# Sector coupling cases in Finland

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**Yuri Kroyan and Totti Nurmi**

Energiateollisuus

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https://www.linkedin.com/in/totti/

# Cases of Sector Coupling provided by:

HELEN

fortum

KEMIJOKI

LEMPÄÄLÄN ENERGIA

VIRTA

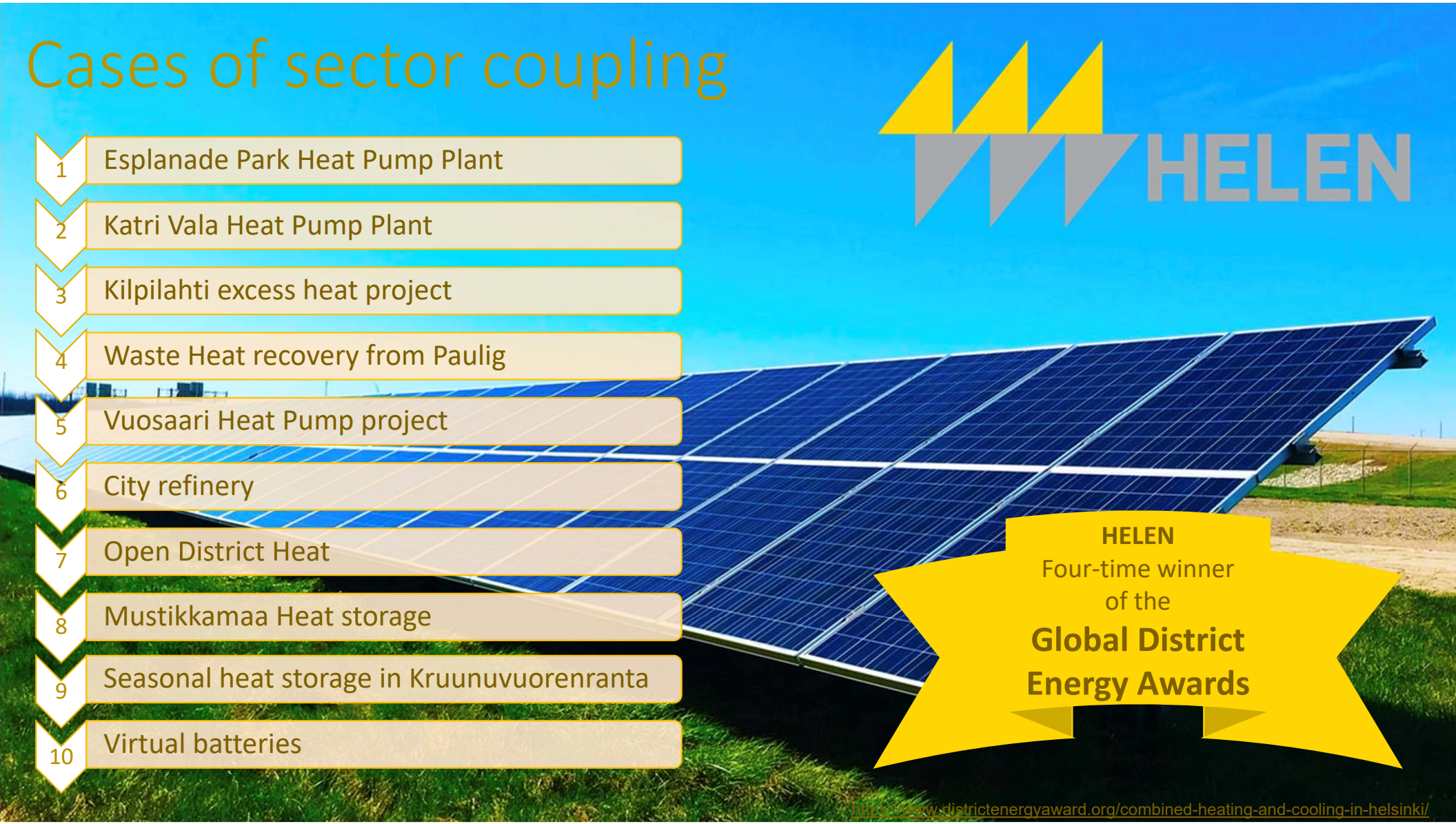
STEP
Sustainable Energy Solutions


| Name of the company | Business type | Size of the company (Helen Group) |
|---|---|---|
| Helen OY<br><br>Helsinki, Finland<br><br>www.helen.fi | World's most efficient energy production company | 1 080 Employees (2018)<br><br>930 M€ Net Sales (2018)<br><br>500 000 Customers |

# Cases of sector coupling

1. Esplanade Park Heat Pump Plant
2. Katri Vala Heat Pump Plant
3. Kilpilahti excess heat project
4. Waste Heat recovery from Paulig
5. Vuosaari Heat Pump project
6. City refinery
7. Open District Heat
8. Mustikkamaa Heat storage
9. Seasonal heat storage in Kruunuvuorenranta
10. Virtual batteries

HELEN

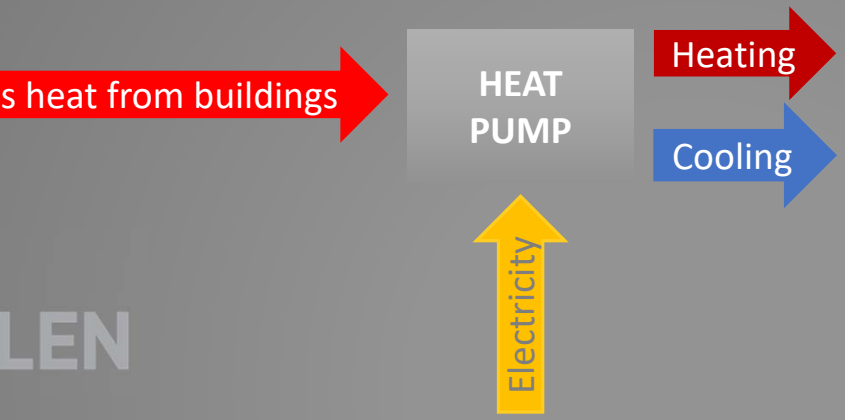


**HELEN**
Four-time winner
of the
**Global District Energy Awards**

https://www.districtenergyaward.org/combined-heating-and-cooling-in-helsinki/

# Case 1

# Esplanade Park Heat Pump Plant

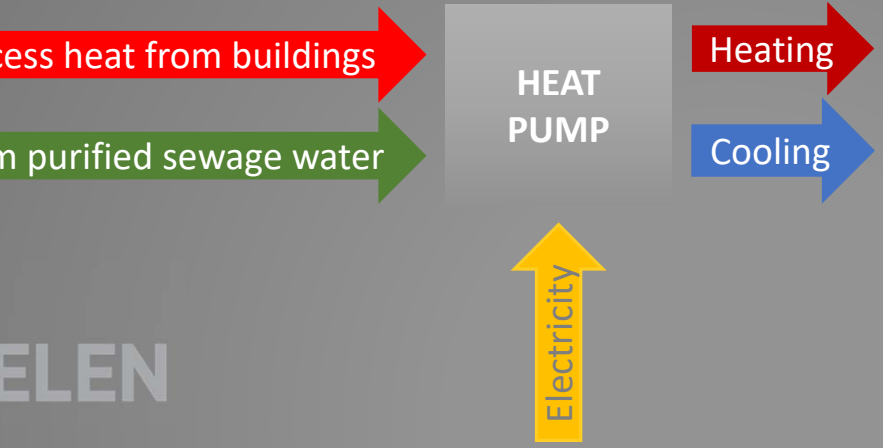



| | | | |
|---|---|---|---|
| Case type | Waste heat management | | |
| Equipment | 2 heat pumps | | |
| Installed capacity | District heat: 22MW | District cooling: 15MW | Cooling storage: 35MW |
| Economics | CAPEX > 10 M euro | | |
| Business model | Sale of the district heating and cooling | | |
| Saved emissions | 20 000 tons of carbon dioxide yearly | | |
| Utilization | Excess heat from buildings and 7.6 MW of electric power | | |
| Final product | Heating and cooling | | |
| Receiver | Residential and commercial customers in the city of Helsinki | | |

https://www.helen.fi/en/news/2018/underground-heating-and-cooling-plant-utilises-waste-heat

# Case 2

# Katri Vala Heat Pump Plant



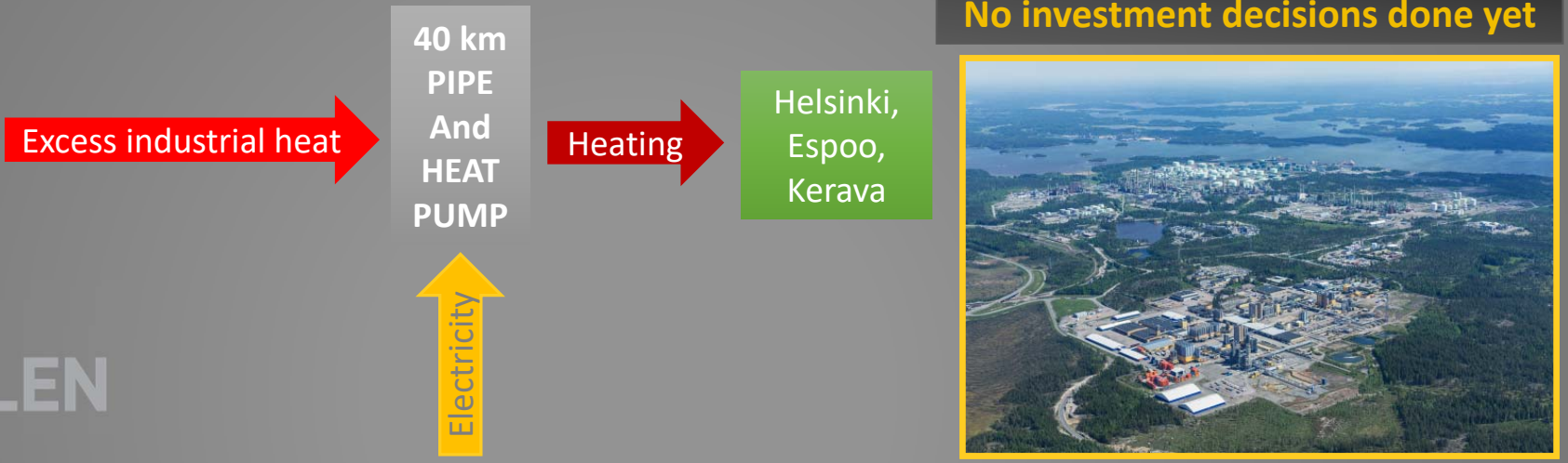

| | |
|---|---|
| Case type | Waste heat management |
| Equipment | 5 heat pumps |
| Installed capacity | District heat: 105MW District cooling: 70MW |
| Economics | CAPEX > 20 M euro |
| Business model | Sale of the district heating and cooling |
| Saved emissions | 150 000 tons of carbon dioxide yearly |
| Utilization | Excess heat from buildings, purified sewage water and 30 MW of electric power |
| Final product | Heating and cooling |
| Receiver | Residential and commercial customers in the city of Helsinki |

https://www.helen.fi/en/news/2018/newheatpump

# Case 3

# Kilpilahti excess heat project (planning phase)

**No investment decisions done yet**

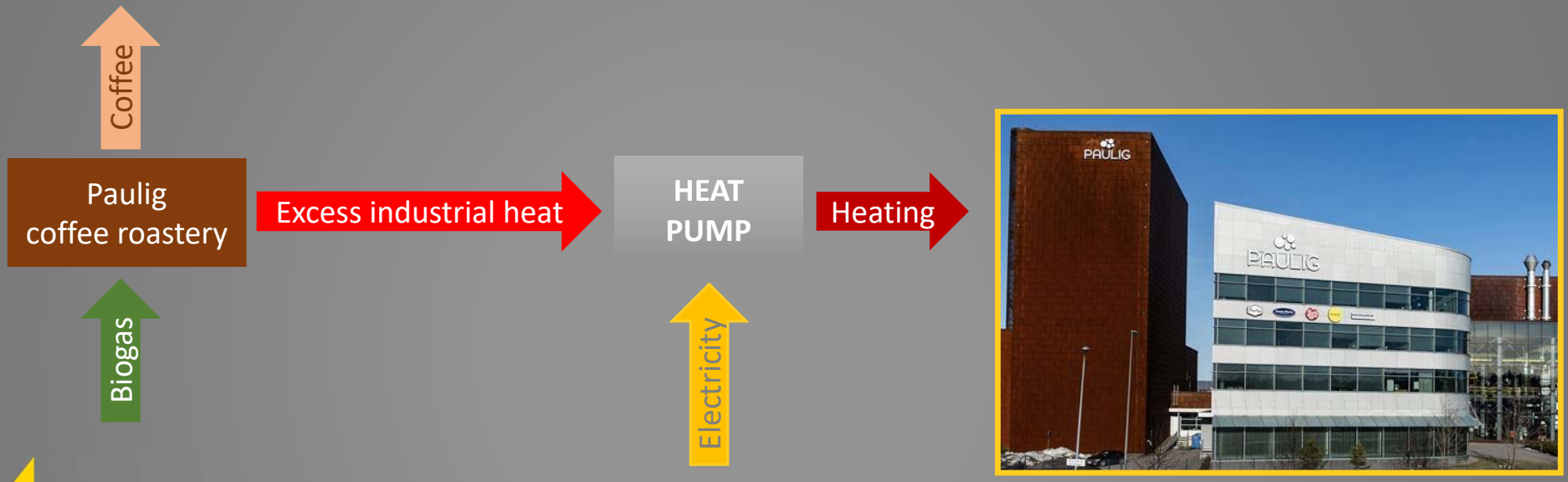



| | |
|---|---|
| Case type and involved parties | Waste heat management (Neste, Helen, Borealis, Fortum, and Keravan Energia) |
| Equipment | 40km pipe |
| Capacity | 3 TWh of heat |
| Economics | CAPEX: 700 – 1,000 M euro |
| Business model | To be decided |
| Utilization | Excess industrial heat from Neste and Borealis plants |
| Final product | Heating and cooling |
| Receiver | Residential and commercial customers in the city of Helsinki |

