microgen
engine corporation

MEC Linear Free Piston Stirling Engine Generator
Informal Technical Discussion with Helge Urdal National Grid

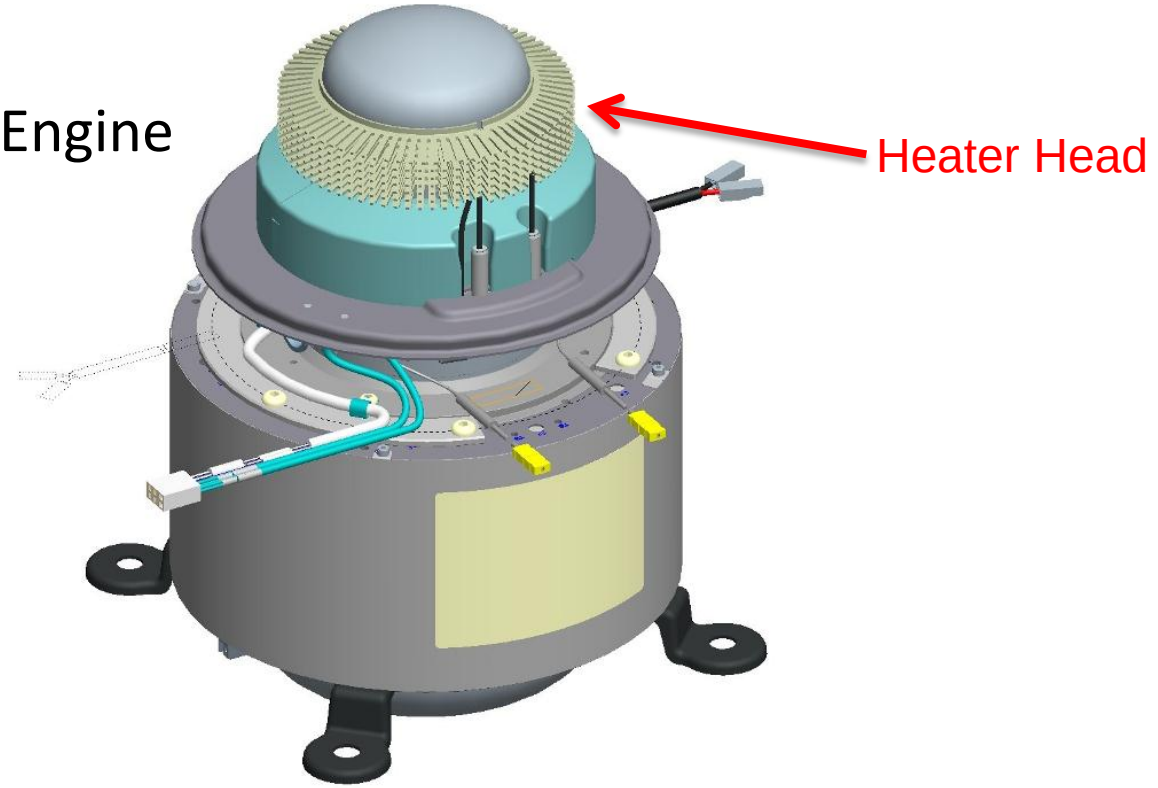
microgen
engine corporation

Contents

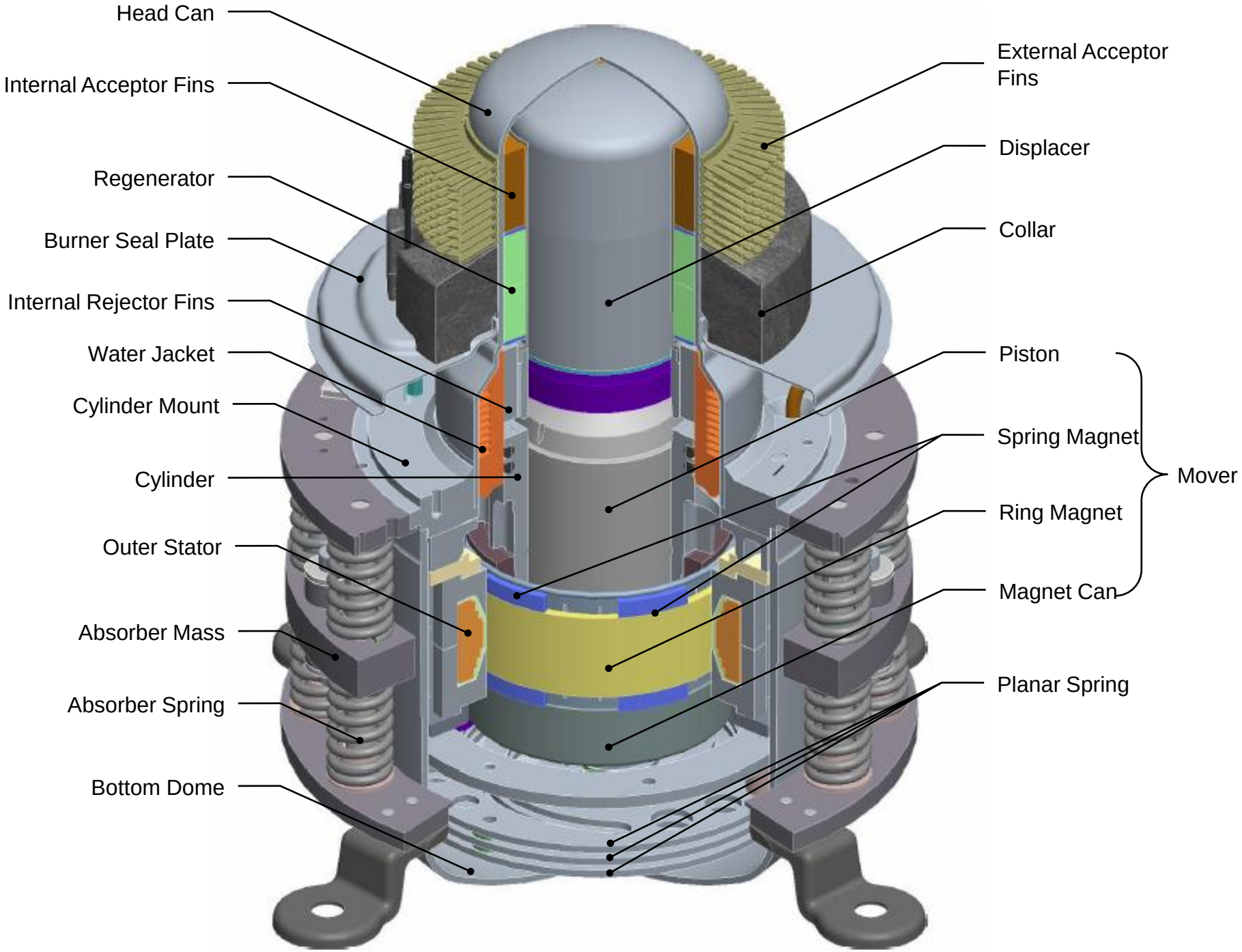
- Technical overview of the MEC Free Piston Stirling Engine Generator
- How is this technology unique?
- Why is fitting an invertor not a solution at this time?
- What is the Impact of Stirling Engine Technology on the Grid?
- Summary and Conclusions

MEC Free Piston Stirling Engine Operation

MEC 1kW Stirling Engine



The MEC Stirling engine heater head is heated to give an electrical power output of 1kW. To achieve this 1 kW of electricity about 4kW of heat will be absorbed by the engine. By controlling a burner, the power will be controlled, based on head temperature, voltage and cooling/heating water temperature.


Head Can
Internal Acceptor Fins
Regenerator
Burner Seal Plate
Internal Rejector Fins
Water Jacket
Cylinder Mount
Cylinder
Outer Stator
Absorber Mass
Absorber Spring
Bottom Dome
External Acceptor Fins
Displacer
Collar
Piston
Spring Magnet
Ring Magnet
Magnet Can
Mover
Planar Spring

microgen engine corporation

What is Unique to MEC ?

- The MEC Linear Free Piston Stirling Engine Generator is like no other Generator on the market:

  - The MEC Engine is a small grid tied synchronous linear generator which was designed to meet and operate throughout statutory frequency ranges 50+/-0.5Hz and up to 264V.

