Converting waste to offer flexible grid balancing services with highly-integrated, efficient solid-oxide plants

Waste2GridS Roadmap

Waste2GridS Consoritum:

ECOLE POLYTECHNIQUE FEDERALE DE LAUSANNE

AGENZIA NAZIONALE PER LE NUOVE TECNOLOGIE, L'ENERGIA E LO SVILUPPO ECONOMICO SOSTENIBIL (ENEA)

DANMARKS TEKNISKE UNIVERSITET

SOLIDpower SA

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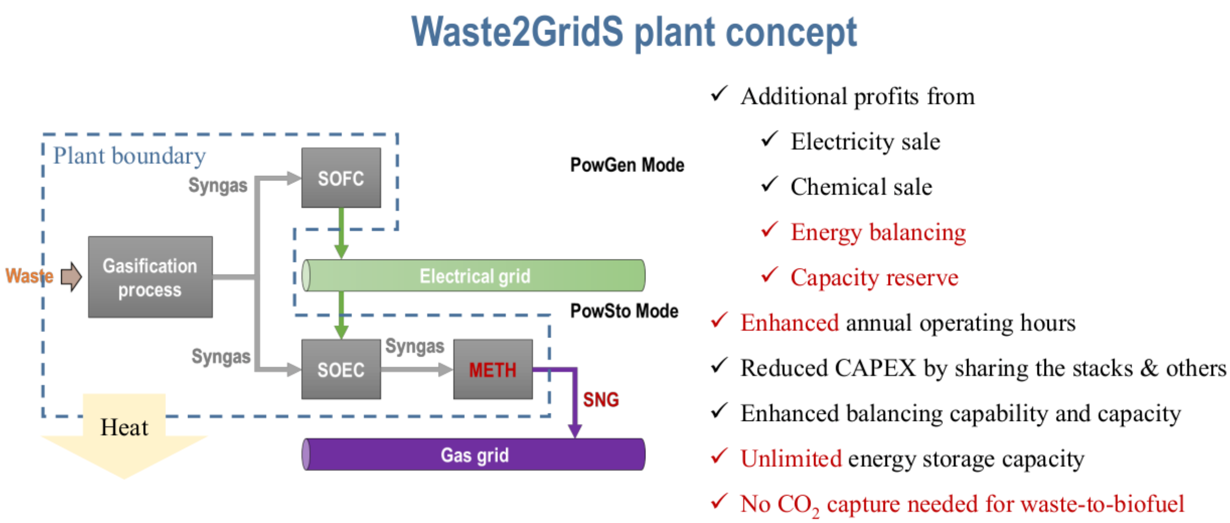
Waste2GridS concept and objective

The Waste2GridS (W2G) project relates to the topic FCH-02-8-2018, ‘waste-stream based power-balancing plants with high efficiency, high flexibility and power-to-X capability’. The W2G plant concept is expected to contribute to accommodate renewable-power in renewable-energy-sources (RES) dominated zones. The W2G plants first convert wastes into syngas (a mixture of H2/CO/CO2) via gasification technologies. Then, the syngas is cleaned and enters the reversible solid-oxide stack subsystem for power or methane production, which provides grid-balancing services.