https://www.helen.fi/en/news/2020/kilpilahti2

# Case 4

# Waste Heat recovery from Paulig



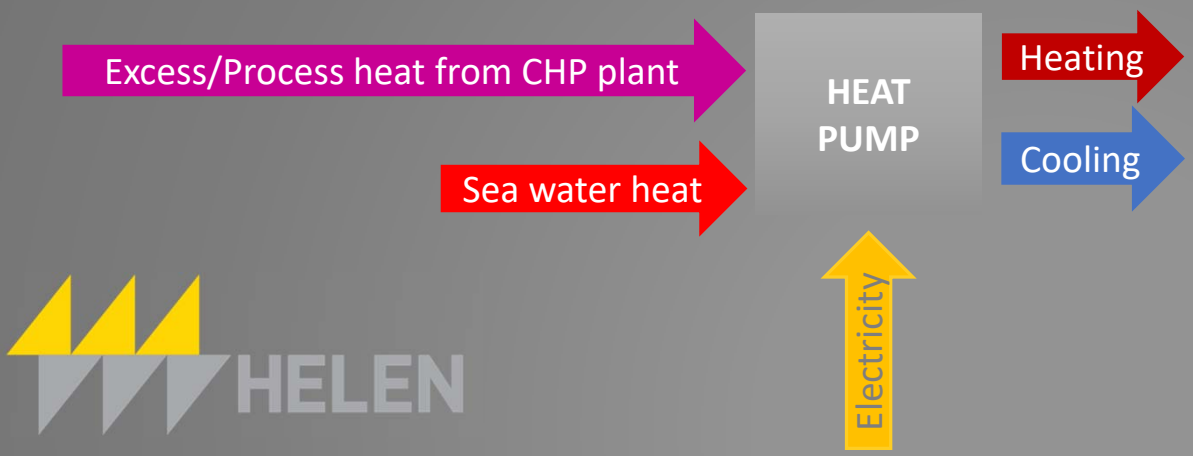

HELEN

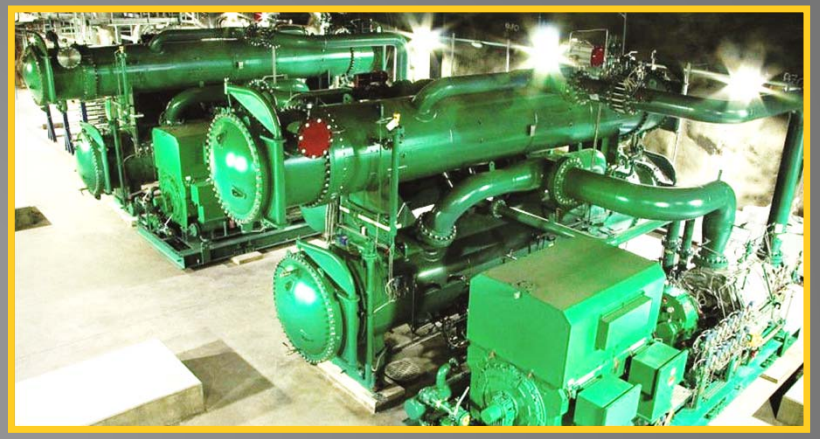
| | |
|---|---|
| Case type | Waste heat management |
| Utilization | Excess industrial heat from Paulig coffee roastery |
| Capacity | Heat for 1 000 two-room apartments |
| Receiver | Residential and commercial customers in the city of Helsinki |

https://www.pauliggroup.com/news/waste-heat-recovery-in-a-coffee-roastery

# Case 5

# Vuosaari Heat Pump project (2020 – 2022)



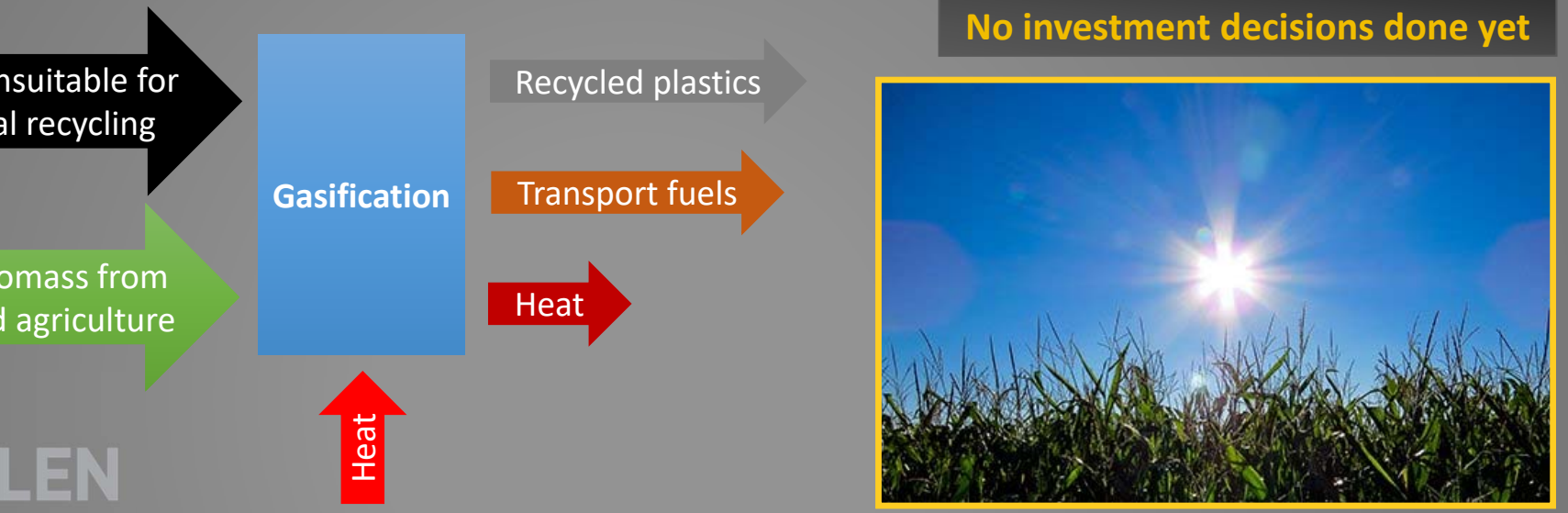
| | |
|---|---|
| Case type | Waste and seawater heat management |
| Equipment | Heat pumps (construction 2020 – 2022 in use) |
| Installed capacity | District heat: 13MW District cooling: 9.5MW |
| Economics | CAPEX > 15 M euro |
| Business model | Sale of the district heating and cooling |
| Saved emissions | 30 000 tons of carbon dioxide yearly |
| Utilization | 20% of the heat from the seawater and 80% of excess heat from Vuosaari Power Plant |
| Final product | Heating and cooling |
| Receiver | Residential and commercial customers in the city of Helsinki |

https://www.helen.fi/en/news/2019/heat-pump-sea-water-heat-vuosaari

# Case 6

# City Refinery (Helen, Lassila & Tikanoja, VTT)

**No investment decisions done yet**



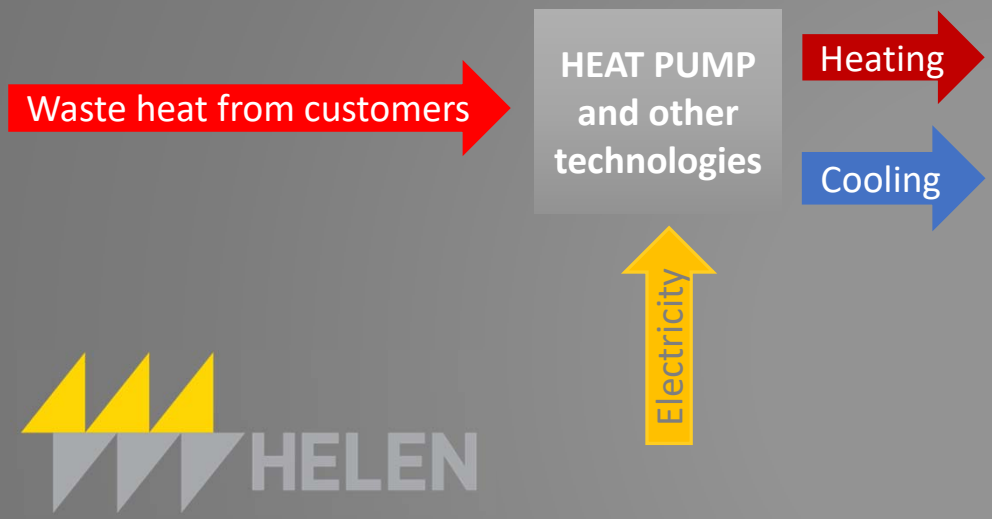



| | |
|---|---|
| Case type | Waste materials management |
| Equipment | Gasifier |
| Economics | CAPEX: 7.9 M euro from MEAE for the demo stage |
| Business model | Sale of materials, fuels and district heating |
| Utilization | Biomass and materials unsuitable for mechanical processing |
| Final product | Raw materials for industry, transport fuels, recycled plastics, 5MW of heat |
| Receiver | Residential, commercial and industrial customers in Finland |

https://www.helen.fi/en/news/2019/city-refinery-meae-aid

# Case 7

# District heating market – open DH




| | |
|---|---|
| Case type | Waste heat management |
| Equipment | Heat pumps |
| Business model | Purchase and sale of the district heating |
| Utilization | Waste heat from buildings of private, commercial and industrial customers |
| Final product | Heating |
| Receiver | Residential, commercial and industrial customers in the city of Helsinki |

https://www.helen.fi/en/news/2018/open_district_heat

# Case 8

# Mustikkamaa rock cavern heat storage

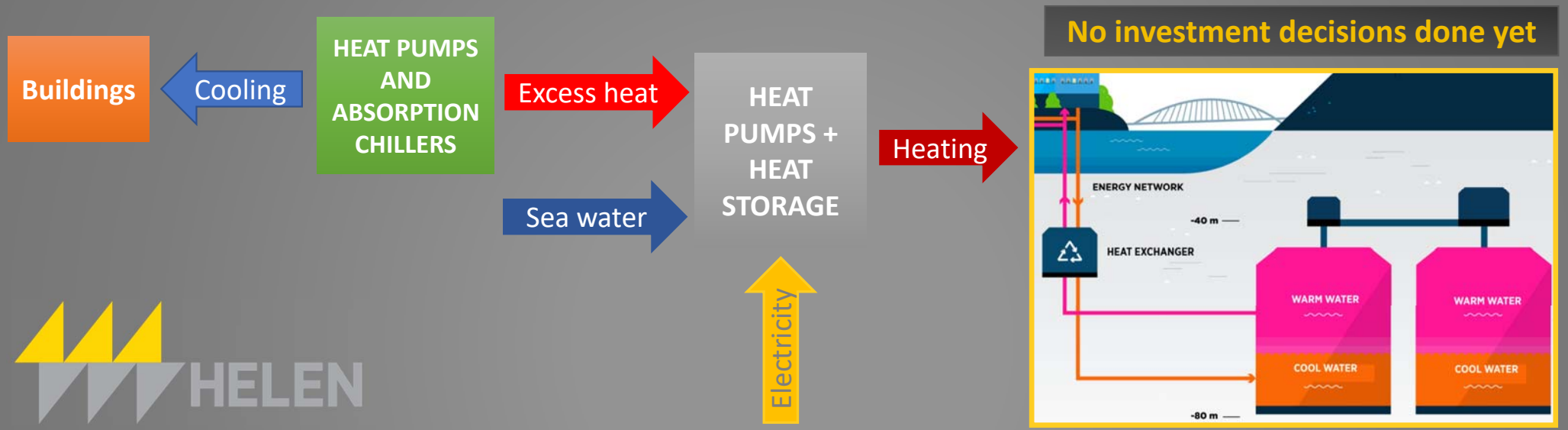
Electricity → ELECTRIC BOILER → District heat → HEAT STORAGE → Heating

| | |
|---|---|
| Case type | Heat storage (construction 2019 – 2021 in use) |
| Equipment | Rock cavern storage (260 000m3), pumps, heat exchangers and water |
| Installed capacity | Heat charging/discharging: 120 MW, 11.6 GWh/4 days, annual heat storage 140 GWh |
| Economics | CAPEX: 15 M euro |
| Business model | Heat storage and utilization |
| Saved emissions | 21 000 tons of carbon dioxide yearly |
| Utilization | District heat |
| Final product | Heating |
| Receiver | Residential and commercial customers in the city of Helsinki |

https://www.helen.fi/en/news/2018/construction-of-rock-cavern-heat-storage-facility-starts