  - The Stirling Engine and Generator are linked as one and operate directly grid connected and completely synchronous with the grid. They do not operate without the grid as they use the grid frequency for piston speed and grid voltage for piston amplitude as well load for the power output. Without the load the engine would just run out of control.

  - The Free Piston of the Stirling Engine operates on gas springs and holds the permanent magnets used for generation in the Linear alternator.

  - The Piston moves with simple harmonic motion at grid frequency and voltage generating very clean electrical power. Other non linear technologies like rotary machines(e.g. IC Engines), and inverter based machines (Fuels Cells, ORC, Wind and PV) which electronically synthesize waveforms, all have far more harmonics.

  - The frequency range for the MEC single cylinder Linear Free piston Stirling Engine is limited by the tuned mass/spring relationships. In particular the Piston mass and the gas spring and the Displacer mass/spring. Since this is a resonant system the frequency of operation is restricted to a maximum of 1Hz due to this relationship.

  - Operation at grid frequencies outside of 50+/-0.5Hz would move the piston and displacer frequencies far away from their resonant frequencies and result in Piston/displacer crashing or overstroke (over amplitude).

What affect does the Grid have on the engine and why is it required ?

- When grid tied the grid controls the following elements of the Stirling engine :-
  - Amplitude of the piston – Voltage of the grid
  - Frequency of the engine – Frequency of the Grid
  - Control of the engine – Voltage/load of the grid. Without this load the engine would run out of control.

- The amplitude of the piston and the displacer will vary depending on the grid; The engine voltage and frequency are essentially equal to the grid values.

- Applying a voltage to the alternator then starts the piston moving the engine self-synchronizes with the grid using a resistor circuit to lower the grid voltage.

- Stopping the engine is performed by simply overloading with a stall resistor.

- Stirling engines can run in off grid mode using a special control module however the connection to the grid is required in MCHP in order to make use of the FIT schemes to make the product financially viable when compared to other technologies.

Inverters

Why can the MEC Stirling synchronous linear generators not just use an off the shelf Inverter ?

- There is not a solution available - Off the shelf Inverters do not provide frequency, load control or voltage control for the generator in two directions. This control is needed with our linear generator which was designed to operate using grid voltages and grid frequency to control amplitudes and generator speed. Without this amplitudes would go too high and mechanical limits would be reached leading to damage. Once started they are controlled by the load voltage and frequency without this they would effectively "overvoltage run- away" pistons would go over amplitude or stall. With the wrong frequency range the piston and displacer would be out of phase and potentially crash or over amplitude. Without the grid the generator would not start. If run outside of the correct frequency range the piston/displacer will not be at resonant frequency.

- Use of an off the shelf inverter removes the direct grid connection that is used to provide the voltage , frequency and more importantly the load required to control the linear generator. Without this grid connection the Stirling engine will not operate.

- Other limitations of grid tied invertor technology includes their reliability which in most cases is reported to be around 5 years & their efficiency. Both of these impose unnecessary limitation and losses on linear generators.