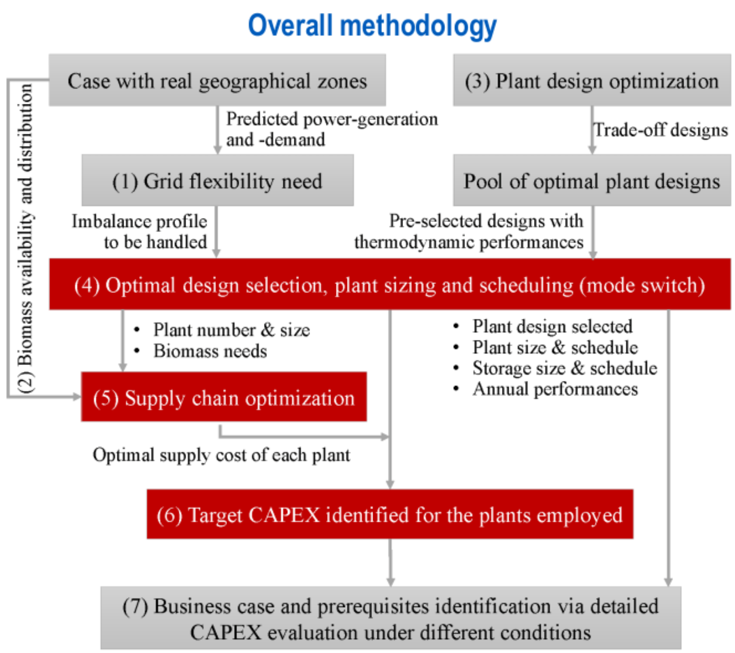


To cope with the increase in the penetration of variable renewable energy sources to meet the ambitious climate and environmental goals, solutions need to be developed at the same time in parallel at the different stages of the value chain, from core technology and component development to system design and integration. This W2G project can provide critical visions for the future large-scale deployment of solid-oxide cell technology, pinpoint the fastest pathways for its industrial and business realization, and thus speed up the whole value chain to establish and enhance the leading position of EU in this field.

The overall objective of the W2G project is to identify the most promising industrial pathways of waste gasification and solid-oxide technology integrated power-balancing plants. Thus, the triple-mode W2G plants provide grid-balancing service by switching among three modes: (i) power generation (PowGen) mode, converting wastes to electricity for the electrical grid, (ii) power storage (PowSto) mode, using the electricity from the grid to convert wastes into methane, (iii) power neutral (PowNeu) mode, converting wastes into methane with no interaction with the grid. The targets of the W2G project are to perform a preliminary investigation on the long-term techno-economic feasibility of the W2G plants to meet different grid-balancing needs and to identify several promising business cases with necessary preconditions.

Overall evaluation methodology

An overall decomposition-based methodology has been proposed to provide a rational techno-economic evaluation of the W2G plants. WP1 (steps 1-2) defined critical boundary conditions for the optimization problem. WP2 (step 3-6) investigated the plant design, defined case studies, and evaluated their economic feasibility, represented by Plant CAPEX target, which is the maximum-possible plant CAPEX levelized to the reference stack (defined as a stack with 64*80 cm2 active cell area). WP3 (step 7) identifies economically potential business cases, based on potential case studies from WP2, and the upscaling strategy and technological bottlenecks.

