<table>
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<tr>
<td>Author(s)</td>
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District heat with Small Modular Reactors (SMR)

Ville Tulkki - Ville.Tulkki@VTT.fi
Esa Pursiheimo,
Tomi J. Lindroos
Preface

This presentation summarizes findings from a VTT’s study of Small Modular Reactors (SMRs) conducted during the 2017. The PARIS project (Potential of Advanced Reactors for Industry and Society) was an internal project where we mapped different reactor types, their possible applications, and modelling requirements. The work is planned to continue with the most promising applications during the 2018.
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1. Introduction to Small Modular Reactors
   ▪ What? When? Where they can be used?

2. District heat with SMRs; Case study 2030
   ▪ Feasibility study with preliminary cost estimates
1. Introduction to Small Modular Reactors (SMR)
   - Small nuclear reactors with fast construction time.
   - First already built, many other concepts following soon.
   - Can replace fossil fuels in district heat production and in industry steam production.
What are SMRs?

- **Small**
  - From ten to few hundreds of megawatts (MW) instead of gigawatt-scale reactors
  - New appliances for smaller users

- **Modular**
  - Standardized product
  - Can install multiple reactor modules for larger demands
  - Major components factory-produced instead of constructed on site

- **Reactors**
  - Nuclear reactors
  - Wide variety of proposed designs
When can we get SMRs?

Canada:
- Reactor designs in pre-licensing pipeline
- Aims to be SMR technology hub

United States:
- NuScale SMR under licensing process
- First plant to be finished mid-2020s

United Kingdom:
- SMR competition on-going

Russia:
- Movable barge SMRs
- RITM-200 ship reactor usable on land also

China:
- HTR-PM dual unit SMR (200 MWe) high temperature reactor ready in 2018
- Aims for strong domestic and international expansion

South Korea:
- SMART light water SMR

Quite soon, actually.
Small modular reactors can be used for electricity production...

- Faster construction
- Lower per unit costs
- Suitable for small grids and users
- Grid support function
- More units mean better supply chain
… but they can also produce heat for industry and district heating

District heating
Bioindustry
From low temperature to high temperature applications

Refineries
Desalination

Synthetic fuels
Catalytic processes

Hydrogen production
Various non-electric applications for nuclear have been done before

- Steam supplied to paper mill by a research reactor in Halden, Norway
- District heating with nuclear power
- Seawater desalination with nuclear power
- Nuclear powered ships
Many ways to split the atom:

- In order to produce power in a nuclear reactor, you need two things in addition to uranium:

  **Coolant** can be
  - Water
  - Gas
  - Molten salt
  - Molten sodium
  - Molten lead

  **Moderator** can be
  - Water
  - Graphite
  - (none)
NuScale

- Factory produced reactor modules
  - 160 MWth Light Water Reactor
- 50 MWe turbine for each reactor
  - Also utilization of heat
  - Exit steam max 300°C
- 1-12 module facility
- Under licensing in USA
  - First power plant planned to be finished mid-2020s

- Preliminary techno-economic case studies on feasibility to district heating

Source: free to use wikimedia figure
https://commons.wikimedia.org/wiki/File:Diagram_of_a_NuScale_reactor.jpg
**HTR-PM**

**High Temperature Reactor – Pebble bed Modular**

- Gas cooled pebble bed reactor
  - Technology initially developed in Germany
- Demonstration reactor should be connected to grid in China next year
  - Reactor outlet T 750 °C
  - Secondary circuit steam at 565 °C
  - 250 MWth per reactor
  - Dual reactor driving one 200 MWe turbine
- 2018 start of construction for second phase
  - 3 x dual reactors for 600 MWe turbine
- Feasibility study on petrochemistry application with Saudi-Arabia, collaboration with Indonesia, Poland…

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“Nuclear energy is also a low-carbon source of heat and can play a relevant role in decarbonising other parts of the energy system where heat is being consumed, e.g. district heating, seawater desalination, industrial production processes and fuel synthesis.”

“On-board nuclear energy storage and power generation could be a clean and relatively cheap solution to decarbonise shipping.”
2. District heat with SMRs; Case study
   - Modelled a Finnish city’s district heat grid at 2030
   - With and without NuScale SMR
   - One NuScale unit could fit in to the modelled district heating system with 10 to 20 years payback time depending on final price and operation costs
### Assumed DH production structure at 2030