# Case 9

# Seasonal heat storage in Kruunuvuorenranta

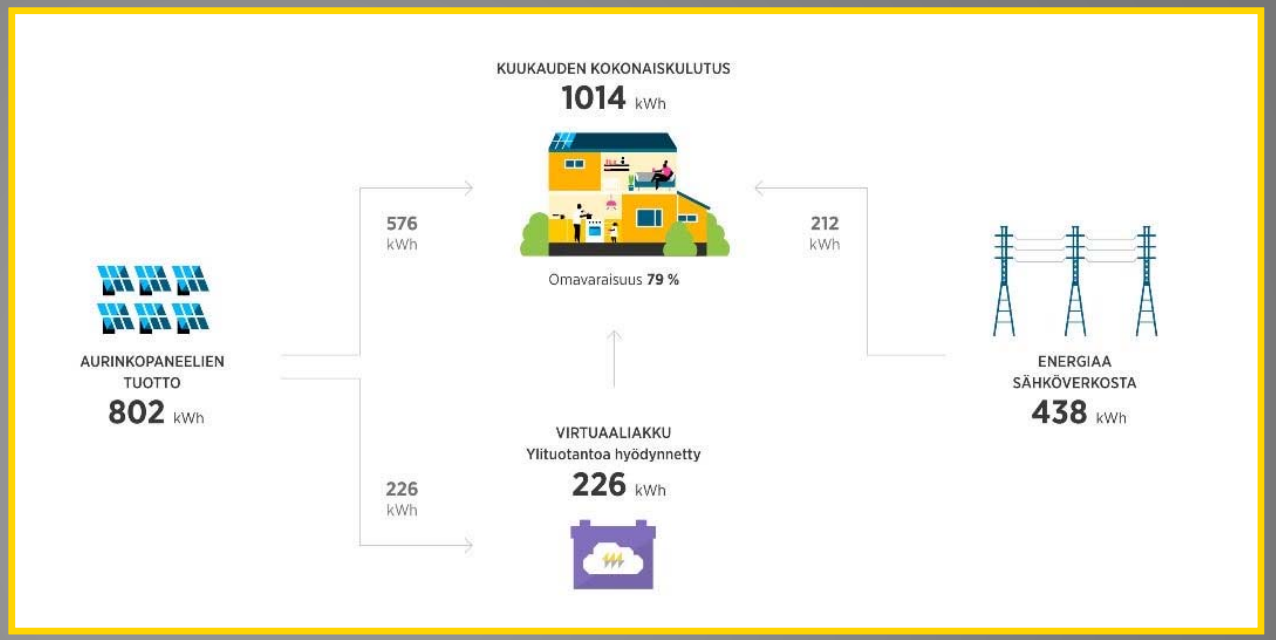



| | |
|---|---|
| Case type | Seasonal heat storage |
| Equipment | Two rock cavern storages (300 000m3), pumps, heat exchangers and seawater |
| Installed capacity | 3 MW, annual production 6-7 GWh |
| Business model | Heat storage and utilization |
| Utilization | Heat from sea water |
| Final product | Heating |
| Receiver | Residential and commercial customers in the city of Helsinki |

https://www.helen.fi/en/news/2018/seasonal-energy-storage-facility-is-planned-for-the-kruunuvuorenranta-rock-caverns

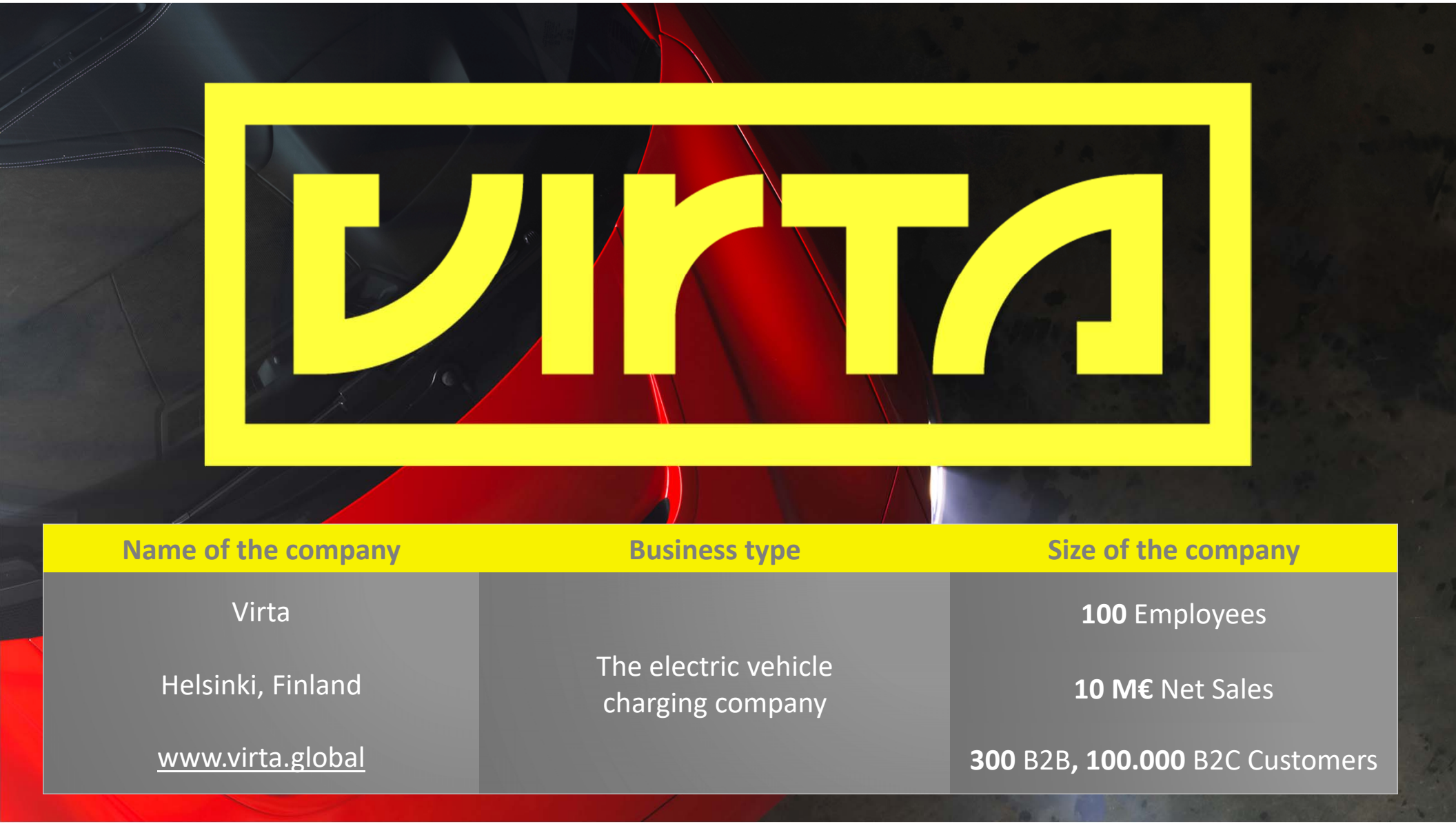
# Case 10

# Virtual battery for solar PV panels




| | |
|---|---|
| Case type | Electricity storage provided by Helen to owners of Solar PV panels |
| Benefit to customers | 100% advantage from the production of electricity via solar PV panels |
| Average surplus production | Around 30% of electricity produced by solar PV panels |
| Business model | Monthly fee |
| Yearly benefits for customer | 5 kWp panel package in a single-family house can yield in 166 euros per year |
| Other benefits | New monitoring system for customers and first-year virtual battery free of charge |

https://www.helen.fi/en/news/2019/virtual-battery-solar-panels



| Name of the company | Business type | Size of the company |
| --- | --- | --- |
| Virta<br><br>Helsinki, Finland<br><br>www.virta.global | The electric vehicle charging company | **100** Employees<br><br>**10 M€** Net Sales<br><br>**300** B2B**, 100.000** B2C Customers |

# Case 1

# Electric vehicle charging

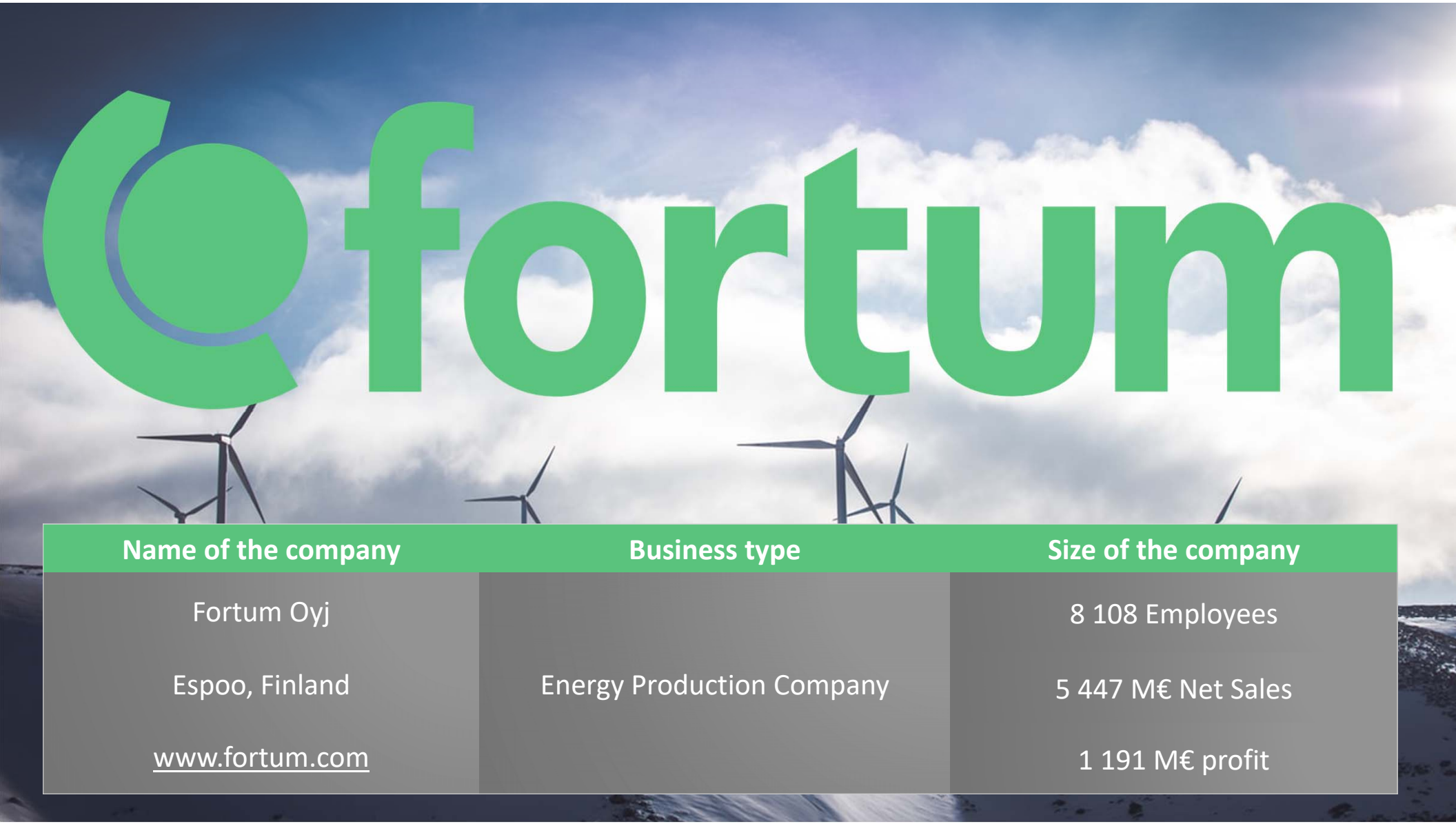
Electricity for charging & needs for grid power balancing