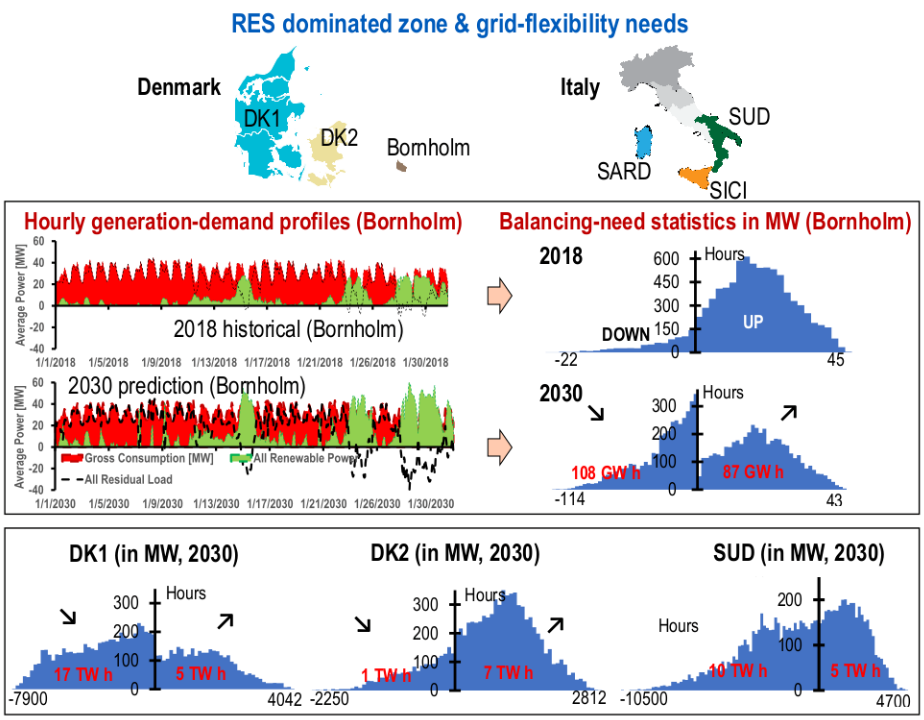


See details in the publication below:

Ligang Wang, Yumeng Zhang, Chengzhou Li, Mar Pérez-Fortes, Tzu-En Lin, François Maréchal, Jan Van herle, Yongping Yang. Triple-mode grid-balancing plants via biomass gasification and reversible solid-oxide cell stack: Concept and thermodynamic performance. ***Applied Energy*** (280), 2020, 115987.

Theoretical flexibility needs

THEORETICAL flexibility needs in 2030 was identified with the multi-timescale data-driven method developed, four of the six zones interested, i.e., DK1, DK2 and Bornholm in Denmark and SUD in Italy, have been concluded with significant theoretical flexibility needs in 2030: The maximum capacity of theoretical UP/DOWN regulations can reach 4042/7900 MW for DK1, 2812/2250 MW for DK2, 43/114 MW for Bornholm island, 4700/10500 MW for SUD. The distributions of UP/DOWN regulation hours and magnitudes are quite different for the four zones with the shares of UP/DOWN regulation hours being 38/62% for DK1, 79/21% for DK2, 55/45% for Bornholm island, and 44/56% for SUD. However, due to other flexibility means, real flexibility needs to be addressed by the W2G plants are much smaller than the theoretical. Therefore, after communicating with the Transmission System Operators in DK, IT and BE, two grid-balancing scenarios scaled down from the theoretical imbalance hourly profiles were defined for deploying W2G plants.



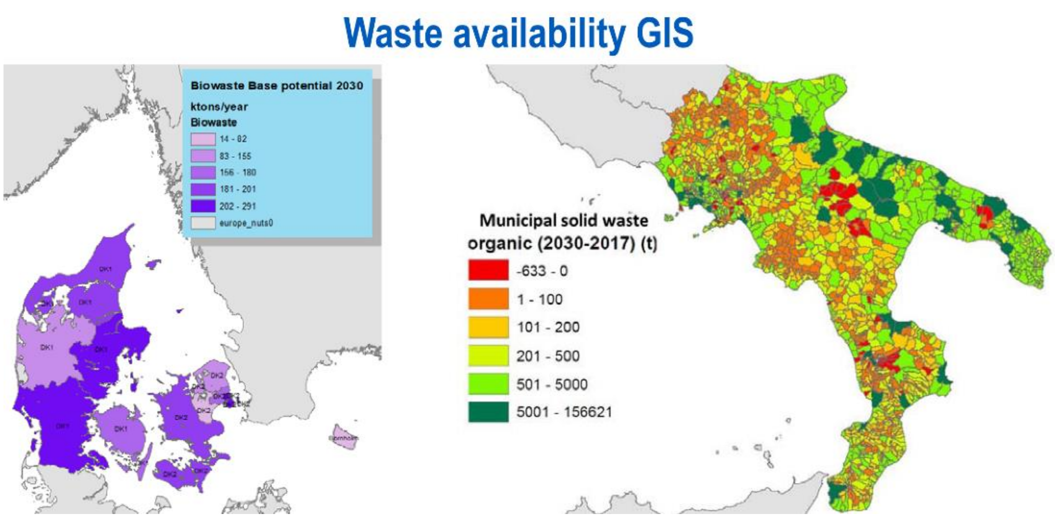
See details in the publication below:

Karen Olsen, Yi Zong; Shi You; Henrik Bindner; Matti Koivisto; Juan Gea-Bermúdez. Multi-timescale data-driven method identifying flexibility requirements for scenarios with high penetration of renewables. ***Applied Energy*** 264, 2020, 114702.

