TORREFACTION AND OTHER PROCESSING OPTIONS

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Depleting fossil fuel resources and GHG/Global Warming

Renewable energy, sustainable fuels

Biomass ➔ Carbon-neutral, local fuel; energy security

Technology barriers to their utilization as energy source
Promising pre-processing technology

Problems
- Large bulk volume
- Wet, high wettability
- Expensive grinding
- Non feedable
- Low energy content
- Inhomogeneous
- Risk of bio contamination

Solved
- High density, densification
- Dry and hydrophobic
- Low grinding costs (red. of 90%)
- Feedable (spherical particles)
- Higher energy density – improved logistics
- Homogeneous
- No bio contamination

Ref: UMEA, 2010
A thermochemical treatment process, similar to roasting or mild pyrolysis.

Energy density increases as ~70% biomass remains with 90% of its original energy content.
THERMAL BREAKDOWN OF WOOD COMPONENTS

WEIGHT PERCENT

TEMPERATURE °C

CELLULOSE
HEMI-CELLULOSE
LIGNIN
WOOD

TORREFACTION RANGE

Ref: WPAC, 2011
<table>
<thead>
<tr>
<th>Parameters</th>
<th>Wood</th>
<th>Wood pellet</th>
<th>Torrefaction Pellets</th>
<th>Charcoal</th>
<th>Coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moisture content (% wt)</td>
<td>30-40</td>
<td>7-10</td>
<td>1-5</td>
<td>1-5</td>
<td>10-15</td>
</tr>
<tr>
<td>Calorific Value (MJ/kg)</td>
<td>9-12</td>
<td>15-16</td>
<td>20-24</td>
<td>30-32</td>
<td>23-28</td>
</tr>
<tr>
<td>Volatiles (% db)</td>
<td>70-75</td>
<td>70-75</td>
<td>55-65</td>
<td>10-12</td>
<td>15-30</td>
</tr>
<tr>
<td>Bulk density (kg/m³)</td>
<td>200-250</td>
<td>550-750</td>
<td>750-850</td>
<td>~200</td>
<td>800-850</td>
</tr>
<tr>
<td>Volumetric energy density (GJ/m³)</td>
<td>2.0-3.0</td>
<td>7.5-10.4</td>
<td>15.0-18.7</td>
<td>6-6.4</td>
<td>18.4-23.8</td>
</tr>
</tbody>
</table>

Ref: KEMA, 2011
Indicative Fuel Properties (Cont.)

Van Krevelen diagram of different fuels

- Wood (dry)
- Charcoal
- Coal/peat

Symbols:
- TW(250)
- TW(260)
- TW(270)
- TW(275)
- TW(280)
- TW(285)
## The added value of torrefaction

<table>
<thead>
<tr>
<th>Higher co-firing percentages</th>
<th>Torrefied biomass can directly milled and co-fired with coals. Product is dry (&lt;5%) and has a calorific value of 20-22 MJ/kg.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost savings in handling and processing</td>
<td>The product is brittle and easily breaks down in small particles. Dedicated biomass equipment (hammer mills, silo storage, biomass feeding systems, biomass burners are not needed. Also it is less sensitive to degradation due to hydrophobic nature.</td>
</tr>
<tr>
<td>Cost savings long in transport</td>
<td>The volumetric energy density of torrefied pellets is 16 GJ/m³ compared to 10 G/m³ of wood pellets</td>
</tr>
</tbody>
</table>

**Torrefaction alone will NOT:**
Significantly reduce sulfur, chlorine and alkali concentrations of the biomass
Biomass collection