**Virta Charger**

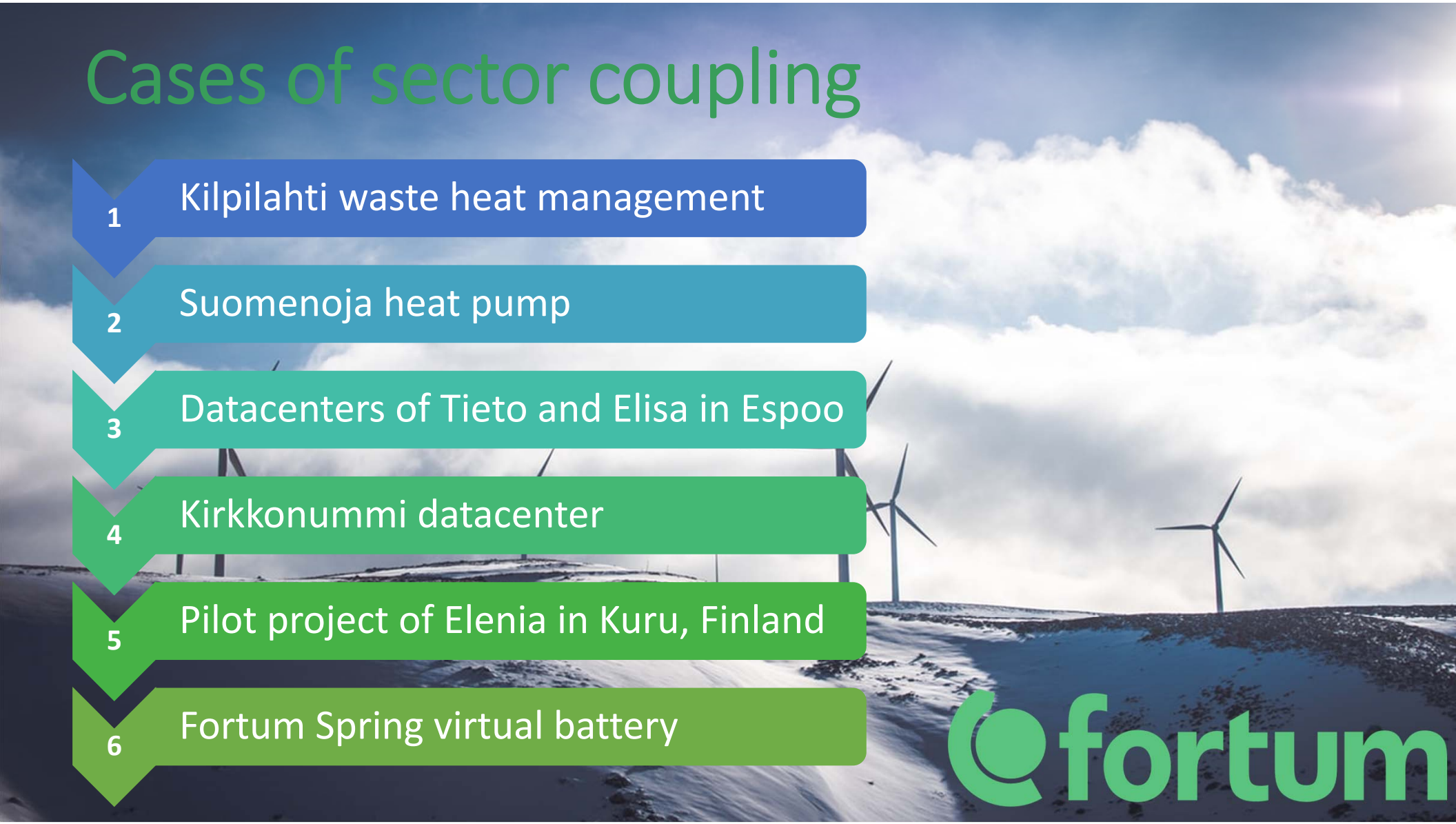
Charging/ Discharging

**Electric Vehicle**


| | |
|---|---|
| Case type | EV charging solutions, V2X (vehicle-to-x), smart charging, energy market services and providing infrastructure |
| Installed capacity | Around 20 000 chargers |
| Economics | Value of connected infrastructure 100 Million Eur |
| Business model | Providing the platform, software solutions and infrastructure for charging EVs |
| Utilization | Millions of charging events annually in 30 countries. Power of charging reflects to the size of a power plant (dozens of Megawatts). |
| Final product | Propulsion (drive), demand response. Virta EV driver mobile app, charging station management platform and aggregation platform |
| Receiver | Private and commercial consumers (B2B and B2C) |

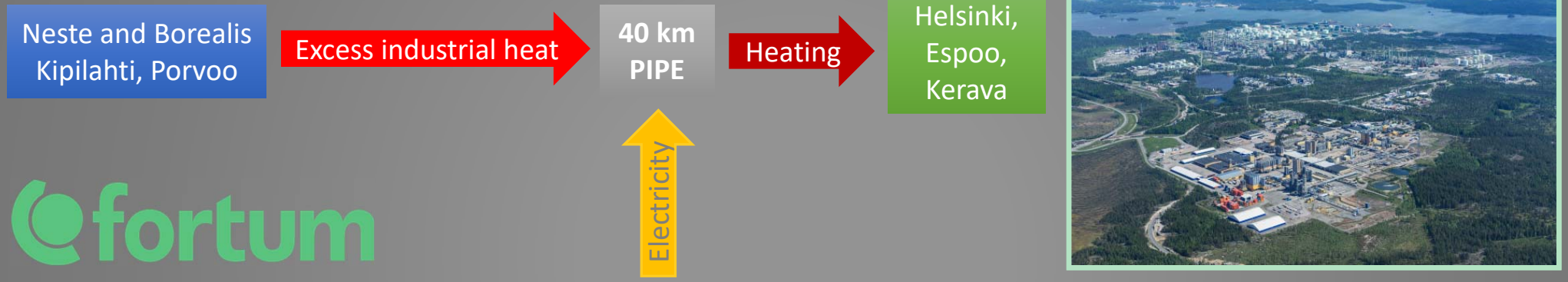



| Name of the company | Business type | Size of the company |
|---|---|---|
| Fortum Oyj<br>Espoo, Finland<br>www.fortum.com | Energy Production Company | 8 108 Employees<br>5 447 M€ Net Sales<br>1 191 M€ profit |


Cases of sector coupling
1
Kilpilahti waste heat management
2
Suomenoja heat pump
3
Datacenters of Tieto and Elisa in Espoo
4
Kirkkonummi datacenter
5
Pilot project of Elenia in Kuru, Finland
6
Fortum Spring virtual battery
fortum

# Case 1

# In planning: Kilpilahti waste heat management



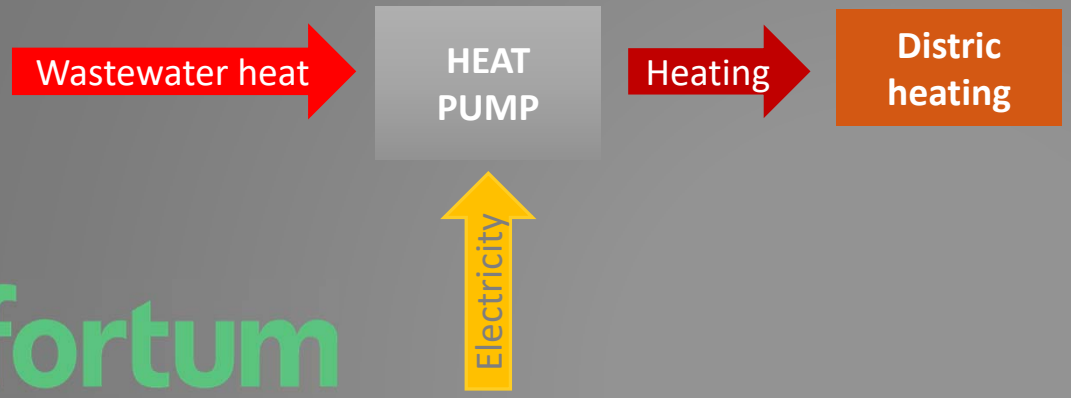



| | |
|---|---|
| Case type and involved parties | Waste heat management (Neste, Fortum, Borealis, Helen, and Keravan Energia) |
| Equipment | 40km pipe |
| Capacity | 1 GW of heat |
| Economics | CAPEX: 700 – 1,000 M euro |
| Business model | Sale of the district heating |
| Utilization | Excess industrial heat from Neste and Borealis plants |
| Final product | Heating |
| Receiver | Residential and commercial customers |
| Completion est. | Investment decisions have not been done yet |

https://www.fortum.fi/media/2019/06/fortum-mukana-selvityksessa-kilpilahden-hukkalampo-voisi-kattaa-noin-neljanneksen-paakaupunkiseudun-kaukolammon-tarpeesta

# Case 2

# Suomenoja heat pump

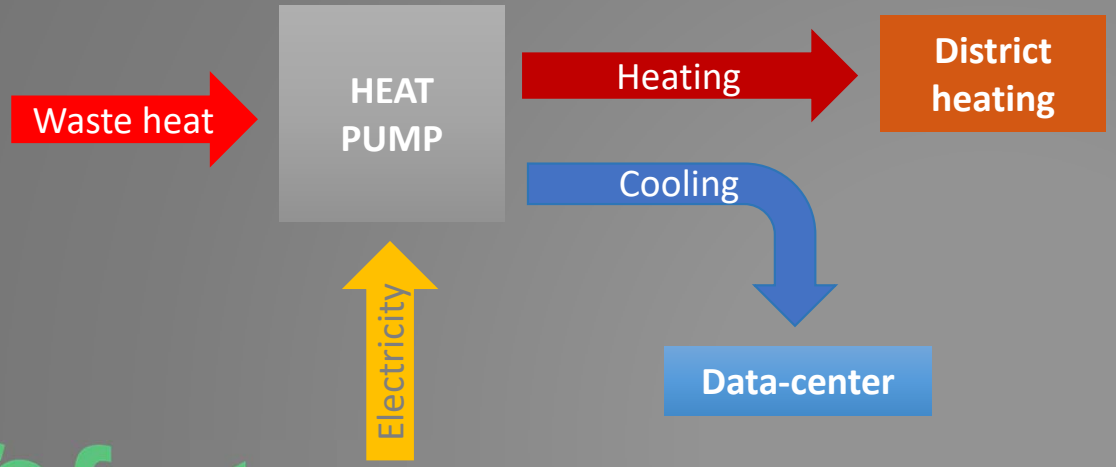



| | |
|---|---|
| Case type | Waste heat management |
| Equipment | Heat pumps |
| Installed capacity | 40 MW (60 MW in 2021) |
| Economics | CAPEX: 8 M€ |
| Business model | District heat production and sales |
| Heat source | Waste heat from HSY wastewater treatment plant |
| Final product | Heating and cooling |
| Receiver | Customers connected to the Espoo DH Network |
| Completion est. | 40MW in operation presently, additional 20MW will be commisioned in Spring 2021 |

https://www.fortum.fi/media/2019/05/fortumille-uusi-lampopumppuyksikko-suomenojalle-hiilineutraalin-kaukolammontuotannon-osuus-nousee-yli-50-prosenttiin-vuonna-2022

# Case 3

# Datacenters of Tieto and Elisa in Espoo

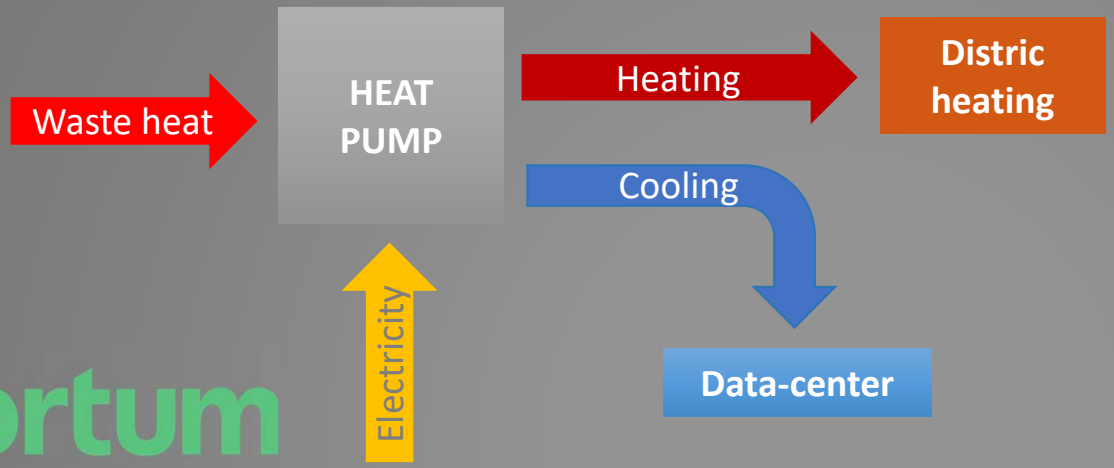



| | |
|---|---|
| Case type | Waste heat from datacenters |
| Equipment | 2 heat pumps |
| Production capacity | 20 GWh/annum of heat |
| Business model | Sales of district heat and provide cooling to the datacenter |
| Heat source | Waste heat from datacenters of Tieto and Elisa |
| Final product | Heating and cooling |
| Receiver | Customers connected to the Espoo DH Network |

https://www.fortum.fi/datakeskusten-hukkalampo-kaukolammoksi

# Case 4

# In planning: Kirkkonummi datacenter




| | |
|---|---|
| Case type | Waste heat from new datacenter |
| Equipment | Heat pumps |
| Installed capacity | 250 MW |
| Economics | CAPEX > 2 000 M€ (incl. data center) |
| Business model | Sale of district heat and provide cooling to the datacenter |
| Heat source | Heat from the datacenter |
| Final product | Heating and cooling |
| Receiver | DH customers in the capital region |
| Completion est. | Investment decisions have not been done yet |

https://www.fortum.fi/tietoa-meista/blogi/forenergy/suuren-datakeskuksen-hukkalampo-voisi-lammittaa-suuren-osan-espoota-hiilineutraalisti

