From today’s systems to the future renewable energy systems

Iva Ridjan
US-DK summer school
AAU Copenhagen
17 August 2015
STRUCTURE OF ENERGY SYSTEMS
Components

Demand
- Electricity
- Heat
- Transport

Supply (Technologies)
- Power plants
- Boilers
- Vehicles

Resources
- Fossil fuels
- Renewables
Supply/Demand Balance
The Future... Smart Energy System

Resources
- Bioenergy Fuels
- Wind etc.
- Solar etc.

Conversion
- Combustion Engines
- Fluctuating Electricity
- Electrofuels
- CHP (or Quad)
- Fluctuating Heat

Exchange and Storage
- Fuel Storage
- Power Exchange
- Electricity Storage
- Thermal Storage

Demand
- Mobility (Vehicles)
- Flexible Electricity
- EVs
- Cooling
- Heating
What happens on the resource side?
Resources in the Future Energy System

• Fuel:
  – Bioenergy

• Dispatchable Renewable Electricity:
  – Hydro with storage
  – Geothermal

• Intermittent Renewable Electricity:
  – Wind
  – Solar
  – Wave
  – Tidal
  – River hydro
Bioenergy

• Can exist in three forms:
  – Biomass
  – Biogas
  – Biofuel

• Ideal substitute for fossil fuels:
  – Stored transportable energy
  – Biomass: replace coal
  – Biogas: replace natural gas
  – Biofuel: replace oil
Bioenergy

**Positives**
- Combustible fuel just like fossil fuels => stored energy
- Exists in three forms: mass, gas, and liquid

**Negatives**
- Limited resource
- Although it is combustible, it will require new conversion technologies
- Food production
The Future is Intermittent!

• With a limited bioenergy resource, we will need to produce most of our electricity from the intermittent resources:
  – Wind
  – Solar
  – Wave
  – Tidal
  – River hydro
Key Question for Today?

What technologies do we need to be able to use these intermittent renewable resources?
List of Common Technologies

• Power plants and CHP:
  – Condensing
  – Back Pressure
  – Extraction
• Boilers
• Heat Pumps
• Electric Vehicles
• Transport Fuel Pathways

• Renewables:
  – Hydro
  – Wind
  – Wave
  – Tidal
  – PV
  – CSP
  – Solar thermal
  – Geothermal
  – Bioenergy
7 STEPS TO 100% RENEWABLE ENERGY

The Integration of Intermittent Renewable Energy
7 Steps and Their Limits

1. 0-25%: Conventional Power Plant regulation

2. 0-25%: Power Plants are converted to Combined Heat and Power which are regulated according to wind production using Thermal Storage and the District Heating network

3. 25-40%: Large-scale heat pumps and thermal storage in the district heating networks

4. 40-55%: Electric grid stabilisation requirements are reduced

5. 55-65%: Add Flexible Electricity Demand and Replace conventional cars with smart-charge electric cars

6. 65-90%: Electrofuels-methanol/DME

7. Syngas: Electrolysers for the production of electrofuels and large-scale fuel storage (i.e. gas and liquid fuel storage)
We will look into:

1. 0-25%: Conventional Power Plant regulation

2. 0-25%: Power Plants are converted to Combined Heat and Power which are regulated according to wind production using Thermal Storage and the District Heating network

3. 25-40%: Large-scale heat pumps and thermal storage in the district heating networks

4. 40-55%: Electric grid stabilisation requirements are reduced

5. 55-65%: Add Flexible Electricity Demand and Replace conventional cars with smart-charge electric cars

6. 65-90%: Electrofuels-methanol/DME

7. Syngas: Electrolysers for the production of electrofuels and large-scale fuel storage (i.e. gas and liquid fuel storage)
THE FLEXIBLE TECHNOLOGIES

Step 1: Regulating the Power Plants
Energy System 0.0

Resources
- Fuels
- Combustion Engines

Conversion
- Power Plants
- Heat-Only Boilers

Exchange and Storage
- Power Exchange

Demand
- Mobility
- Electricity
- Cooling
- Heating
Conventional Power Plants (0-25\%)
Types of Power Plants

• Engines

• Gas Turbines

• Steam Turbines
Types of Power Plants

- Engines
- Gas Turbines
- Steam Turbines
Types of Power Plants

• Engines

• Gas Turbines

• Steam Turbines
Gas is More Flexible

• Regulation:
  – Coal-based steam:
    • 5% of load within 30 seconds
    • 4%/minute between 50-90% of max load
    • 2%/minute below 50% and above 90% of max load
  – CCGT: 10%/minute

• Gas engines and turbines can start within 15 minutes

• So, is this good enough for the wind?
An Extreme Example
(Jutland Hurricane 8th January 2005)
THE FLEXIBLE TECHNOLOGIES

Step 2: CHP & District Heating
District Heating & Thermal Storage (0-25%)

- **Resources**: Wind etc., Fuels
- **Conversion**: Combustion Engines, Fluctuating Electricity, CHP, Boilers
- **Relocation**: Power Exchange
- **Exchange and Storage**: Thermal Storage
- **Demand**: Mobility, Electricity, Cooling, Heating
District Heating
Types of District Heating

• Nordic: used in Sweden, Iceland, Finland, and Denmark. Supply temperature of ~100°C with a focus on efficiency.
  – Future: low-temperature of 40°C - 60°C.