Tree logs

Chipping

Wood

Torrefaction

Pelletizing

Torrefied wood chips

Transportation

Wood Pellets

Moisture: 35%
Bulk density: 225 kg/m$^3$
Energy density: 2.5 GJ/m$^3$

Pretreatment

Pelletizing

Torrefied Pellets

Bulk density: 800 kg/m$^3$
Energy density: 16 GJ/m$^3$

Wood Pellets

Moisture: 8%
Bulk density: 700 kg/m$^3$
Energy density: 10 GJ/m$^3$

Pelletizing

Torrefaction

Moisture: 4%
Bulk density: 300 kg/m$^3$
Energy density: 7.5 GJ/m$^3$
TYPICAL TORREFACTION PROCESS FLOW

Advantage: Two marketable products: Pellets & Torrefied pellets

Advantage: Lower energy cost for hammer mill

Raw Material Infeed (chips) → Classifier → Rotary Drum Dryer → Hammer mill → Pelletizer → Torrefier → Cooler
Torrefaction--process

Initial heating

Pre-drying

Post drying and intermediate heating

Torrefaction

Solids cooling

Ref: ECN, 2005
## Overview of Torrefaction technologies providers

<table>
<thead>
<tr>
<th>Reactor technologies</th>
<th>Direct</th>
<th>Indirect</th>
<th>Parties in advanced stage of commercialization</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotary drum dryer</td>
<td></td>
<td>X</td>
<td>BioEndev/ETPC (SWE), Torr-Coal (NL)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>X</td>
<td>CDS (UK), BIO3D (FR), Andritz/EBES (DK/AT), 4Energy Invest (BE), Atmosclear SA (CH)</td>
</tr>
<tr>
<td>Multiple Hearth Furnace/TurboDryer</td>
<td>X</td>
<td></td>
<td>Wyssmont, Integro (USA)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>CMI-NESA (BE)</td>
</tr>
<tr>
<td>Torbed reactor</td>
<td>X</td>
<td></td>
<td>Topell (NL)</td>
</tr>
<tr>
<td>Screw conveyor</td>
<td></td>
<td>X</td>
<td>ETPC (S), BTG, FoxCoal, Biolake (NL), Agri-Tech, RTF (USA)</td>
</tr>
<tr>
<td>Belt conveyor</td>
<td>X</td>
<td></td>
<td>Stramproy (NL), REMASCO (CA), New Earth Eco Technology (USA)</td>
</tr>
<tr>
<td>Compact moving bed</td>
<td>X</td>
<td></td>
<td>ECN (NL), Thermya (FR), Buhler (USA)</td>
</tr>
<tr>
<td>Fixed bed</td>
<td>X</td>
<td></td>
<td>Alterna (CA)</td>
</tr>
<tr>
<td>Microwave</td>
<td>X</td>
<td></td>
<td>Rotawave (UK)</td>
</tr>
</tbody>
</table>

Ref: KEMA, 2011
Most reactor configuration/technologies applied for torrefaction are proven in other applications (drying, pyrolysis, gasification, combustion).

All of them have their own advantages and disadvantages.

Overall efficiency depends on their design configuration in heat integration in the form of either direct or indirect.

Process control (temperature, residence time, particle size, mixing) is the key for better performance of the reactor.
<table>
<thead>
<tr>
<th>Technology</th>
<th>Indirect heating</th>
<th>Direct heating</th>
<th>Proven technology</th>
<th>Proven scalability</th>
<th>High heat transfer</th>
<th>Good temperature control</th>
<th>Acceptance of fines</th>
<th>Acceptance of large particles</th>
<th>Total Pro</th>
<th>Sealing of reactor</th>
<th>Un-even treatment</th>
<th>Fouling</th>
<th>Potential challenges</th>
<th>Total Con</th>
<th>Overall Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>ROTARY DRUM</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>2</td>
<td></td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>MOVING BED</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>2</td>
<td></td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>SCREW</td>
<td>X</td>
<td></td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>2</td>
<td>X</td>
<td>X</td>
<td>3</td>
<td></td>
<td>3</td>
<td>-1</td>
</tr>
<tr>
<td>MULTIPLE HEATING ZONE</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>6</td>
<td>X</td>
<td></td>
<td>1</td>
<td></td>
<td>1</td>
<td>5</td>
</tr>
<tr>
<td>FLUIDIZED BED</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td>4</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>0</td>
<td>4</td>
</tr>
<tr>
<td>MICROWAVE</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td>3</td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td>0</td>
<td>3</td>
</tr>
</tbody>
</table>