# Case 5

# Pilot project of Elenia in Kuru, Finland

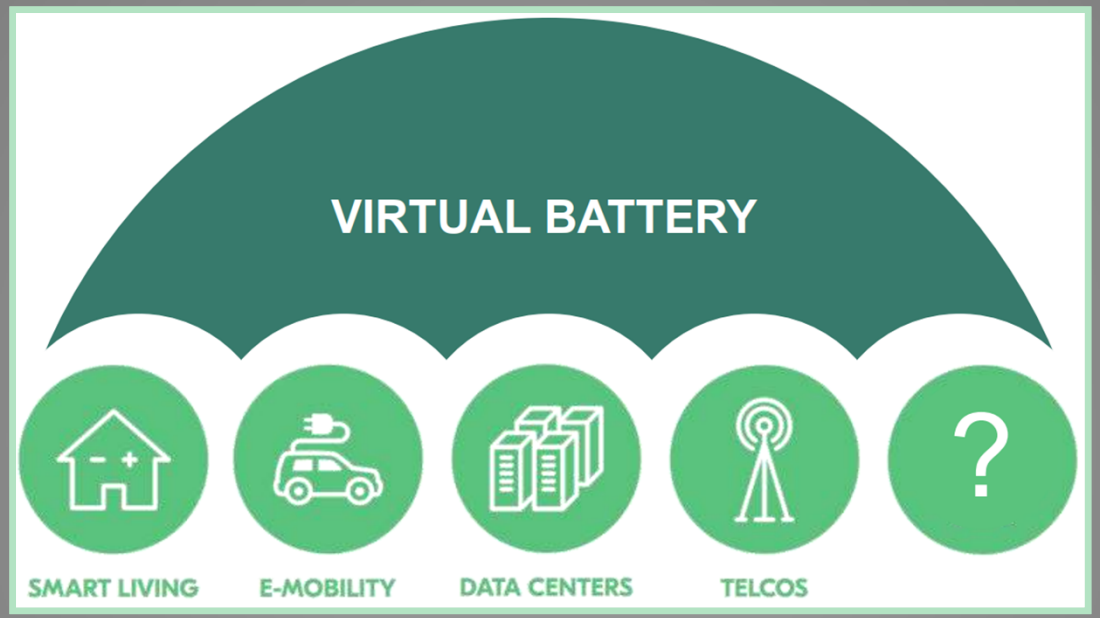

fortum

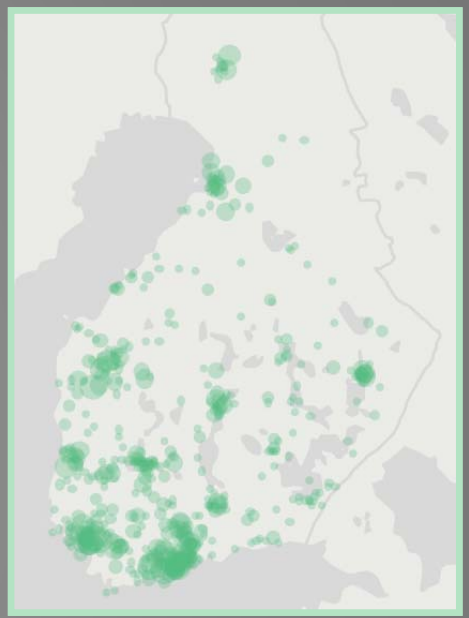
| | |
|---|---|
| Case type | Battery service |
| Installed capacity | 300 kWp (71 kW average), 220 kWh |
| Operating time | 3 hours (with full battery) |
| Business model | Battery service to Elenia and FRC-N to Fingrid |
| Utilization | The battery is used approximately 100h annually to provide electricity during power outages and rest of the year for frequency control |
| Final product | Electrical storage capacity with automatic isolation connected to 100 customers (mainly summer cottages) |
| Receiver | Elenia and Fingrid |

https://www.elenia.fi/uutiset/fortum-ja-elenia-rakentavat-s%C3%A4hk%C3%B6n-varastointia-s%C3%A4hk%C3%B6j%C3%A4rjestelm%C3%A4n-tasapainon-yll%C3%A4pitoon-ja

# Case 6

# Fortum Spring virtual battery



| | |
|---|---|
| Case type | Virtual battery |
| Installed capacity | 2000 customers |
| Business model | Selling capacity of customers to the grid operator while providing smart demand response |
| Final product | Smart control of grid connected devices |
| Receiver | Energy customers all over Finland |

https://www.fortum.com/products-and-services/smart-energy-solutions/virtual-battery-spring

# STEP

## Sustainable Energy Solutions

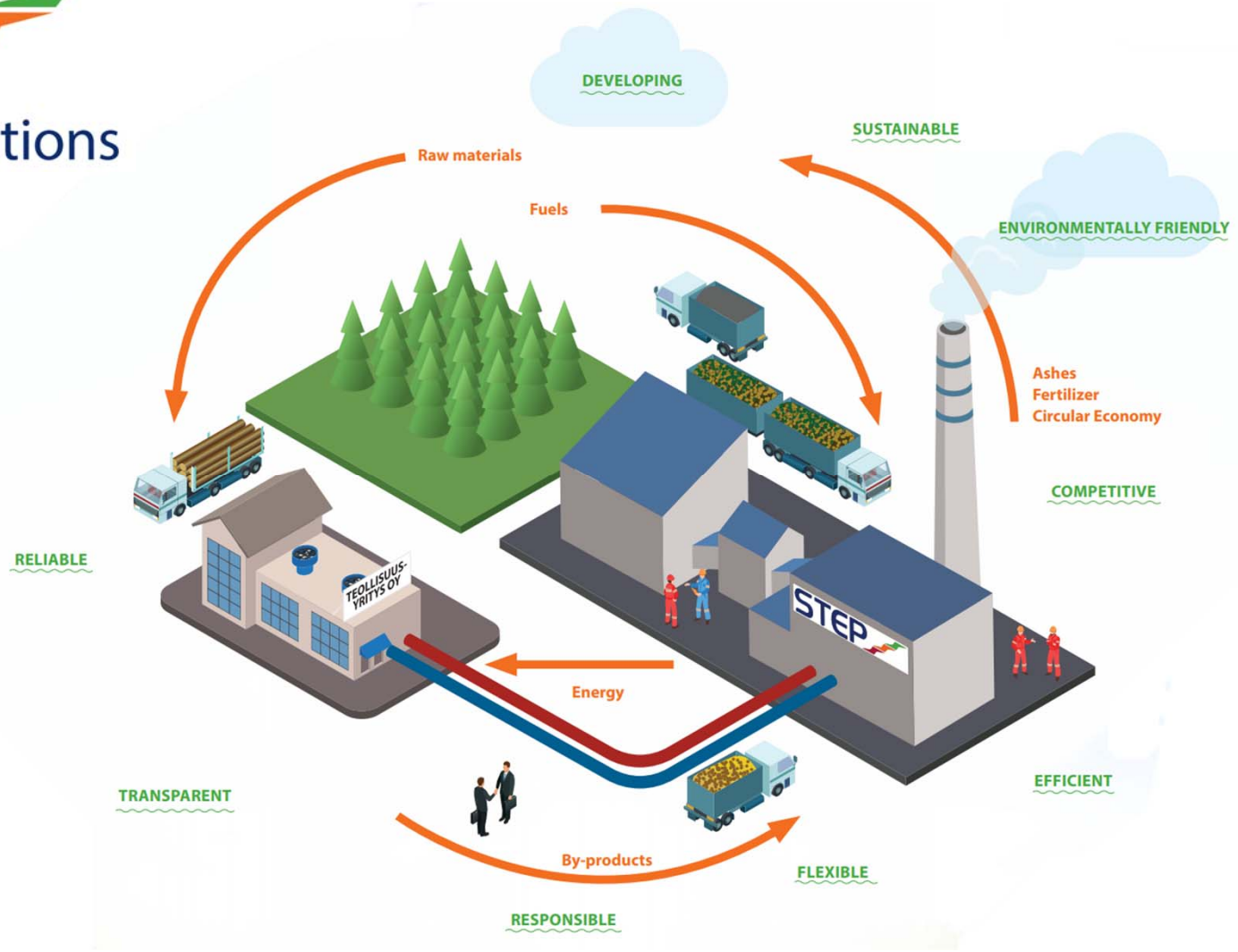
| Name of the company | Business type | Size of the company |
|---|---|---|
| Suomen Teollisuuden Energiapalvelut - STEP Oy<br><br>Pori, Finland<br><br>www.stepenergy.veolia.fi | Energy Services, Energy Production | 41 Employees<br><br>39,2 M€ Revenue<br><br>2,9 M€ Profit |

STEP

Sustainable Energy Solutions

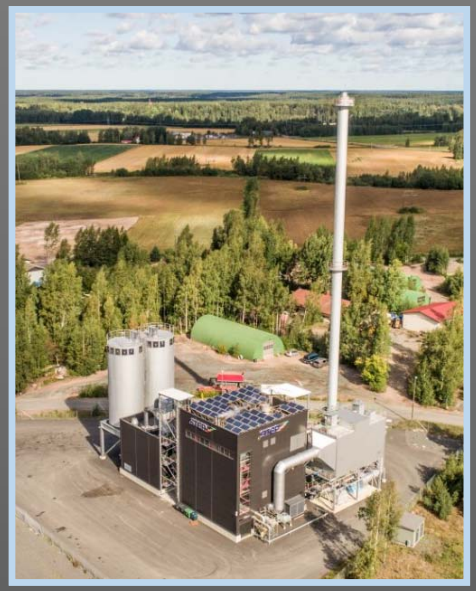
## Sector coupling cases:

1. Harjavalta Industrial Park
2. Koskenkorva Bioenergy plant – circular economy
3. Hankkija animal feed production
4. Findest Protein factory (Honkajoki)



# Case 1

# Harjavalta Industrial Park



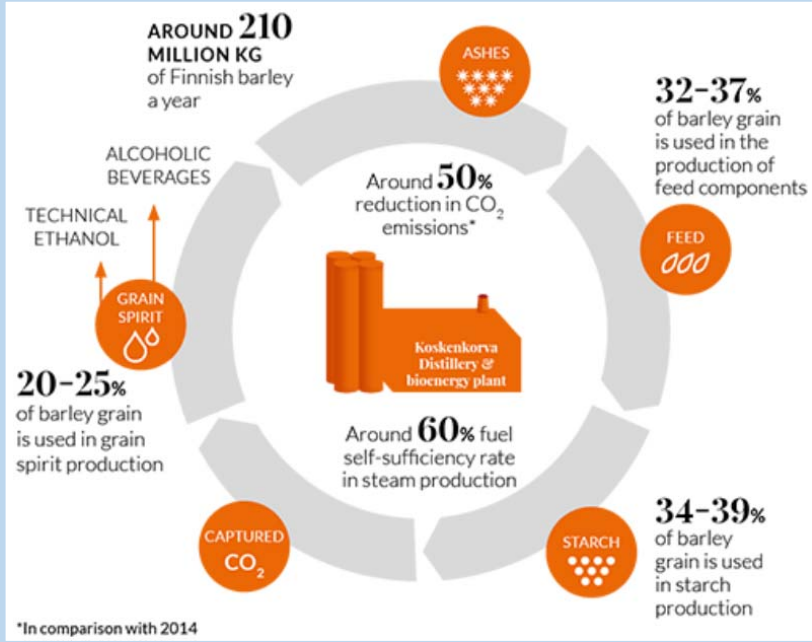
STEP
Sustainable Energy Solutions

| | |
|---|---|
| **Case type** | Energy production coupled with industrial park (factories) and residentials |
| **Equipment and utilization** | Biosteam boiler: 30 MW, Steam boilers: 10+13+20+21 MW (biogas, natural gas, light fuel oil), bioheat boiler: 3MW (wood pellets), heat recovery boilers: 12+20+24 MW, steam turbine: 6,3 MWe |
| **Business model** | Production and sale of steam, process heat, district heat, compressed air, process water and electricity |
| **CO2 reduction** | 70 000 tons of CO2 from industrial park |
| **Receiver** | Factories (Nornickel, Boliden, Aga Ab, Yara Oy, Valtasiirto Oy) and city of Harjavalta |

https://www.stepenergy.veolia.fi/sites/g/files/dvc3531/files/document/2018/11/STEP_esite2018_en.pdf

# Case 2

# Koskenkorva Bioenergy plant – circular economy




STEP
Sustainable Energy Solutions

| | |
|---|---|
| **Case type** | Energy production coupled with food industry |
| **Equipment and utilization** | Biosteam: 10MW (barley husks, woodchips), CFB: 20MW (milled peat, oat husks), backup boiler: 15MW (HFO, sulphur=0.5%) |
| **Capacity** | 220 000 MWh annual production |
| **Business model** | Sale of the process steam, compressed air, process water |
| **Receiver** | Altia's Koskenkorva distillery and A-Rehu |

https://www.stepenergy.veolia.fi/sites/g/files/dvc3531/files/document/2018/11/STEP_esite2018_en.pdf

# Case 3

# Hankkija animal feed production


STEP
Sustainable Energy Solutions

| | |
|---|---|
| **Case type** | Energy production coupled with animal feed production |
| **Equipment and utilization** | 2.5MW biosteam boiler (oat husks, peat, woodchips) and 3MW backup boiler (light fuel oil) |
| **Business model** | Production and sale of the steam to Hankkija's feed mill and district heat |
| **Receiver** | Hankkija Oy (Animal Feed producer) in Seinäjoki |

https://www.stepenergy.veolia.fi/sites/g/files/dvc3531/files/document/2018/11/STEP_esite2018_en.pdf

# Case 4

# Findest Protein (Honkajoki)


STEP
Sustainable Energy Solutions

| | |
|---|---|
| **Case type** | Energy production coupled with food industry (protein production) |
| **Equipment and utilization** | 4 MW biosteam boiler (bark, sawdust, peat, woodchips) and 8 MW backup boiler (LPG, light fuel oil) |
| **Business model** | Production and sale of the steam and burning of odorous gases |
| **Receiver** | Findest Protein factory |

https://www.stepenergy.veolia.fi/sites/g/files/dvc3531/files/document/2018/11/STEP_esite2018_en.pdf

LEMPÄÄLÄ

LEMPÄÄLÄN LÄMPÖ

LEMPÄÄLÄN ENERGIA

| Name of the company | Business type | Company details |
|---|---|---|
| Lempäälän Energia Oy<br>Lempäälä, Finland<br>www.lempaalanenergia.fi | Energy Company | Established in 1973<br>1 – 2 M€ Revenue |