• Central Europe: Supply temperature of ~250°C with a focus on industrial process heat.

• Eastern Europe: Supply temperature of ~140°C with an unknown focus.
Supply Technologies for District Heating

- Boilers
- Combined heat and power plants
- Thermal storage
- Heat pumps
Boilers

Centralised
- Backup and peaks
- Usually supply 5% of annual district heating demand
- Relatively cheap
- 90% Efficiency

Individual
- Liquid, gas, and solid fuels
- Oversized for coldest day
- 65-90% Efficiency

8/17/2015
Copenhagen, Denmark
Combined Heat & Power Plants

100 Units Fuel

Power Plant

35 Units Electricity
50 Units Heat
CHP Regulation

Wind Power

CHP Plant

Thermal Storage

Electricity Demand

Hot Water Demand

Wind Power

CHP Plant

Thermal Storage

Electricity Demand

Hot Water Demand
Plant Scale Can Vary

Centralised

Centralised CHP
Decentralised CHP
Wind turbine
Interconnector (AC)
Interconnector (DC)

Electric power infrastructure 1985

Decentralised

Centralised CHP
Decentralised CHP
Wind turbine
Offshore wind turbine
Interconnector (AC)
Interconnector (DC)

Electric power infrastructure 2009

Copenhagen, Denmark
Key Differences

Centralised
1. Efficiency: plants are not located near the heat demands, so mostly condensing PP.
2. Flexibility:
   - Big steam or gas turbines
   - Very few of them
3. Fuels:
   - Coal
   - Gas
   - Nuclear
   - Biomass

Decentralised
1. Efficiency: plants are located near the heat demands, so mostly extraction CHP.
2. Flexibility:
   - Small turbines or engines
   - Lots of them
3. Fuels:
   - Gas
   - Biogas
   - Biomass
Benefits of District Heating

• Improves the efficiency of the system (CHP, O&M, etc.)

• Enables more renewable energy resources to be utilised

• Increases the comfort-levels for the end-user

• Reduces the thermal capacity necessary

• Creates short-term and long-term flexibility
THE FLEXIBLE TECHNOLOGIES

Step 3: Heat Pumps
Heat Pumps & Thermal Storage (25-40%)
Heat Pumps

100 Units Electricity → Heat Pump (COP = 3.5) → 350 Units Heat
Mechanical Heat Pumps

• Very efficient:
  – Conventional electric heating = 100%
  – Heat pumps ~350%

• Excellent renewable integration technology

• Utilises low temperature heat sources

• Can be used for heating or cooling

• Individual and centralised systems
PES & CO2

- Fuel TWh/year
- CO2 Mt/year

REF
Power Plants
District Heating
Heat Pumps

Copenhagen, Denmark
Costs & Wind Power

<table>
<thead>
<tr>
<th></th>
<th>2020 Total Costs M€/year</th>
<th>Wind Power %</th>
</tr>
</thead>
<tbody>
<tr>
<td>REF</td>
<td>18,000</td>
<td>0%</td>
</tr>
<tr>
<td>Power Plants</td>
<td>17,000</td>
<td>5%</td>
</tr>
<tr>
<td>District Heating</td>
<td>16,000</td>
<td>10%</td>
</tr>
<tr>
<td>Heat Pumps</td>
<td>15,000</td>
<td>15%</td>
</tr>
</tbody>
</table>

8/17/2015 Copenhagen, Denmark
7 Steps and Their Limits

1. 0-25%: Conventional Power Plant regulation

2. 0-25%: Power Plants are converted to Combined Heat and Power which are regulated according to wind production using Thermal Storage and the District Heating network

3. 25-40%: Large-scale heat pumps and thermal storage in the district heating networks

4. 40-55%: Electric grid stabilisation requirements are reduced

5. 55-65%: Add Flexible Electricity Demand and Replace conventional cars with smart-charge electric cars

6. 65-90%: Electrofuels-methanol/DME

7. Syngas: Electrolysers for the production of electrofuels and large-scale fuel storage (i.e. gas and liquid fuel storage)
THE FLEXIBLE TECHNOLOGIES

Step 6: Electrofuels & Fuel storage
Electrofuels & Fuel Storage (65-90%)
Electrofuels

• **Aim:** to get electricity into the transport sector, in particular for modes that cannot utilise direct electrification (i.e. trucks, ships, planes)

• **Why:**
  – No oil
  – Limited biofuels
  – Large intermittent electricity resource (i.e. wind, solar, tidal, etc)
Creating Electrofuels

• Carbon capture:
  – Carbon trees
  – Power plants
  – Industry

• Dissociation of Oxides:
  – Steam electrolysis (H₂ & O₂)
  – Co-electrolysis (H₂ & CO)

• Fuel Synthesis:
  – Determines your final fuel
SUMMARY

A 100% Renewable Energy System in 7 Steps
Energy System 0.0

Resources
- Fuels
- Power Plants
- Heat-Only Boilers

Conversion
- Combustion Engines

Exchange and Storage
- Power Exchange

Demand
- Mobility
- Electricity
- Cooling
- Heating
Conventional Power Plants (0-25%)
District Heating & Thermal Storage (0-25%)
Reduction in Electric Grid Regulations (40-55%)
Flexible Demand and SEV (55-65%)
Energy System 6.0 (65-90%)
To be answered...