Waste Availability

The sustainable potentials of organic waste and residual biomass, including Agriculture Residues (Straw and Pruning), Forest (net increment and residues), MSW (organic, wood and paper fraction) and Bio-Waste, for the four RES-dominated zones were quantified for 2030. Denmark is divided into 3 RES-Dominated zones with the 2030 biomass base potential for forest residues of around 1850 k.t. d.m, agriculture residues of 1484 k.t. d.m, biowaste of 1931 k.t. d.m. Italy southern regions 'in-around' SUD (the identified zone) have the 2030 annual base potential of 826,384 t.d.m straw, 1,221,102 t.d.m Prunings, 3,317,461 tons of forest increment, an additional stream of 1,287,385 tons of MSW organic fraction. All wastes distributions have been provided as visualized with a high resolution of up to 100 m.

The theoretical flexibility needs of the four zones and in-and-around waste availability are roughly compared and concluded that the theoretical grid flexibility needs might be fully satisfied with the complete disposal of the municipal organic waste generated in 2030, pointing to an intriguing perspective for the deployment of RSOC systems at a large scale.

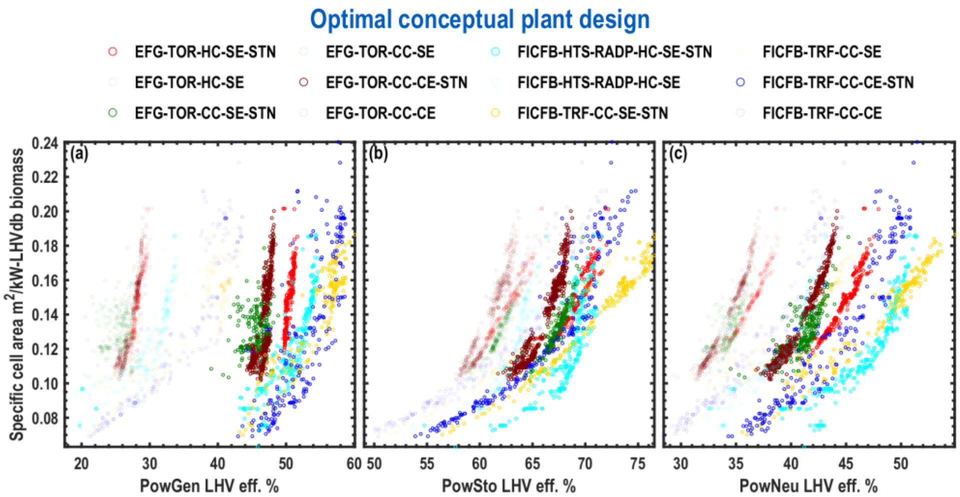


See details in the publication below:

Claudio Carbone, Francesca Gracceva, Nicola Pierro, Vincenzo Motola, Yi Zong, Shi You, Mar Pérez-Fortes, Ligang Wang, Alessandro Agostini. Potential deployment of reversible solid-oxide cell systems to valorize organic waste, balance the power grid and produce renewable methane: a case study in the Southern Italian Peninsula, ***Frontiers in Energy Research***, 2021, DOI: 10.3389/fenrg.2021.618229.

Plant design

The optimal conceptual plant design has concluded that the efficiency reaches up to 50–60% for PowGen mode, 72–76% for PowSto mode, and 47–55% for PowNeu mode. The efficiency difference among different technology combinations, e.g., hot/cold syngas cleaning, with the same gasifier type, is less than 5% points. When penalizing the syngas not converted in the stacks, the optimal plant designs interact with the electrical and gas grids in a limited range. Steam turbine network can recover 0.21–0.24 kW electricity per kW dry biomass energy (lower heating value), corresponding to an efficiency enhancement of up to 20% points. The Pareto designs are further selected to create a pool of plant designs. With different plant designs, the plants of the same number of stacks can interact with the electrical and gas grids at different magnitudes.