# A self-sufficient and intelligent energy system in Marjamäki industry area (Lempäälä).

1. Batteries
2. Solar PV Panels
3. Fuel Cells
4. Gas Engine
5. Absorption machine


LEMENE
LEMPÄÄLÄN ENERGIAYHTEISÖ

# Case 1

# Batteries


LEMPÄÄLÄN ENERGIA

| | |
|---|---|
| Case type | Electricity storage |
| Equipment | Two batteries |
| Capacity | 1.6MWh (2.4MW charge/discharge) and 1.3MWh (1.6MW charge/discharge) |
| Function | Storing of excess electricity, grid stabilization, increasing the system efficiency |
| Receiver | Marjamäki industry area |

https://www.esitteemme.fi/lemene/WebView

# Case 2

# Solar PV panels

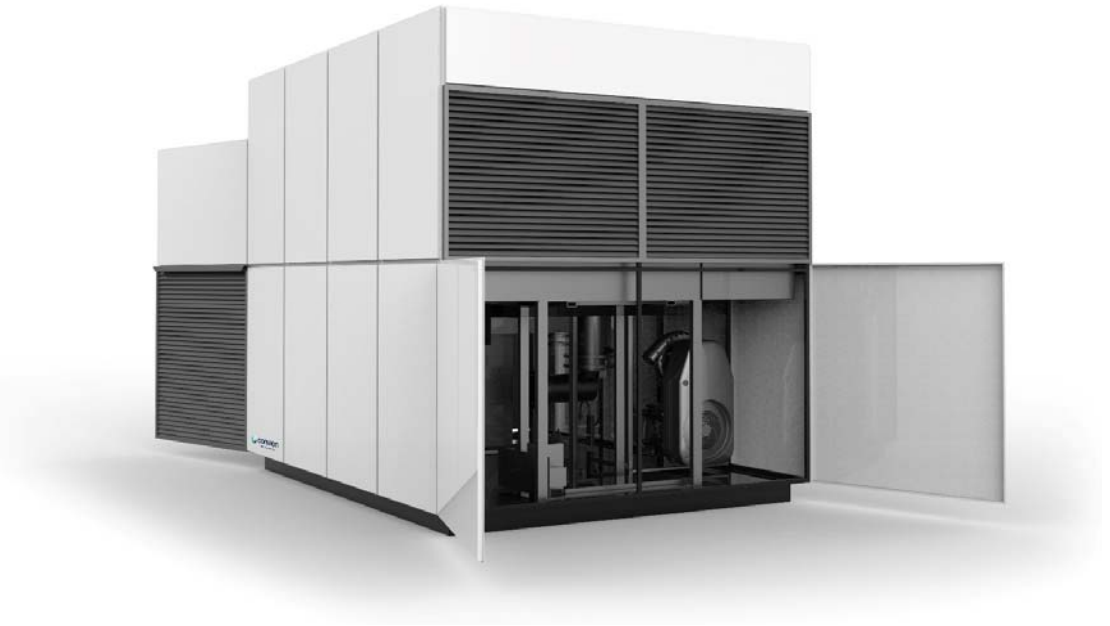

LEMPÄÄLÄN ENERGIA

| | |
|---|---|
| Case type | Electricity production |
| Equipment | Solar panels |
| Capacity | 4MW |
| Receiver | Marjamäki industry area |

https://www.esitteemme.fi/lemene/WebView

# Case 3

# Fuel Cells

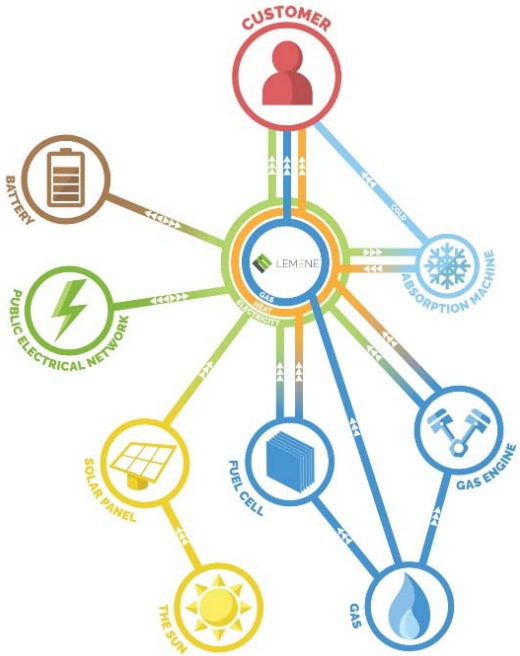
LEMPÄÄLÄN ENERGIA

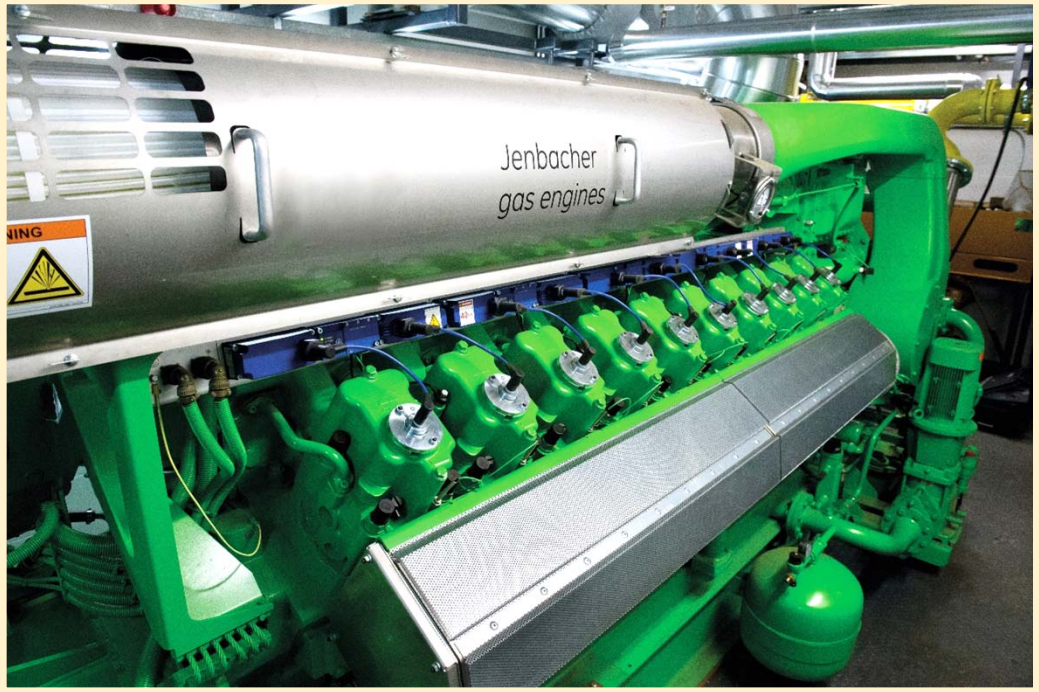
| | |
|---|---|
| Case type | Electricity production |
| Equipment | Two fuel cells units from Convion |
| Capacity | 130 kW (65 each unit) |
| Utilization | Methane (Biogas/Natural gas) |
| Receiver | Marjamäki industry area |

https://www.esitteemme.fi/lemene/WebView

# Case 4

# Gas engine



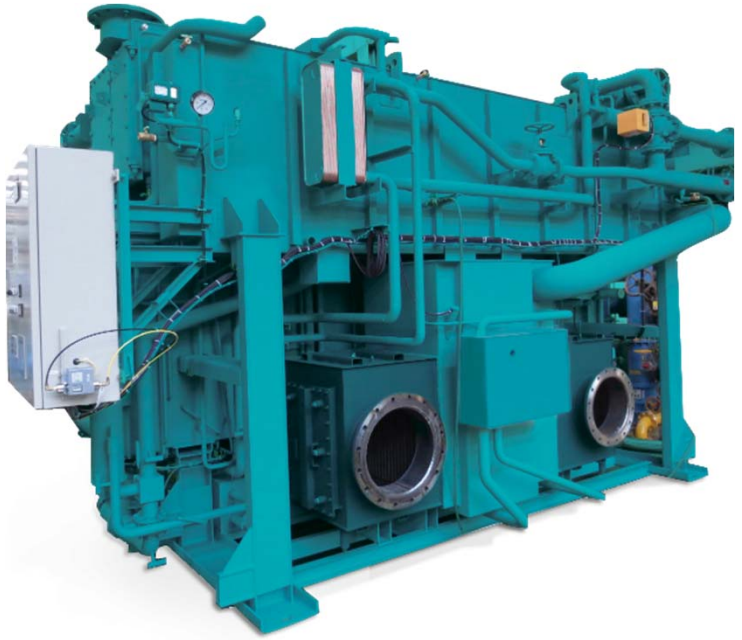

LEMPÄÄLÄN ENERGIA

| | |
|---|---|
| Case type | Electricity production |
| Equipment | 6 engines |
| Capacity | 8.1 MW in total |
| Utilization | Methane (Biogas/Natural gas) |
| Receiver | Marjamäki industry area |

https://www.esitteemme.fi/lemene/WebView

# Case 5

# Absorption machine

LEMPÄÄLÄN ENERGIA

| | |
|---|---|
| Case type | Providing cooling |
| Equipment | Absorption chiller |
| Capacity | 600 kW in total |
| Utilization | Electricity |
| Additional production | Heat |
| Receiver | Marjamäki industry area |

https://www.esitteemme.fi/lemene/WebView

https://www.york.com/-/media/york/absorption-chillers/yhaucej-multi-energy.png?la=en&hash=820EE2C78A349C02D6152D8BDBE658990D54E00B

# KEMIJOKI

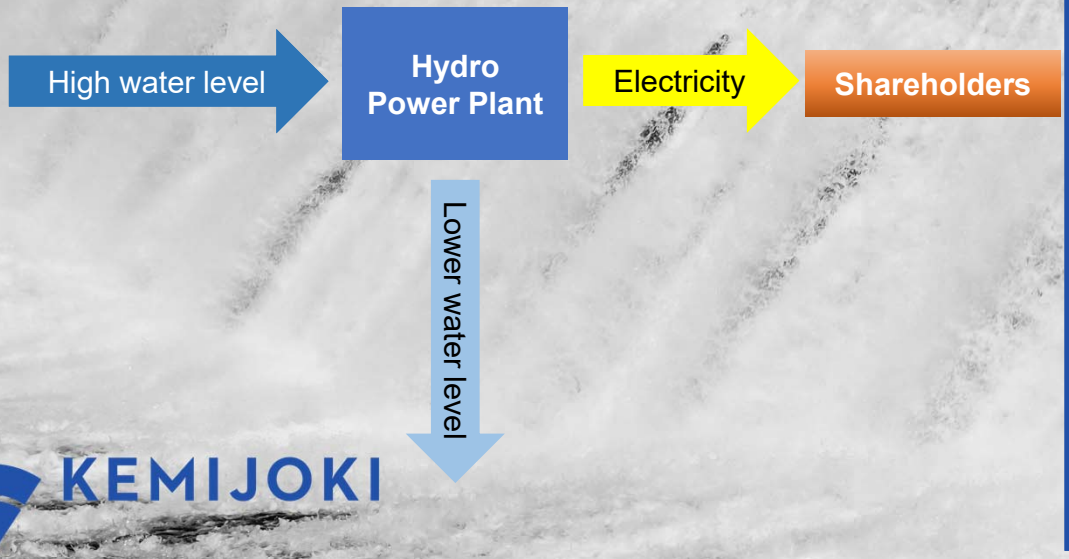
| Name of the company | Business type | About company |
|---|---|---|
| Kemijoki OY<br>Rovaniemi, Finland<br>www.kemijoki.fi | Production of hydropower | **Established in 1954**<br>**20 Power Plants**<br>**40** Employees and **~200** contractors |

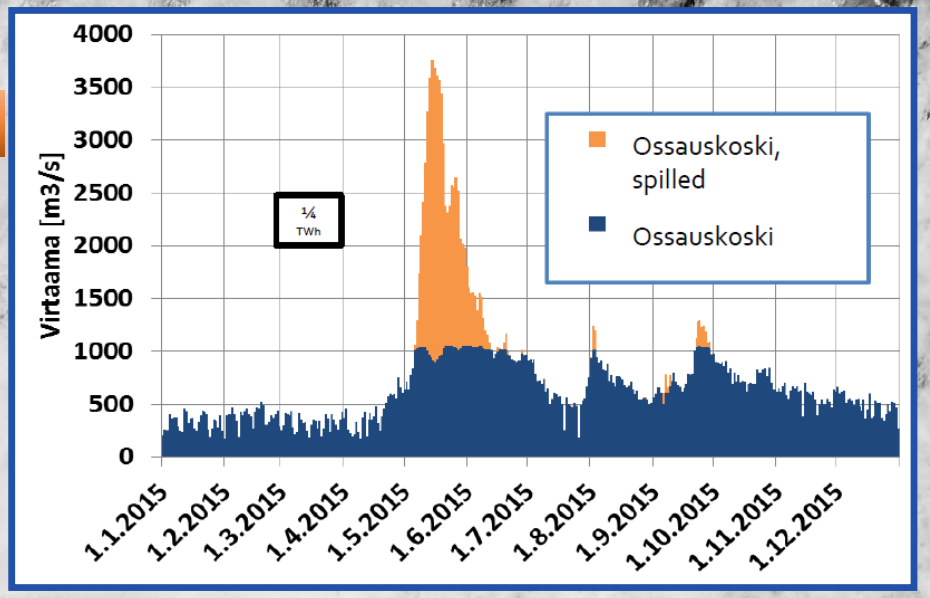
# Cases of sector coupling

1. Hydropower and flood management
2. Hydropower storage
3. Demand response
4. Sierilä hydropower plant with protection of nature and local community