<table>
<thead>
<tr>
<th>DH production unit</th>
<th>Code</th>
<th>DH capacity</th>
<th>ELC capacity</th>
<th>OM *</th>
<th>Minimum load</th>
<th>Total efficiency</th>
<th>Start-up cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenario 1: NuScale DH</td>
<td>NuScale DH</td>
<td>152 MW</td>
<td>-</td>
<td>5.6 €/MWh**</td>
<td>40%</td>
<td>81%</td>
<td>-</td>
</tr>
<tr>
<td>Scenario 2: NuScale CHP</td>
<td>NuScale CHP</td>
<td>94 MW</td>
<td>35 MW</td>
<td>8.9 €/MWh**</td>
<td>40%</td>
<td>94%</td>
<td>-</td>
</tr>
<tr>
<td>Scenario 3: no NuScale</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Natural gas combined cycle CHP</td>
<td>NGCC</td>
<td>214 MW</td>
<td>234 MW</td>
<td>0.7 €/MWh</td>
<td>50%</td>
<td>90%</td>
<td>11700 €</td>
</tr>
<tr>
<td>Biomass steam turbine CHP</td>
<td>BioCHP</td>
<td>156 MW</td>
<td>74 MW</td>
<td>1.8 €/MWh</td>
<td>25%</td>
<td>88%</td>
<td>4500 €</td>
</tr>
<tr>
<td>Gas turbine + waste heat CHP</td>
<td>GtCHP</td>
<td>76 MW</td>
<td>42 MW</td>
<td>0.4 €/MWh</td>
<td>40%</td>
<td>90%</td>
<td>2100 €</td>
</tr>
<tr>
<td>Heat pump</td>
<td>HP</td>
<td>40 MW</td>
<td>-</td>
<td>-</td>
<td></td>
<td>400% ***</td>
<td>-</td>
</tr>
<tr>
<td>Biomass heat plant</td>
<td>BioDH</td>
<td>80 MW</td>
<td>-</td>
<td>2.1 €/MWh</td>
<td>-</td>
<td>90%</td>
<td>-</td>
</tr>
<tr>
<td>Natural gas heat plant</td>
<td>GasDH</td>
<td>580 MW</td>
<td>-</td>
<td>0.8 €/MWh</td>
<td>-</td>
<td>90%</td>
<td>-</td>
</tr>
</tbody>
</table>

Assumptions based on public sources to correspond to the scale of Espoo CHP network as per the earlier work reported in [http://www.vtt.fi/inf/julkaisut/muut/2016/VTT-R-01173-16.pdf](http://www.vtt.fi/inf/julkaisut/muut/2016/VTT-R-01173-16.pdf) (section 2.4)

* OM cost per produced DH
** Includes fuel cost
*** COP value 4.0
Assumed DH consumption and electricity spot price

Other assumptions

<table>
<thead>
<tr>
<th>Assumption</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emission permit price</td>
<td>20 €/ton</td>
</tr>
<tr>
<td>Natural gas price</td>
<td>27 €/MWh</td>
</tr>
<tr>
<td>Biomass price</td>
<td>35 €/MWh</td>
</tr>
<tr>
<td>Heat tax - CHP (gas)</td>
<td>12.1 €/MWh</td>
</tr>
<tr>
<td>Heat tax - boiler (gas)</td>
<td>17.4 €/MWh</td>
</tr>
<tr>
<td>Grid cost (HP)</td>
<td>35 €/MWh</td>
</tr>
</tbody>
</table>

Minimum heat load of 80MW models hot water consumption.

Average electricity spot price ranges from 15 €/MWh (factor 0.4) to 52 €/MWh (factor 1.4).

Assumptions based on public sources as per earlier work reported in http://www.vtt.fi/inf/julkaisut/muut/2016/VTT-R-01173-16.pdf
NGCC and BioCHP have summer maintenance shut-outs.

Heat plants (bio and gas) have no limits in terms of flexibility or minimum load.

Small heat storage (50 MWh) is used in the model to represent storage properties of DH pipeline.
Role of natural gas fired power plants decreases in NuScale scenarios.

Heat pump utilisation remains in high level due to high efficiency.

Even with high level base load supply by NuScale high utilisation of biomass fired heat plant is required.
Utilisation rate of DH production units

Utilisation rate of NuScale is not sensitive to DH demand or electricity price.

DH demand and electricity price variation affects strongly average DH production cost.

High electricity prices are necessity for higher NGCC operation.
In DH mode NuScale operates at low load during summer due to high DH capacity, whereas in CHP mode capacity is more compatible with DH load.

Number of peak load hours of biomass fired heat plant relatively high.
Production cost of DH in NuScale scenarios is 58-62% of BAU scenario.

Fuel cost and electricity trading affect most production cost.

Taxes are low since natural gas fired units are operated at relatively low level.
Marginal cost of DH production

Marginal cost in NuScale CHP scenario is negative during summer hours due to sold nuclear electricity.
Investment payback period

Discount rate of 5% is used.

Fixed OM cost of 0.043 M€/MW is used for NuScale in annual costs.
Sensitivity of investment

License costs are assumed to be part of the CAPEX
Small Modular Reactors (SMR)

* Are small nuclear reactors with fast construction time.
* First have been already built and many other concepts will follow soon.
* Can replace fossil fuels in district heat production and in industry steam production for both high and low temperature heat.

One NuScale SMR unit would fit to the model district heating system with high utilization ratio. The estimated payback time would be from 10 to 20 years depending on assumed costs and prices.