Ref: WPAC, 2011
### COMMERCIALIZATION PROJECTS (selected)

<table>
<thead>
<tr>
<th>Party</th>
<th>Demo tech</th>
<th>Target date</th>
<th>Capacity tonne/h</th>
<th>Party</th>
<th>Demo tech</th>
<th>Target date</th>
<th>Capacity tonne/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torr-coal</td>
<td>Torr-coal</td>
<td>2010/11</td>
<td>4.5</td>
<td>Agritech</td>
<td>Torre-tech</td>
<td>2011</td>
<td>5</td>
</tr>
<tr>
<td>4Energy</td>
<td>Stramproy</td>
<td>2010/11</td>
<td>5.5</td>
<td>RFT</td>
<td>RFT</td>
<td>2012</td>
<td>5</td>
</tr>
<tr>
<td>Torrsys</td>
<td>Torrsys</td>
<td>2011/12</td>
<td>5</td>
<td>Stramproy</td>
<td>Stramproy</td>
<td>2010/11</td>
<td>5.5</td>
</tr>
<tr>
<td>EBES</td>
<td>ACB</td>
<td>2012</td>
<td>1.5</td>
<td>New Earth</td>
<td>ECO-PYRO</td>
<td>2012</td>
<td>2</td>
</tr>
<tr>
<td>Integro</td>
<td>Wyssmont</td>
<td>2010/11</td>
<td>2</td>
<td>ECN</td>
<td>BO2</td>
<td>2012</td>
<td>5</td>
</tr>
<tr>
<td>Konza</td>
<td>Konza</td>
<td>2012</td>
<td>10</td>
<td>IDEMA</td>
<td>Thermya</td>
<td>2011</td>
<td>2.5</td>
</tr>
<tr>
<td>Topell</td>
<td>Torbed</td>
<td>2011</td>
<td>8</td>
<td>Atmosclear</td>
<td>Airless</td>
<td>2011</td>
<td>5</td>
</tr>
<tr>
<td>ETPC</td>
<td>BioEndev</td>
<td>2013</td>
<td>4.5</td>
<td>Diacarbon</td>
<td>Diacarbon</td>
<td>2014</td>
<td>8</td>
</tr>
<tr>
<td>BTG</td>
<td>BTG</td>
<td>2014</td>
<td>5</td>
<td>CanBiocool</td>
<td>Rotawave</td>
<td>2011</td>
<td>12</td>
</tr>
<tr>
<td>Foxcoal</td>
<td>Foxcoal</td>
<td>2010/11</td>
<td>4.2</td>
<td>C2SKY</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Biolake</td>
<td>ECN</td>
<td>2011</td>
<td>5</td>
<td>WPAC</td>
<td>TBA</td>
<td>2012</td>
<td>5</td>
</tr>
</tbody>
</table>

*In Ontario, REMASCO is expected to have demonstration plant of 1 ton/hr in 2011*

Ref: WPAC, 2011
Technology status

+ 50 development projects under way (EU & NA)
+ 10 claiming to be in production before end 2011
  - eight distinctly different technologies
  - only few front-runners with > 5 tonnes/hour

- Mostly experience built up with wood torrefaction
- Large differences observed in product properties and qualities
- Uncertainties about large scale processing of product (handling, storage, milling, explosion risk, dust and odor emissions, combustion properties)
- Pelletization possible, but in most cases additives are needed (dependent on torrefaction temperature)
- Milled product is highly reactive and should be kept inert
- Hydrophobicity & leaching uncertainty
Samples of Torrefaction of agri-residue

Tests performed at 250°C temperature and 1 hour residence time

Rice husk  Sawdust  Peanut husks  Bagasse  A

Ref: Dutta, 2010
## Technical Challenges

### Feedstock flexibility
Present technologies mainly concentrate on processing wood chips for a narrow bandwidth of particle size. Agricultural residues are still a challenge, because they ignite easily, have a low bulk density and have long fibres.