KEMIJOKI

# Case 1 Hydropower and flood management




KEMIJOKI

| | |
|---|---|
| Case type | Production of hydropower and flood management |
| Installed capacity | 1.1GW of hydropower |
| Economics | CAPEX: <2000 EUR per kW of production capacity |
| Business model | Sale of electricity to the shareholders + sale of ancillary services to TSO |
| Utilization | 4.5TWh flexible production |
| Final product | Electricity |
| Receiver | Shareholders |

# Case 2

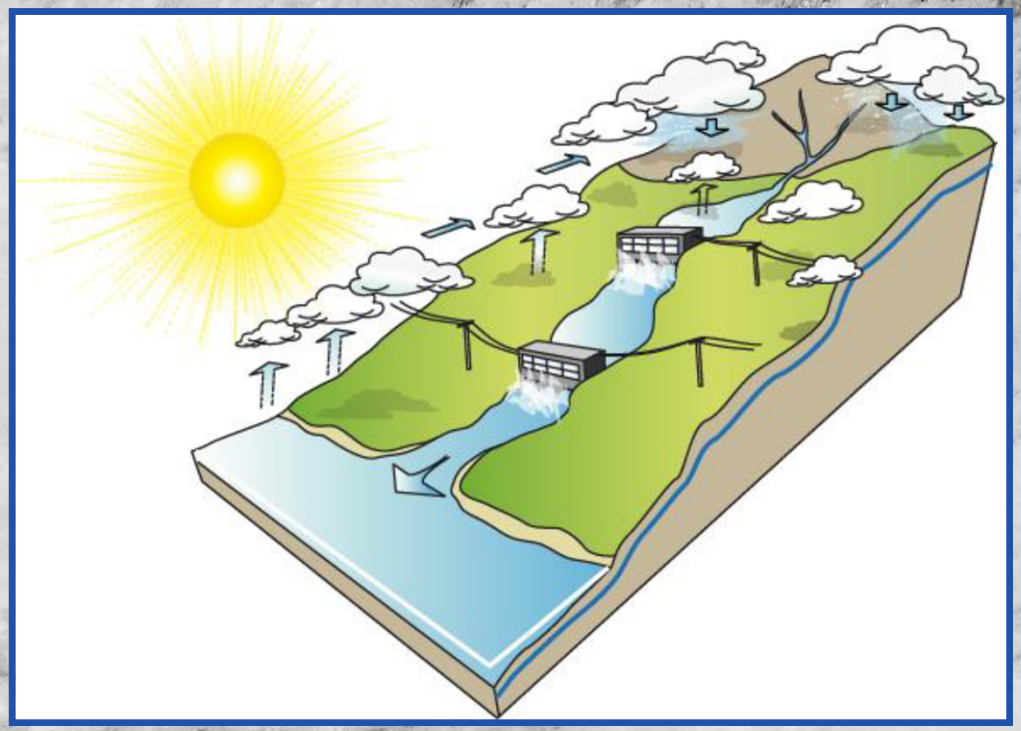
# Hydropower storage

High water level

The hydrologic cycle

Hydro Power Plant

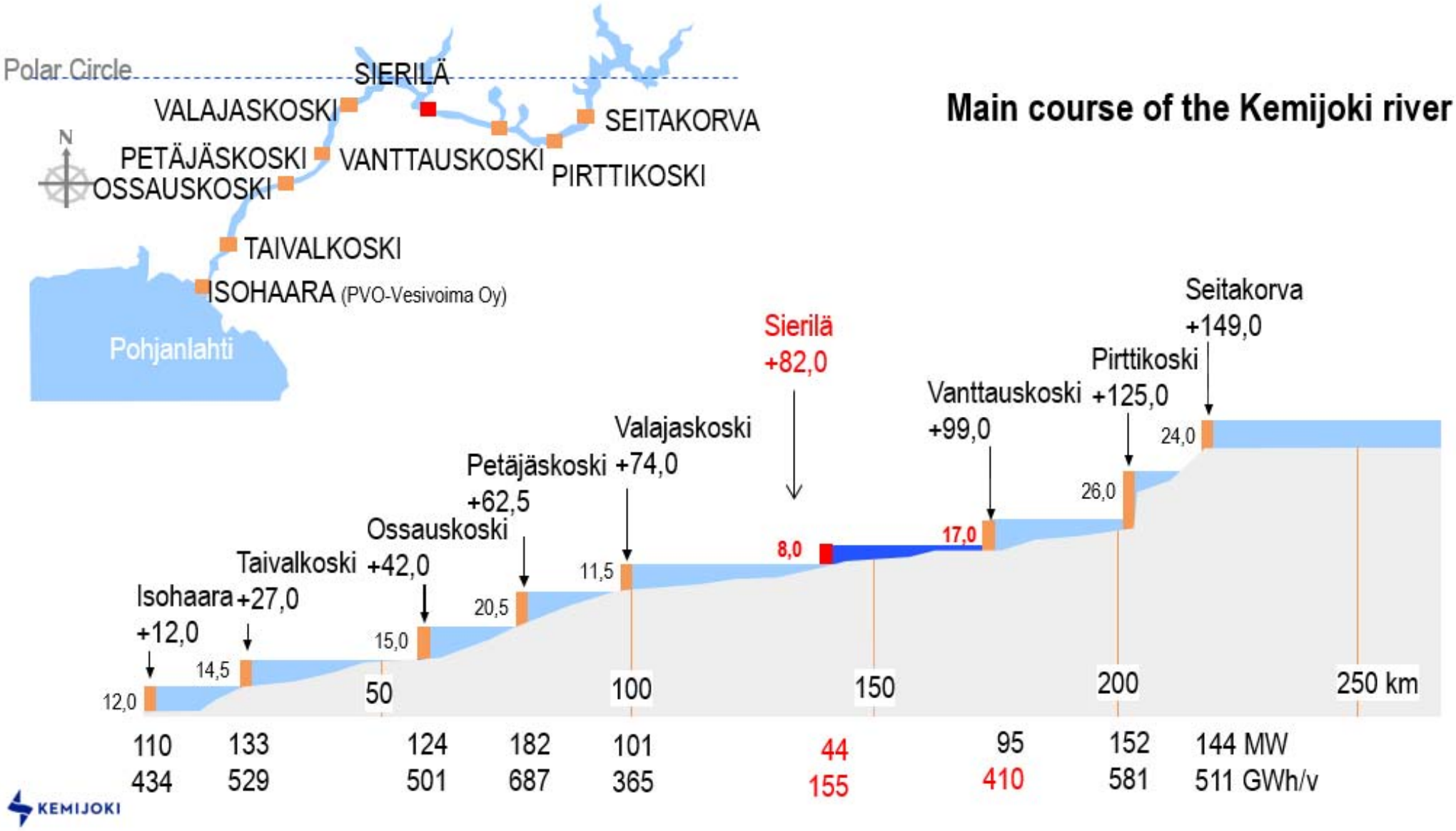
Lower water level



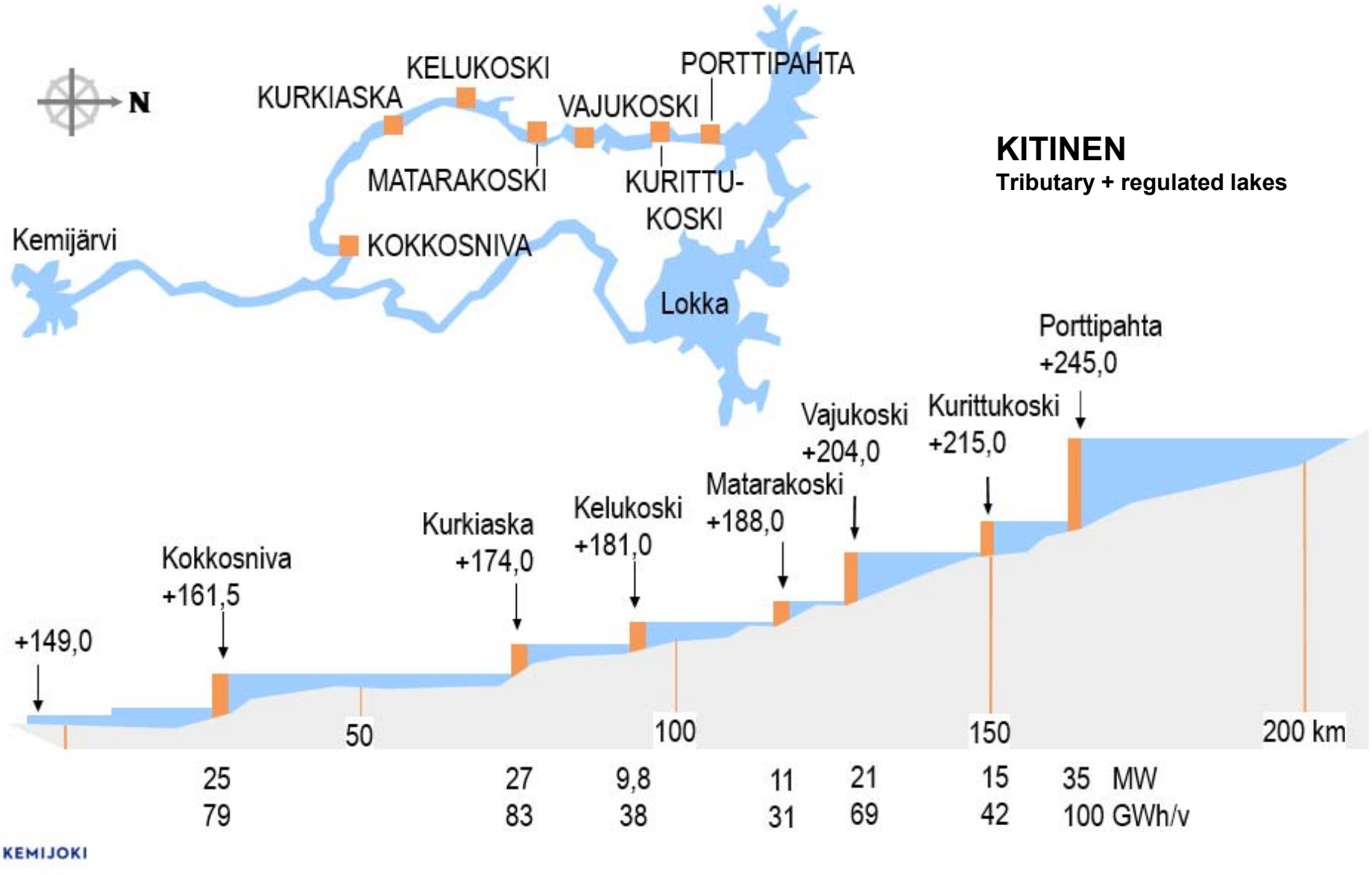
KEMIJOKI

| | |
|---|---|
| Case type | Excess energy storage |
| Installed capacity | 1TWh of water storage (~3,6km$^3$), 500GWh of loss (during the floods) |