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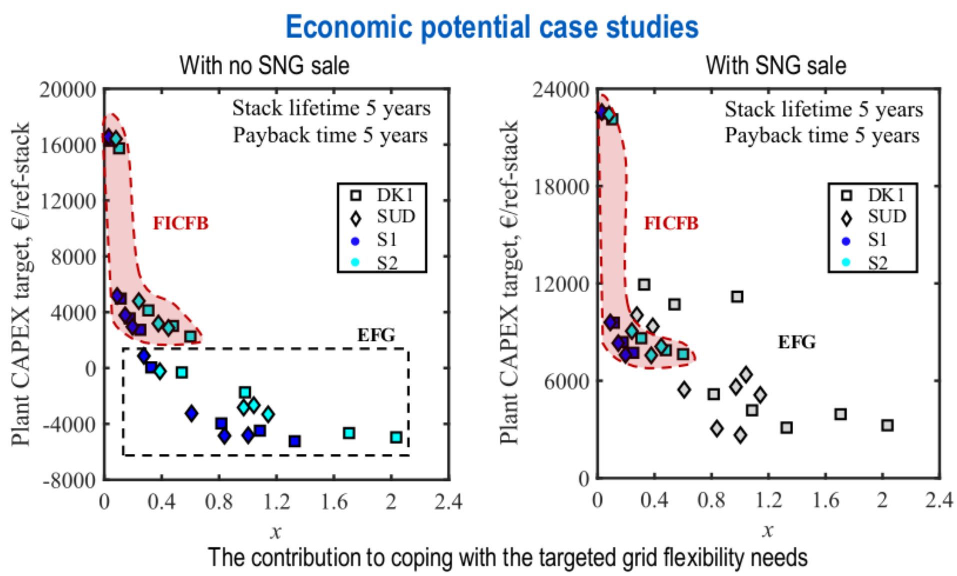
Economic feasibility

The case studies with all details of the number, designs, sizes and operation of the plants deployed as well as the optimized waste supply chain are established to cope with the defined grid flexibility needs. It is concluded that the plants at the sizes of up to a few hundreds of MWth biomass feed, corresponding to a PowGen capacity of up to a hundred of MWe and a PowSto capacity of up to a few hundreds of MWe, can achieve potentially-high economic feasibility with the plant CAPEX target reaching over 22000 €/ref-stack for a payback time of 5 years, a stack lifetime of 5 years, a balancing energy price of 40 €/MWh and a gas sale price of 0.8 €/kg. Large plants of thousands of MWth biomass feed can hardly be economically potential, due to high biomass supply costs, which contributed to more than 50% or even several times of the profits from grid-balancing services. The economic feasibility is affected by their contribution to addressing the targeted flexibility needs. The higher the contribution to cope with minor imbalances, the more capacities deployed will be coordinated to operate under PowNeu mode, which is much less profitable than the PowGen and PowSto modes. The increased average annual utilization hours of the PowNeu mode cause a decrease in plant CAPEX target. Moreover, the grid-balancing scenarios do not affect the economic feasibility of the case studies established.