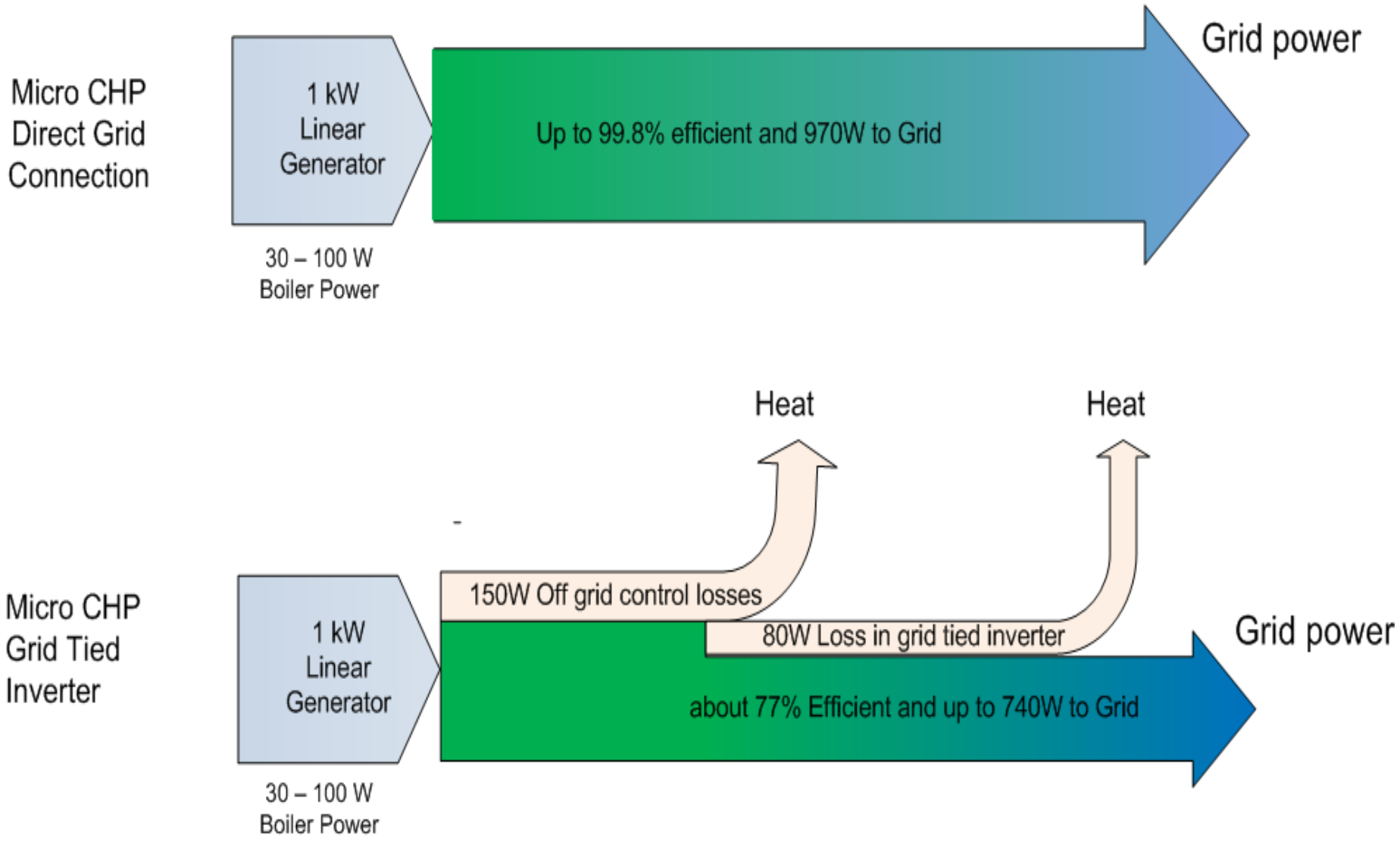
- Variable frequency power supply – effectively off grid which is expensive, no export therefore no payback via FIT, it addition it needs a load in the system >1kW to dissipate the power generated.

Bespoke Grid-Tied Inverter Efficiency considerations

- Bespoke grid-tied inverter – nothing available:
  - Estimated loss of efficiency through electronic power conversion.
    - Power Factor Correction and AC-DC losses (Circa 15%, 150W)
    - DC to AC inverter losses (Circa 10%, 80W)
    - Engine would generate 1000 W and deliver only 770 W!
    - The loss of 230 W would affect the carbon savings making the technology far less attractive.
  - Development and Validation cycle would be costly and long. Appliance manufacturers require confidence and this resulted in 1.5 million engine durability hours before the design was released to manufacture.

microgen
engine corporation

Sankey Diagram with Efficiencies



European MCHP Forecast

European Market Forecast to 2020

DELTA
Energy & Environment

Our market forecasts cover micro-CHP (≤5 kWe) in Europe. Our forecasts this year are significantly below those from August 2011, due to very slow market development for new 1 kWe products and re-assessment of the factors affecting market growth.

Why Scenarios?

There are currently many uncertainties about how micro-CHP markets will develop. Creating three scenarios is a way of dealing with this uncertainty.

Currently, we are in the Low Scenario. We expect to move into the Medium scenario in the next few years.