### Up-Scaling
At this stage of development only results from pilot plants are available. It will be a challenge for developers to develop a full commercial torrefaction plant, which incorporates the necessary design and process modification for good commercial performance.

### Process optimization
Although some experience has been gained with pilot plant testing, real operational data will reveal the performance of the torrefaction process. The trade-off between energy yield, product quality and production cost is important.

### Product validation
The product needs to be validated by large co-firing trials. Are torrefaction suppliers able to commercially provide a product which meets the specifications of an utility? And is the product really sustainable?
## Business challenges

<table>
<thead>
<tr>
<th>Financing</th>
<th>Most torrefaction developers are small companies with a limited financial base. Convincing investors to finance the necessary R&amp;D and up-scaling efforts is a real challenge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Market maturity</td>
<td>A dominant torrefaction concept will emerge out of a large variety of technologies and initiatives to commercially provide biomass according to the specifications. A product standardization is needed to make the market more transparent and reliable.</td>
</tr>
<tr>
<td>Availability of product</td>
<td>The urgency and quantity of demand is significantly higher than the supply. Torrefaction suppliers are facing the challenge to scale-up their first commercial demonstration plants in a rapid pace</td>
</tr>
</tbody>
</table>
Biomass Conversion Pathways

- **Thermal**
  - Excess air: Combustion → Heat
  - Partial air: Gasification → Fuel Gases (CO + H₂)
  - No Air: Pyrolysis → Liquids

- **Biological**
  - Pretreatment → Fermentation → Ethanol

- **Physical**
  - A/D → Hydrolysis (Heat & Pressure) → CH₄ → Liquids

- **Pretreatment**
  - A/D
  - CH₄
  - Liquids

- **Ethanol**
Biomass Pyrolysis (liquefaction)

- **Rapid Heat Transfer**
- **Oxygen Free Environment**
- 60 – 70 wt% liquids
- 10-15 wt% char
- 10-15 wt% gases

**Storable Product**
Industrial Pyrolysis Reactor

- Hereshoff Carbonizer
- Pillard Rotary Carbonizer
- Keil-Pfaulder Converter
- Cornell Retort
- Thompson Converter
Gasification

Feedstock Flexibility
- Organic Rich Material (inc. Minor amounts of plastics and rubber)
- from Urban Residue Stream
- Industrial, Commercial Operations
- Agriculture/Food Processing
- Black liquor
- Forest Residues
- Agricultural Residues
- Energy Crops

Feedstock Preparation & Feeding

Gasifier Module

Gas Conditioning

Air or Enriched Air $O_2$ Separation (option)

Ash/Slag Sludge Stabilization

Steam (option)

Clean Synthetic Gas

LCV or MCV gas
- Combustion
- Combustion + Boiler
- Combustion in ICE or Gas Turbine (IGCC)

MCV gas
- Single Pass Reactor

Catalytic Reforming & Shift
- CO$_2$ Removal & use, including Sequestration
- Recycle Reactor
- Other $C_1$ Derived Chemicals

Tail Gas (MCV)

Process Heat e.g. Lime Kiln

Process Steam & District Heating

Electricity & Heat (CHP)

Transportation Fuels

Fuel Cell Stationary and Transportation

Alcohols Fischer Tropsch -$CH_4$, DME (Catalyst Choice)

H$_2$

Ammonia (Fertilizer)

$LCV = low$ calorific value gas 4 - 6 MJ Nm$^3$ 100 - 150 Btu/scf

$MCV = medium$ calorific value gas 20 MJ Nm$^3$ 450 Btu/scf
Biomass gasification process

