO-SYNGAS

- the entrained flow case study:
  - biomass pre-treatment can significantly improve BtL economics; reduced transport costs outweigh additional capital costs
CONCLUSIONS ON BIO-SYNGAS

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  - biomass pre-treatment can significantly improve BtL economics; reduced transport costs outweigh additional capital costs
  - pre-treatment there (near wood source) is preferred over pre-treatment here (next to gasifier plant): making wood pellets is worthwhile, but pyrolysis or torrefaction is more attractive (€),
CONCLUSIONS ON BIO-SYNGAS

• the entrained flow case study:
  - biomass pre-treatment can significantly improve BtL economics; reduced transport costs overweigh additional capital costs
  - pre-treatment *there* (near wood source) is preferred over pre-treatment *here* (next to gasifier plant): making wood pellets is worthwhile, but pyrolysis or torrefaction is more attractive (€),
  - but overseas Fischer-Tropsch is favorable (€)!
SNG PRODUCTION
NETHERLANDS: LAND OF NATURAL GAS

- almost 50% (~1500 PJ/year) of primary energy is Natural Gas
- 135 000 km pipe line: in average within 120 m
- 94% of houses connected to gas grid
- international grid connections
NATURAL GAS FOR TRANSPORTATION
coming up soon...

• CNG filling stations network upcoming: 250 filling stations in NL in 2011
• considered as step to biogas (and bioSNG…)
• www.CNGnet.nl

AutoWeek nr. 6, 13 Feb. 2008
ECN TECHNOLOGY DEVELOPMENT

_objective_

- full-scale BioSNG plants (100+ MW)
- 70-75% net energy efficiency from biomass to BioSNG
- pure CO$_2$ as by-product, available to double CO$_2$-reduction potential
- fuel flexible

- 5 €/GJ BioSNG plus biomass feedstock costs
- …major contribution to CO$_2$ reduction: in transport, power, heat, chemical industry, …
ECN TECHNOLOGY DEVELOPMENT
the reference

lignite-to-SNG (US)
~3000 MW input
~55% SNG (100 PJ/y) and ~13% energy by-products
ECN TECHNOLOGY DEVELOPMENT

the choices of ECN

gasification -> gas cleaning -> upgrading to NG specification
ECN TECHNOLOGY DEVELOPMENT

the choices of ECN

- gasification
- gas cleaning
- upgrading to NG specification

using existing technologies
ECN TECHNOLOGY DEVELOPMENT
the choices of ECN

- gasification
- gas cleaning
- upgrading to NG specification

using existing technologies
selection and combining
ECN TECHNOLOGY DEVELOPMENT

*the choices of ECN*

- Gasification
- Gas cleaning
- Upgrading to NG specification

Using existing technologies

Selection and combining

New technology development
ECN TECHNOLOGY DEVELOPMENT

gasification technology

**MILENA technology:**
- high methane yield
- complete conversion
- fuel flexible

25 kW

800 kW
ECN TECHNOLOGY DEVELOPMENT

gas cleaning (1)

**OLGA tar reduction:**
- no methane reduction
- tar recycle to gasifier

2 m³/h

200 m³/h

2 000 m³/h

25 000 m³/h
ECN TECHNOLOGY DEVELOPMENT

gas cleaning (2)

S, Cl, dust, …:
new combinations of existing technologies and materials

2 $m^3/h$ test facility: 10 multipurpose reactors
ECN TECHNOLOGY DEVELOPMENT

status

- operating system at lab-scale (~2 m³/h): biomass conversion to clean CH₄, H₂, CO, CO₂, H₂O, ready for SNG synthesis

- gasifier and tar removal available at pilot-scale (~200 m³/h)

- planned by HVC/ECN:
  - ~10 MW demo (Milena, OLGA, engine), 2012
  - ~50 MW demo (Milena, OLGA, SNG), 2015
CONCLUSIONS ON BIO-SNG

• bioSNG has great potential
• ECN approach: make use of coal-based technology if possible, only develop biomass-specific parts
• high-methane gasifier preferred
• biomass-to-SNG efficiency can be 70-75%
• 40% of (already C-neutral) carbon from biomass leaves system as CO\textsubscript{2}: bioSNG can go far beyond CO\textsubscript{2}-neutral
• bioSNG costs are among the cheapest renewables
FINAL REMARKS
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• biomass gasification plays key role for 2\textsuperscript{nd} generation biofuels (and much more)
FINAL REMARKS

- biomass gasification plays key role for 2nd generation biofuels (and much more)
- (biomass) gasification is “hot”
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• there are no winners yet
FINAL REMARKS

• biomass gasification plays key role for 2nd generation biofuels (and much more)
• (biomass) gasification is “hot”
• … but not mature yet
• there are no winners yet
• but there are many bad choices…
MORE INFORMATION

Bram van der Drift

e: vanderdrift@ecn.nl

t: +31 224 56 4515

w: www.ecn.nl

PO Box 1
NL 1755 ZG Petten
the Netherlands

publications: www.ecn.nl/publications
fuel composition database: www.phyllis.nl
tar dew point calculator: www.thersites.nl
IEA bioenergy/gasification: www.ieatask33.org
Milena indirect gasifier: www.milenatechnology.com
OLGA: www.olgatechnology.com
SNG: www.bioSNG.com and www.bioCNG.com