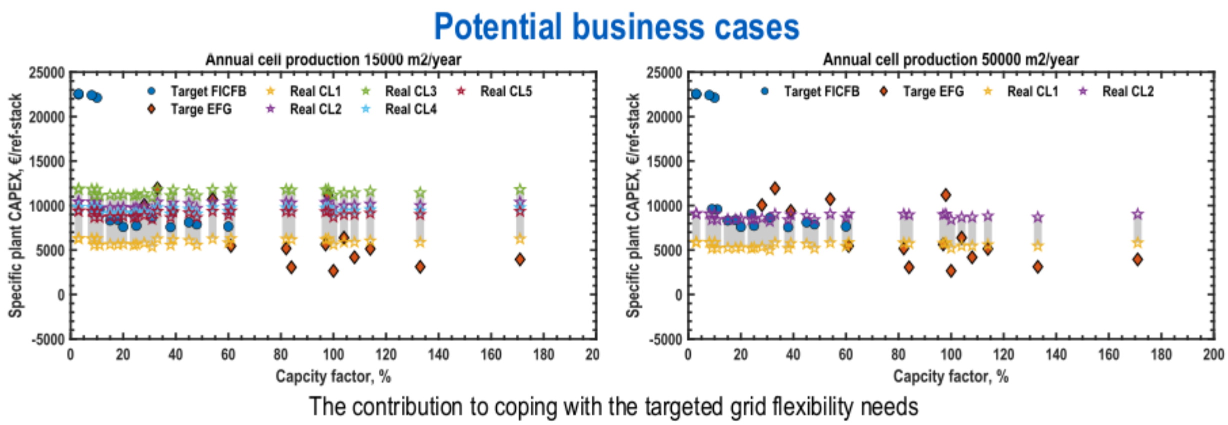


See details in the publication below:

Yumeng Zhang, Ningling Wang, Chengzhou Li, Liqiang Duan, Jan Van herle, François Maréchal, Tzu-En Lin, Ligang Wang, Yongping Yang. Triple-mode grid-balancing plants via biomass gasification and reversible solid-oxide cell stack: Economic feasibility evaluation via plant capital-cost target, ***Frontiers in Energy Research***, 2021, under review.

Potential business cases

Plant CAPEX Target was further compared with Plant CAPEX Real for each case study. The plant CAPEX real of the case studies is within 5000–12000 €/ref-stack, thus with a plant CAPEX target of over 20000 €/ref-stack, at least two case studies with the plants of around 100 MWth biomass feed, deployed in Ostjylland (DK) and Campania/Calabria (IT), become potential business cases, even considering engineering and contingency costs apart from the gross Grassroot CAPEX. The business cases can be enabled by the state-of-the-art circumstances: 5-year payback time, 40 €/MWh energy balancing price, 5-year stack lifetime, 0.8 €/kg natural-gas selling price, and 1600 €/kWe stack costs evaluated with SOFC power. The long annual operation hours of PowGen and PowSto modes (e.g., over 7500 hours) are critical to enable business cases. With the increasing operation hours of the PowNeu mode, the stack costs need to be below 200–600 €/kWe SOFC stack to enable more potential business cases.



All in all, one conclusion, in short, is that the triple-mode W2G plants at a scale of up to a few hundreds of MWth biomass feed (corresponding to a PowGen capacity of up to a hundred of MWe and a PowSto capacity of up to a few hundreds of MWe) are proven to be economically potential when the stack costs are reduced to below 2000 €/kWe SOFC, even with the current grid-balancing prices. The key to enabling high economic feasibility is high annual hours of PowGen and PowSto operation, regardless the imbalance profiles.