# Main course of the Kemijoki river

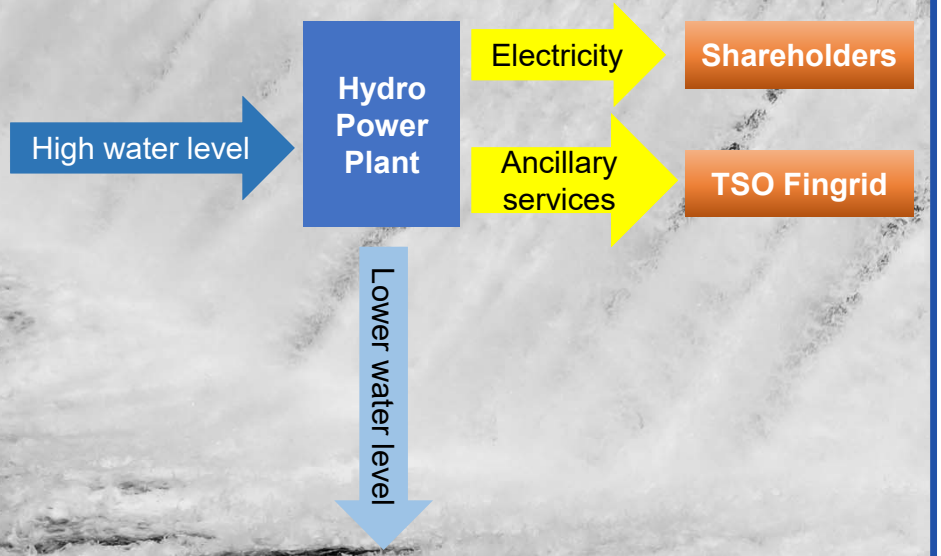


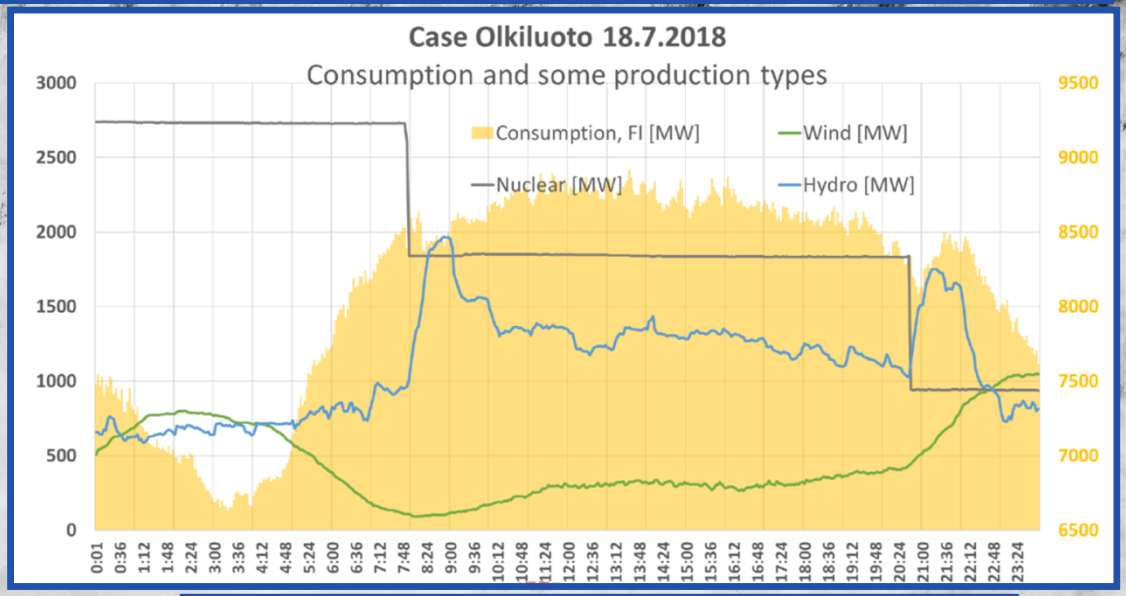

KEMIJOKI

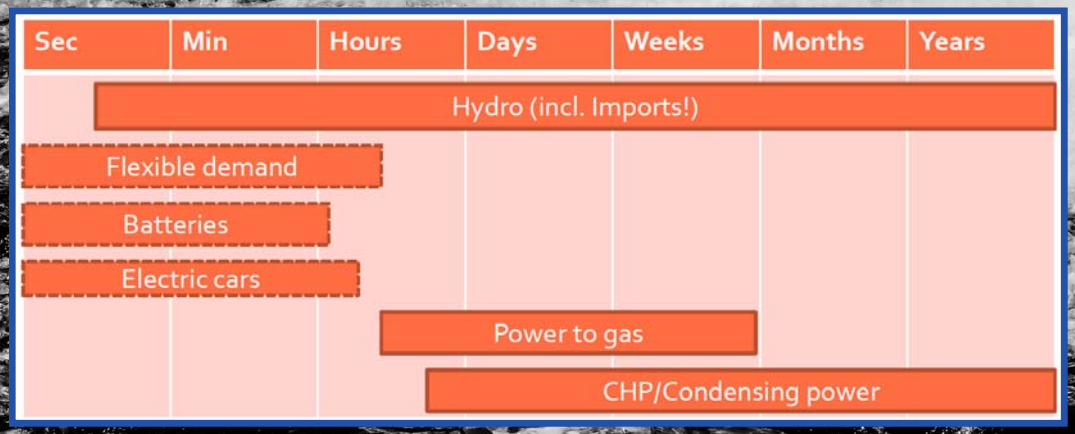

N
KELUKOSKI
KURKIASKA
VAJUKOSKI
PORTTIPAHTA
MATARAKOSKI
KURITTU-
KOSKI
Kemijärvi
KOKKOSNIVA
Lokka
KITINEN
Tributary + regulated lakes
Porttipahta
+245,0
Kurittukoski
+215,0
Vajukoski
+204,0
Matarakoski
+188,0
Kelukoski
+181,0
Kurkiaska
+174,0
Kokkosniva
+161,5
+149,0
50
100
150
200 km
25
79
27
83
9,8
38
11
31
21
69
15
42
35 MW
100 GWh/v
KEMIJOKI

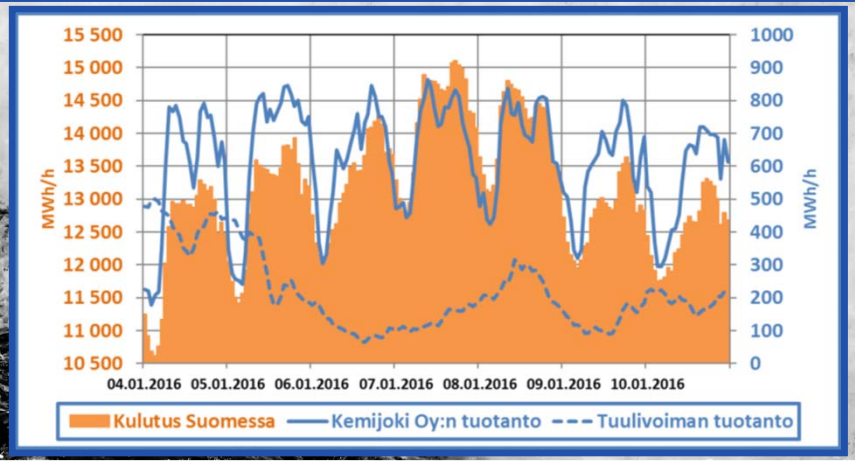
# Case 3

# Demand response



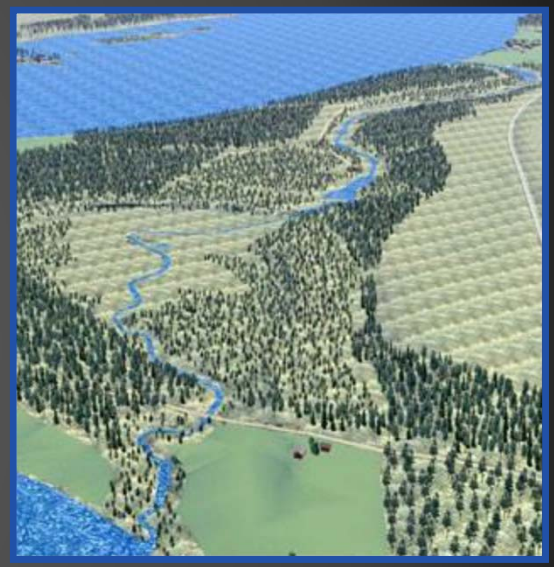



# Case 4 Sierilä hydropower plant with protection of nature and local community

**Project in a planning phase**

- Concerning landscape and vegetation, area around Sierilä currently resembles the original main channel of the river Kemijoki, partially affected by settlement and other human activities.
- Kemijoki has drafted diverse action plans to mitigate the impact on recreational use and the environment:
  1. In the plans: bank protection for a 17-kilometer distance in total.
  2. Landscaping in 16 places, boat launching places, mooring places and swimming places.
  3. Building and restoring compensatory habitats, transporting endangered species to new areas.
- The planned natural Mukkaoja diversion channel would make it possible for fish to migrate over the dam. Preparations to build a fish pass are also a part of planning the structures of the power plant.



| | |
|---|---|
| Case type | Production of hydropower coupled with nature protection and recreation |
| Installed capacity | 44 MW |
| Economics | CAPEX: ~3500 EUR per kW of production capacity |
| Business model | Sale of electricity to the shareholders |
| Utilization | 155GWh yearly |
| Final product | Electricity |

# Challenges and opportunities related to regulations

# Heat and electricity aspects

- Electricity tax has a considerable impact on the cost-effectiveness of the heat pumps. Could this be copied to other heat production methods using electricity that produce heat to the district heating system?
- Status of waste/excess heat: renewable or not?
- Electic boilers would be a good addition as renewable electricity production increases. They could offer a way to store emissionless electricity to heat. Problem is that they cause peaks that do not necessarily last for long periods. Power charge wreck viability of electric boilers.
- Also important to address the tax treatment of
  - Heat pumps that are in connection to district heating network
  - Waste heat

# Electric vehicles and chargers

- Taxation, in many countries e.g. double electricity taxation inhibits or even stops the market takeoff for V2G technology.
- Electricity tax and grid tariff should incentivize for flexibility. Variable tariffs should be considered.
- The regulation model often supports DSOs to do investments for cables instead of having smart solutions which increases OPEX. This needs to be changed.
- Lack of smart metering and settlement – no dynamic products are existing for retail customers.
- Electricity market participation is done for big power plants. Minimum bid size is too big and e.g. in many places data requirements are the same for 1 charging point and big power plant – this financially stops the business.
- Aggregation is unknown or impossible. Small resources won`t participate in markets if this is not possible. Aggregation from different balances should be adopted more widely to unlock potential.

# Additional materials

# Outcomes

## Report


https://energia.fi/julkaisut/materiaalipankki/greenlink_sectory_coupling_the_final_report.html#material-view

Identified pathways and potentials for sector coupling.


## MODEL

Developed dynamic model for entire Finland – possibilities of creating and testing other scenarios.

# Sector Coupling Pathways and Potentials

| | |
|---|---|
| T | Transport |
| I | Industry |
| R | Residential |
| C | Commercial |
| FP | Fuel production |

| Energy source Examples | Generation | Option | | Feedstocks or additions | Conversion General | Conversion Infrastructure | Total Efficiency | Examples of costs CAPEX | End product | End-use |
|---|---|---|---|---|---|---|---|---|---|---|
| Wind | Electricity | P2X | Power to Gas | H2O | Electrochemical | Electrolysis | 70 - 95% | 750 - 1200 €/kW | H2 | T, I, FP |
| Solar PV | | | | CO2, H2, heat | Chemical | Methanation | 70 - 80% | 800 - 1200 €/kW | Methane | T, I, R, C, FP |
| Hydro | | P2H | Power to heat | Heat source | Mechanical | Heat pump | 200-700% | 610 k€/MW | Heat | I, R, C, FP |
| Biomass | | | | - | Electrical | Large electric | >99% | 190 k€/MW | | |
| Nuclear | | Storage | Potential energy | Infrastructure | Mechanical | Pumped hydro | 75-85 % | 150 €/kWh | Electricity | T, I, R, C, FP |
| Hydrogen FC | | | | - | | CAES | 70-89 % | 400 - 1200 €/kW | | |
| Peak shaving | | | Kinetic | - | | Flywheels | 93-95 % | 500 – 2 000 €/kW | | |
| MSW | | | Batteries | Electrolyte | Chemical | Industrial batteries | 70-90 % | 1000 - 3000 €/kW | | |
| | | | | | | Vehicle to Grid | 70-90 % | 0,05 €/kWh (el) | | |
| Air | Heat | H2X | Heat to gas and liquids | Biomass | Biochemical | Digestion | 20 - 70% | 8-100 €/kWh | Methane | T, I, R, C, FP |
| Geothermal | | | | | | Landfill gas (LFG) | 50 - 99% | | | |
| Waste | | | | | | Fermentation | 80 - 90% | | Bioethanol | T, I, C, FP |
| Metal refining | | H2H | Heat to heat | Electricity | Thermal | Heat pump | 200-700% | 610 €/kW | Heat | I, R, C, FP |
| Chemical industry | | Storage | Sensible heat | H2O | Thermal (change of | Liquids | 50 - 90% | 0.1-10 €/kWh | Heat | I, R, C, FP |
| Food industry | | | | | | Solids | | | | |
| Nuclear | | | Latent heat | Phase Change Materials (PCM) | Thermal (phase change) | PCM: Solids-Liquid | 75 - 90% | 10-50 €/kWh | | |
| Solar thermal | | | | | | PCM: Liquid-Gas | | | | |
| Biomass | | | | | | PCM: Solid-Solid | | | | |
| Hydrogen | X (materials) | X2P | Gas to Power | H2, CH4 | Thermal and electrochemical | Fuel cells | 25 - 35% | 6000 €/kW | Electricity and propulsion | T, I, R, C |
| Methane | | | iquid to Powe | Liquid fuels | | Combustion | 20 - 51% | 500 k€/MW | | |
| Hydrocarbons | | | Solid to Power | MSW, biochar | | Combustion | 30 - 80% | 1m€/MW | Electr. and heat | T, I, R, C |
| Biomass | | X2X | X to biocrude | biomass, H2 | Thermocemical conversion | Gasification | 75% | 625 €/ton (annual) | Gaseous, liquid and solid fuels | T, I, R, C, FP |
| Lignin | | | | | | Pyrolysis | 35 - 40% | 815 €/ton (annual) | | |
| Vegetable wastes | | | | | | HTL | 30 - 40% | 560 €/ton (annual) | | |
| Cellulose | | | X to biodiesel | CH3OH | Physiochemical | Transestrification | 60 - 95% | 124 €/ton (annual) | FAME | T, I, FP |
| Starch | | | X to alcohols | easts or bacterias | Biochemical | Fermentation | 80 - 90% | 150 - 5597 €/ton (annual | Bioethanol | T, I, FP |
| MSW | | | X to biogas | Bacterias | | Anaerobic digestion | 20 - 70% | 430 €/ton | Methane | T, I, R, C, FP |

# Acknowledgment

We thank the following people for their contribution and great cooperation!

| | |
|---|---|
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| VIRTA | Ville Väre |
| LEMPÄÄLÄN ENERGIA | Kai-Kristian Koskinen and Mikko Kettunen |


We still need more actions...

# Thank you for your attention!

Yuri Kroyan

Totti Nurmi