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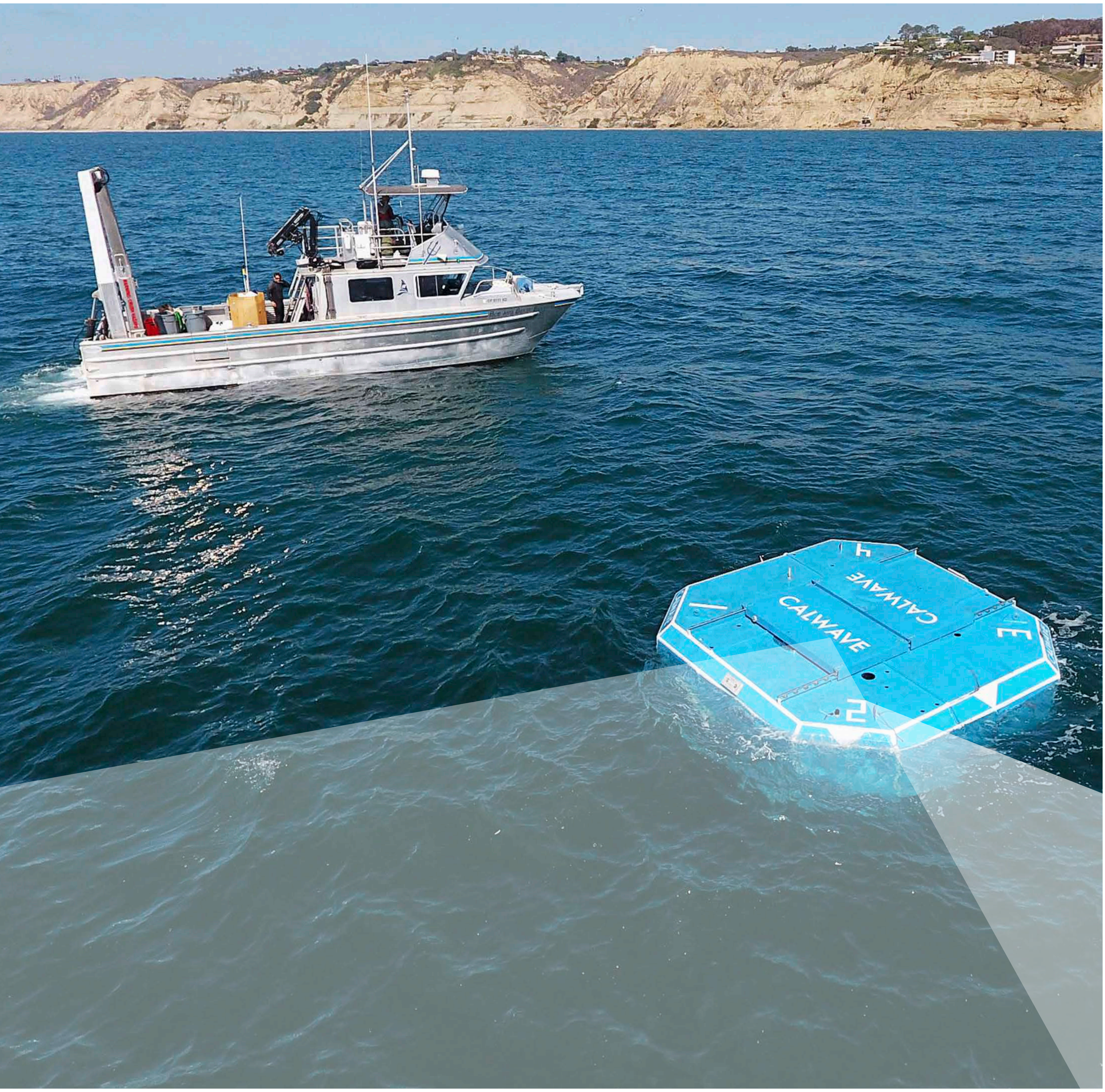
Electricity From Wave Energy