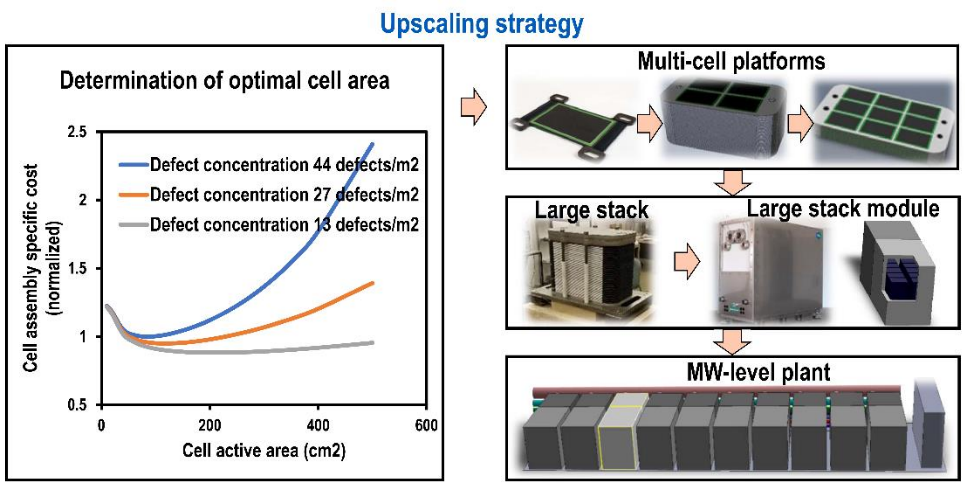
Technical bottlenecks

Technological bottlenecks of the plants are given in all aspects:

- Gasification
  - Materials to resist corrosion caused by high-temperature, chemical (organic acid, Cl and S) and the melting of salts
  - Process and design: tar generation control with proper bed materials; residence time for sulfur capture and tar conversion; pressure drop and carbon loss; expensive; the scale-up ability and product impurity of FICFB gasifier
- Syngas cleaning
  - Materials to resist corrosion caused by high-temperature, chemical (organic acid, Cl and S)
  - Tar removing or conversion process
  - Deep syngas cleaning to reach the stack requirement: < 1 ppm H_2S, <8 ppm chlorine compounds, no Siloxanes
  - Innovative, less expensive deep gas cleaning process and units needed
- Stack
  - Metal to resist high-temperature corrosion, various impurities (S, Cl, etc)
  - Cheaper and better performing cell materials, particularly not using Co
  - Cell/stack durability with impurity tolerance enhancement and advanced process control to reduce degradation and carbon deposition
  - Scale-up and manufacturing
- Methanation
  - Cheaper, durable, highly selective catalyst
  - Reactor and process design to realize good temperature control, and high controllability
  - Dynamic operation
- System
  - Matching of plant design and application
  - Steam turbine network to enhance the overall performance
  - Mode switch and operational flexibility to reduce the switch time and proper management of the standby mode of methanation reactors
  - Heat exchanger design to enable multiple operating mode with components under different operating schemes
- Deployment
  - Size strongly limited by the biomass supply chain: very large single plants up to 1000 MWth not feasible
  - Grid integration: service qualification with the plant established and tested.

Upscaling strategy

The upscaling strategy of the RSOC systems paves the path to scale up the SORC systems to multi-MW market via the opportunities at different levels: cell size, multi-cell stack platforms, large stack modules (LSM) and plant. The main findings include (1) For larger defect densities (>20 defects/m2), active areas of 80-150 cm2 are preferable; (2) With a 5x5 cell configuration, the power density can be increased by 95% compared to 2x2; (3) At the stack level, the production cost can be reduced significantly by increasing both the number of cells per layer and the number of layers; (4) The building blocks of Multi-MW scale RSOC plants are large stack modules (LSM) that integrate multiple stacks in a single insulated box with the balance of plant components necessary for their autonomous operation; (5) Four concepts of LSM were designed based on the 10 and 40 kW stacks described above, with power ratings of 50, 100, 200 and 400 kW respectively. (6) The LSMs will be assembled in 1-4 MW sections (or power blocks) connected to a centralized bidirectional AC/DC converter.



Roadmap 2030

	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Components										
Biomass/waste gasification	TRL 7-8									
Low-cost deep syngas cleaning units for stack impurity tolerance	Waste2Watts/BLAZE TRL 7-8									
System										
Biomass gasification - SOFC demonstration	BLAZE (TRL7-8)									
MWe level SOC stack scaleup and systems	MULTIPLHY (TRL 7-8)									
MWe level RSOC system	GrinHy2.0 (TRL 7-8)									
MWe level biomass gasification - RSOC systems										
Tens of MWe level Waste2GridS plants										
Service										
Grid service qualification			Qualification along the operation of different systems							