One of the best way to optimize the extraction of energy from biomass and to obtain a standardized gas from very different materials

\[
\text{Air, Steam, CO}_2, \text{ and/or O}_2 + \text{BIOMASS} \rightarrow \begin{array}{l}
\text{CO, H}_2, \text{CO}_2, \text{H}_2\text{O, CH}_4, \text{C}_2\text{H}_4 \\
\text{+ unconverted tars (all organic compound with mass > C}_6\text{H}_6)
\end{array}
\]

Low Calorific Value: 4 - 6 MJ/Nm³ Using air and steam/air
Medium Calorific Value: 12 - 18 MJ/Nm³ Using oxygen and steam

The main challenges of biomass gasification are:

- Good control of temperature in the reactor
  - High heating rate (hundreds of degrees per second) and high temperatures (around 800°C) are necessary to maximize the gas yield

- TARS conversion
  - TARs condense in the cold parts \(\Rightarrow\) plugging of tubes or agglomeration phenomena
  - TARS removal by filtration \(\Rightarrow\) lost of efficiency since they still contain energy
## Biomass gasification reactors

### Fixed bed technology

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Updraft gasifier</td>
<td>Simple design, good maturity.</td>
<td>Low calorific value gas with a high tar and fines content.</td>
</tr>
<tr>
<td>Downdraft gasifier</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Fluidized bed technology

<table>
<thead>
<tr>
<th>Reactor Type</th>
<th>Advantages</th>
<th>Drawbacks</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bubbling fluidized bed</td>
<td>Good gas and solid mixing, uniform temperatures and high heating rates, greater tolerance to particle size range and safer operation due to good temperature control compared to fixed bed gasification</td>
<td>Low density biomass fuel (with respect to the bed particles) segregates to the surface of the bed. This segregation phenomenon is increased by the formation of volatiles and gaseous species bubbles around the fuel particle, reducing the conversion rate. Fused ash and tar condensation provokes defluidization.</td>
</tr>
<tr>
<td>Circulating fluidized bed</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Diagrams

- **Updraft gasifier**
- **Downdraft gasifier**
- **Bubbling fluidized bed**
- **Circulating fluidized bed**
Gasification based process scheme

- IGCC
- Dual fuel + steam cycle
- Dual fuel
- Gas engine
- Pressurised FB or CFB
- CFB
- Updraft fixed bed
- Downdraft fixed bed

Ref: BTG, 2005
<table>
<thead>
<tr>
<th>Plant</th>
<th>Tech.</th>
<th>Feedstocks</th>
<th>Power</th>
<th>Costs</th>
<th>Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>ENAMORA, Spain</td>
<td>BFB</td>
<td>Almond shell, industry residue</td>
<td>Fuel: 3500 kW; Electrical: 750 kWe</td>
<td>Euro: 1.1 million</td>
<td>Private</td>
</tr>
<tr>
<td>Greve-in-Chinti, Italy</td>
<td>CFB</td>
<td>RDF</td>
<td>Fuel: 2X15 MW; Electrical: 6.7 MWe</td>
<td>Euro: 20 million</td>
<td>Own</td>
</tr>
<tr>
<td>Gussing, Australia</td>
<td>Dual FB-CHP</td>
<td>Wood chips, wood residues</td>
<td>Fuel: 8 MW; Heat: 4.5 MWth; Electrical: 2 MWe</td>
<td>Euro: 8.7 million</td>
<td>Public: 60% Private: 40%</td>
</tr>
<tr>
<td>Lahti, Finland</td>
<td>CFB, Co-firing</td>
<td>Wood, board, paper, plastics, RDF</td>
<td>Fuel: 40-70 MW; Heat: 40-70 MWth; Power: 20 MWe of 176 MWe coal power plant</td>
<td>Euro: 12 million</td>
<td>25% by EU</td>
</tr>
<tr>
<td>Rundersdorfer, Germany</td>
<td>CFB</td>
<td>Biomass</td>
<td>Fuel: 100 MW</td>
<td>N/A</td>
<td>Own</td>
</tr>
<tr>
<td>SVZ, Germany</td>
<td>Fixed, Slagging, Entrained</td>
<td>RDF, oil slurries, mixture of tar and sewage sludge</td>
<td>Fuel: 420 MW; Electrical: 75 Mwe; Chemical: 120 kt/a Methanol</td>
<td>Euro: 335 million</td>
<td>N/A</td>
</tr>
<tr>
<td>Vermont, USA</td>
<td>Indirect CFB</td>
<td>Wood chips, residue wood, pellets,</td>
<td>Fuel: 44 MW; Heat: n.a; Electrical: 9 MWe</td>
<td>U$: 14 million</td>
<td>DOE, FERCO</td>
</tr>
<tr>
<td>DTU, Denmark</td>
<td>Two stage fixed bed</td>
<td>Wood chips (45% moisture)</td>
<td>Fuel: 70 MW; Heat: 39 MW; Electrical: 17.5 kWe</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>
To help industries and communities generate and enjoy cleaner energy