Resources
- Bioenergy Fuels
- Wind etc.
- Solar etc.

Conversion
- Combustion Engines
- Fluctuating Electricity
- Electrofuels
- CHP (or Quad)
- Fluctuating Heat

Exchange and Storage
- Fuel Storage
- Power Exchange
- Thermal Storage

Demand
- Mobility (Vehicles)
- Flexible Electricity
- Cooling
- Heating
- EVs
EXTRA SLIDES
Removing Grid Regulations (40-55%)

- Inertia and balancing are no longer dependent on traditional sources
- There are now more active components!
- Grid Share = 0%
- Min CHP/PP = 0 MW

Electric grid stabilisation requirements:

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Minimum grid stabilisation production share</td>
<td>0.3</td>
</tr>
<tr>
<td>Stabilisation share of CHP2</td>
<td>0</td>
</tr>
<tr>
<td>Heat Pump Maximum load</td>
<td>0.5</td>
</tr>
<tr>
<td>Stabilisation share of Waste CHP</td>
<td>0</td>
</tr>
<tr>
<td>Stabilisation share smart charge EV and V2G</td>
<td>0</td>
</tr>
<tr>
<td>Stabilisation share transmission line</td>
<td>0</td>
</tr>
<tr>
<td>Minimum CHP in gr. 3:</td>
<td>300</td>
</tr>
<tr>
<td>Minimum PP:</td>
<td>0</td>
</tr>
</tbody>
</table>
The Traditional System

Non Active Components

- Demand
- RES (Renewable Energy Sources)
- DG (Distributed Generation)

Active Components

- Centralised CHP and Power Plants
System 1: Activating DG CHP-units

Non Active Components

- Demand
- RES (Renewable Energy Sources)

Active Components

- Centralised CHP and Power Plants
- DG (Distributed Generation)
System 2: CHP-Units and Heat Pumps

Non Active Components
- Demand
- RES (Renewable Energy Sources)

Active Components
- Centralised CHP and Power Plants
- DG (Distributed Generation)
- Heat Pumps
System 3: Activating RES & the Electricity Demand

Non Active Components

Demand

RES (Renewable Energy Sources)

Active Components

Centralised CHP and Power Plants

DG (Distributed Generation)

Heat Pumps

Wind Power

Flexible Electricity (e.g. SEV)
Flexible Demand and SEV (55-65%)
Demand Side Management (Flexible Electricity)

- Allows users to self regulate according to the price of electricity: the demand side of the “Smart” grid

- Could also be paid for simply being available to change your demand up/down, but without actually doing it
Buildings (~10%)

**Time Dependent**
- Cooker
- Microwave
- Computer
- Television
- Iron

**Demand Side Manageable**
- Fridge
- Freezer
- Hot Water (with storage)
- Space Heating
Industry (~10%)
Transport

• Electric vehicles:
  – Battery (BEV)
  – Smart (SEV)
  – Vehicle to Grid (V2G)
Flexible Demand

• Like Electricity Storage
  – Power capacity (MW): the maximum instantaneous amount you can move
  – Storage Capacity (TWh): the total amount you can move OR the length of the time you can move it over

• Better than Energy Storage
  – Moving demand can have an efficiency of 100%
  – Electricity storage has a maximum efficiency of ~85%
Flexible Demand

- Residential:
  - According to the iPower project (www.ipower.net.dk)
  - Approximately 20-35 kWh can be moved over 1 day in a home: check his slides.

![Possible time shift table]

<table>
<thead>
<tr>
<th>150 m² detached house</th>
<th>Δt [K]</th>
<th>Possible heat storage [kWh]</th>
<th>Heat loss coefficient UA at t₀ -12°C [kW]</th>
<th>Possible time shift [h]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium thermal mass: 80 Wh/m²K</td>
<td>2</td>
<td>24</td>
<td>70'les: 12</td>
<td>2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BR08: 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BR10: 6</td>
<td></td>
</tr>
<tr>
<td>High thermal mass: 120 Wh/m²K</td>
<td>2</td>
<td>36</td>
<td>70'les: 12</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BR08: 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BR10: 6</td>
<td></td>
</tr>
<tr>
<td>+ heavy under floor heating</td>
<td>2-4</td>
<td>60?</td>
<td>70'les: 12</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BR08: 7</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>BR10: 6</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DHW tank</th>
<th>Δt [K]</th>
<th>Possible heat storage [kWh]</th>
</tr>
</thead>
<tbody>
<tr>
<td>200 l</td>
<td>15</td>
<td>3.4</td>
</tr>
</tbody>
</table>

8/17/2015 Copenhagen, Denmark
Questions?

iva@plan.aau.dk