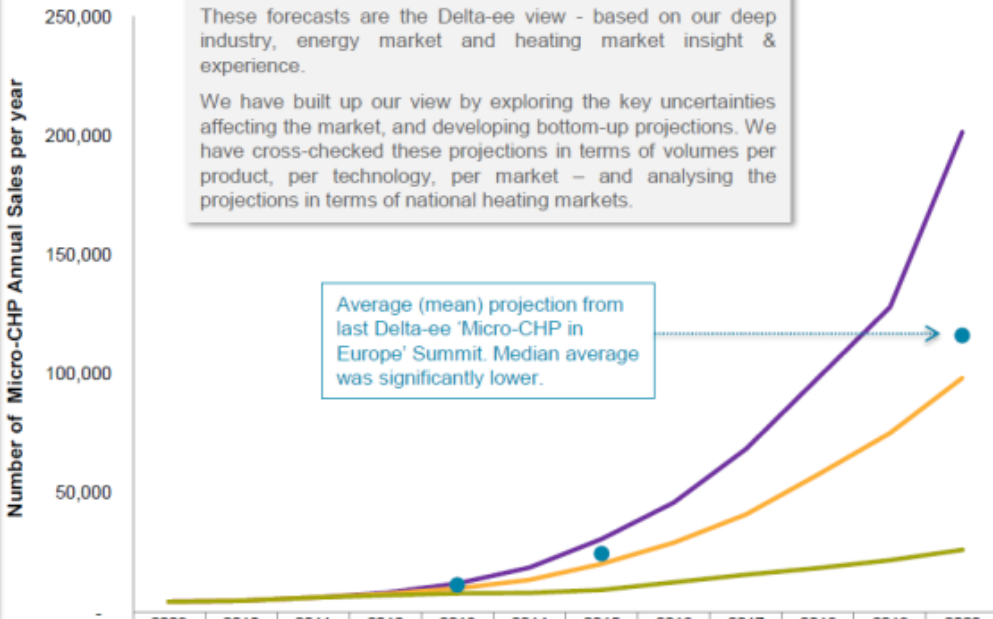
There are conceivable futures that take us into the Medium or even **High Scenario**.

The forecast for each scenario is based on a certain 'story' – described on the following slides. Markets could be higher or lower than each scenario forecast.