- Thermal gasification
- SCW gasification
- Torrefaction
- Biomass Co-firing
- Chemical looping gasification
- Multi stage Air-Steam gasification
Chemical Looping Gasification Process

Facilitates in-process CO₂ capture and sorbent regeneration

Continuous production of H₂ enriched product gas

Meets present two major challenges

Chemical Looping Gasification Process

- Continuous production of H₂ enriched product gas
- Meets present two major challenges
- Provides a higher quality energy
- Reduces emission of Carbon dioxide
Concluding remarks

- Torrefaction technology appears to be a promising pre-processing technology of biomass for replacing coal.
  - Presently torrefaction technology is making its first careful steps towards commercialization while the technology and product quality are still surrounded by uncertainties
    - Limited feedstock flexibility (favours woody biomass only)
  - However a few European utilities (Essent B.V., DELTA N.V.) have taken the risk by signing long-term off-take contracts with torrefaction suppliers, and other utilities (RWE Innogy) are also participating in the development of torrefaction.
  - The North American torrefaction initiatives are still in pilot scale phase, where R&D efforts and financing are needed to make the up-scaling steps towards commercial demonstration.
    - Driven by public and private partnership (Ex: DOE, EPRI, CEATI, WPAC) and utilities who have to deal with renewable obligation schemes (Ex: OPG) where universities play an important role.
  - The market is mainly driven by the utilities and also have potential in residential and industrial heating sectors.
Thank you.

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Email: adutta@uoguelph.ca
Tar conversion:

It can be done thermally or catalytically (a lower process temperature improves control of exhaust species).

Cleaned gasification gas contains mostly gas phase (light hydrocarbons + H₂, CO₂, CO, H₂O)

The catalytic tars conversion can both decrease tar production and modify gas composition.

There are two ways for catalytic tar removal:

1: Primary method: the catalyst is mixed with biomass directly inside the gasifier.
   - Single-stage process

2: Secondary method: the catalyst is placed down stream the gasifier.
   - Dual-stage process

Primary methods are more difficult to set up (multiphase catalysis), but reduce the costs of the overall process (reactor set up is simplified).
The diagram illustrates the CLG SYSTEM, which involves the reaction \( \text{CaCO}_3 = \text{CaO} + \text{CO}_2 \). The system includes a screw feeder and a distributor plate, with CO\(_2\) for fluidization and H\(_2\) for external heating. CO\(_2\) is used for sequestration, and H\(_2\) for applications. The heat exchanger is indicated, and water is involved in the process. The diagram references Dutta, 2010.
<table>
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<th>Technology</th>
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Ref: WPAC, 2011