Our Methodology

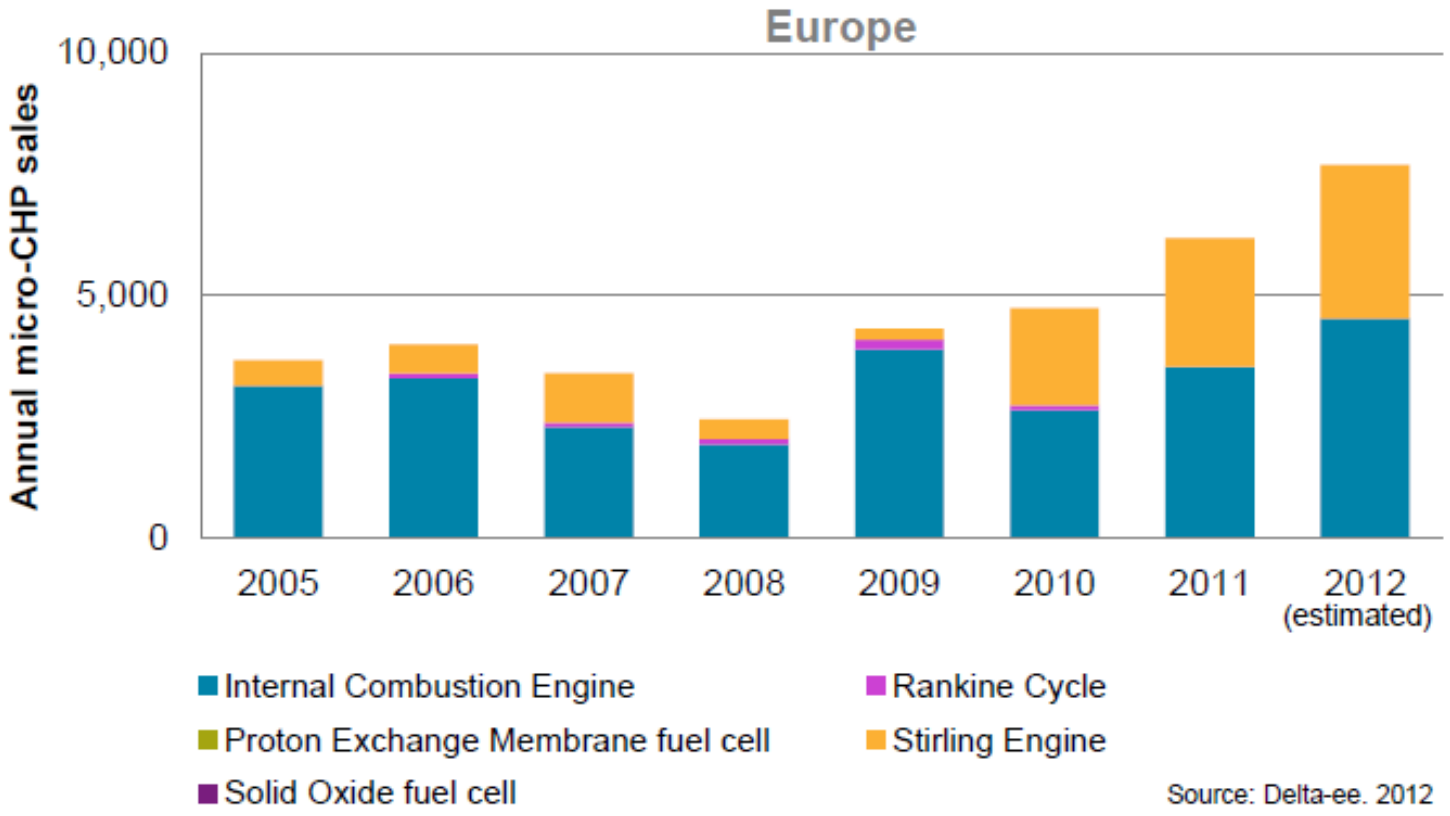
These forecasts are the Delta-ee view - based on our deep industry, energy market and heating market insight & experience.

We have built up our view by exploring the key uncertainties affecting the market, and developing bottom-up projections. We have cross-checked these projections in terms of volumes per product, per technology, per market – and analysing the projections in terms of national heating markets.



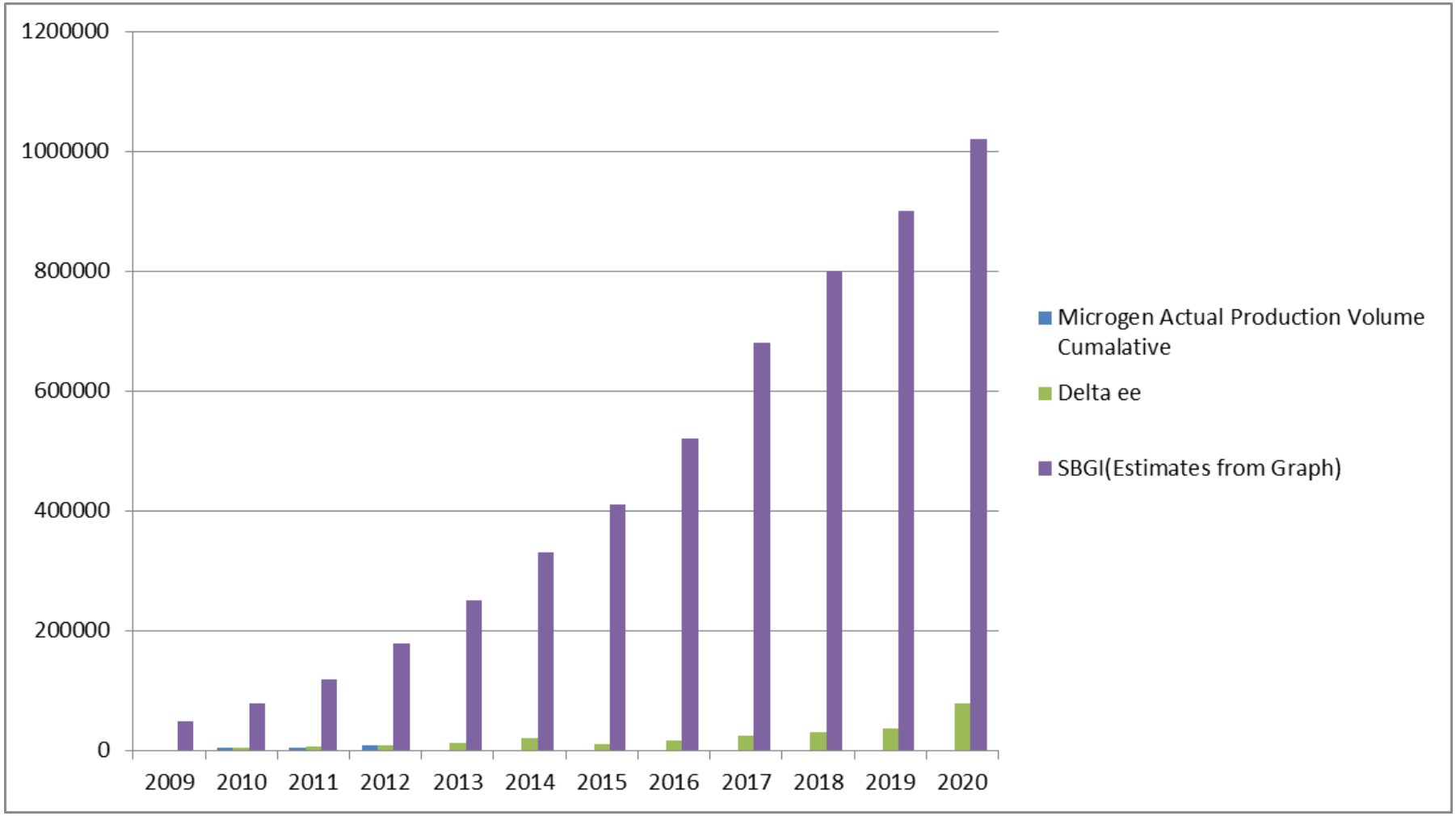
	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
High Growth scenario	4,330	4,750	6,120	8,060	11,960	18,710	30,650	45,995	68,505	98,345	128,145	201,820
Medium Growth scenario	4,330	4,750	6,120	7,560	9,850	13,510	20,235	29,080	41,040	57,730	75,160	98,340
Low Growth scenaro	4,330	4,750	6,120	7,000	7,800	8,050	9,300	12,500	15,660	18,520	21,810	26,080
Mean "Micro-CHP in Europe" Summit Survey 2012					11,422		24,498					116,214

MCHP Sales Breakdown by Technology



Stirling includes Whispergen rotary drive and MEC free piston.

Microgen Actual Build Volumes V Estimates



You can see the Microgen figures also support the low Scenario

Conclusions

- Simply adding an “off-the-shelf” Grid Tied Inverter is not an option for the Microgen as one does not exist at this time.

- A bespoke Inverter solution is also not available at this time and even if it was the capital costs will increase significantly of the MCHP unit (initial estimates are around the 500 Euro). If we just consider this cost, the reduction in power output and loss of efficiency and forget the development time and costs the payback time for the customer would exceed 10 years and product life so no payback !!! MCHP devices are distress purchases in the first place !!

- So what is Microgen asking for ? Market levels of Stirling based MCHP are still much lower than expected due to lack of FIT, change in legislation unsettling buyers, its still a new and innovative unknown technology and as yet we do not even know if we will become a significant cross border generation technology as the market is still in its infancy and investor confidence low. Due to the sudden proposed change in grid connection requirements Microgen are seeking a period of time to firstly see if the market interest is there for a Stirling MCHP unit. Should the market exist then Microgen can find a effective design solution to effectively meet the ENTSO-E requirements for frequency range. Investors will also be willing to support as they will see the market penetration is sufficient to provide yet more investments.

- We are in a unique situation where we have designed a highly efficient domestic heating product to meet 10 years of defined grid connection requirements and these are about to change dramatically. Please don’t kill technology innovation and Microgen, give us the window opportunity to establish the market and provide an effective solution in terms of cost and efficiency.