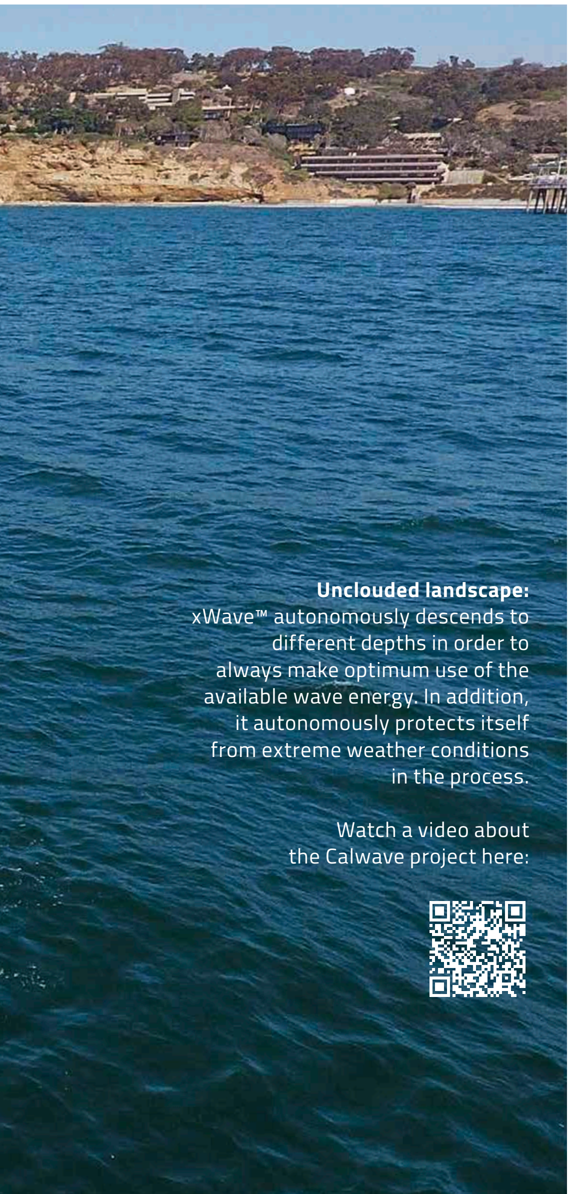
# OCEANS OF POTENTIAL



Electricity From Wave Energy

# OCEANS OF POTENTIAL

Wave energy is the world's largest untapped renewable energy source. CalWave from California wants to change that: The company's goal is to reliably and consistently supply a quarter of the world's energy requirements with energy from ocean waves.
In July 2022, the company completed a highly successful pilot project with its xWave™ system off the coast of San Diego. And for its next prototype, the company is utilizing M-Target for Simulink® for application development, as well as hardware from Bachmann.



**Unclouded landscape:**
xWave™ autonomously descends to different depths in order to always make optimum use of the available wave energy. In addition, it autonomously protects itself from extreme weather conditions in the process.

Watch a video about the Calwave project here:

### Huge potential

Ocean waves are packed with hydrokinetic energy: According to the Ocean Energy Council, a wave breaking along a mile of coastline releases up to 35,000 horsepower. But a few miles off shore is where waves have the greatest energy potential. This can be harnessed with wave energy converters anchored to the seabed that convert energy into electricity, then transport it via a cable to coastal regions.

According to the U.S. Energy Information Administration, the annual energy potential along United States coasts is 2.64 trillion kWh. "This means that, in total, about one-third of American electricity demand could be met by wave energy alone," says Thomas Boerner, chief technology officer at CalWave Power Technologies, Inc.

### A perfect addition

Compared to other forms of renewable energy, wave energy is more constant and predictable: "The day-night profile of wave energy looks very similar, there aren't usually any fluctuations correlating with the day-night cycle, and seasonal fluctuations are less significant compared to other renewables," explains Boerner.

Moreover, the production profile of wave energy is counter-cyclical to that of wind and solar. While wind produces the most electricity in the summer months, waves are strongest in winter – making wave energy an ideal complement to existing forms of renewable energy. With its xWave™ system as a wave energy converter (WEC), CalWave aims to maximize this potential.

### Protective water

Back in 2012, CalWave founder Marcus Lehmann became fascinated by wave energy. Inspired by the muddy seabed that effectively absorbs it, he built the first device to convert wave energy into electricity. Experimentation continued with prototypes in the wave tank at the University at Berkley, and the first patents soon followed. After CalWave was founded, the company spent four years working diligently on the system concept. Power electronics, closed-loop control and the drivetrain underwent continuous development. The automation and SCADA system were also consistently tweaked.

The COVID pandemic complicated the procurement, testing and integration of hardware for the first field test. Coordinating the logistics of all involved parties was also a challenge. "Fortunately, thanks to Bachmann, we had extremely short lead times in procuring hardware and software components for the Bachmann automation system. In addition, the Bachmann team went through the automation requirements with us in detail, and advised us on how to assemble the systems in the best possible way. Their support was extremely valuable," says the Chief Technology Officer, looking back at the development period.

But conditions on the deployment site – the open ocean – also presented developers with a challenge: The xWave™ design had to withstand 50-year storms. During strong storms, waves can reach destructive proportions. Withstanding such high forces on the surface would require huge material expenditure. CalWave therefore operates its system entirely underwater, avoiding these potentially damaging waves. In addition, the wave energy converter is equipped with unique load management mechanisms: xWave™ can be lowered or raised relative to the seabed, depending on the immediate wave propagation, to harness wave energy at the ideal absorption depth.

"Such load management mechanisms were specifically integrated into the xWave™ concept right from the start, enabling a highly efficient design and significant cost advantages," Thomas Boerner is pleased to report.

### Maximum performance

Several drivetrains generate electricity from the wave-induced movement of the superstructure relative to the seabed. The goal was to utilize each wave as much as possible. Since the entire platform is below the water's surface, wave energy is utilized over multidimensional degrees of freedom, improving overall efficiency. In addition, the system can also change the geometry of the absorbing body to further optimize the scalable system. "With these mechanisms, we keep not just the drive within an optimal operating range, but the entire unit – very similar to the approach used in wind energy," explains the engineer.

### Successful pilot

In September 2021, half a kilometer off the coast of San Diego, a pilot project kicked off to rigorously test the system under real conditions. It was California's first long-term trial of wave energy usage.

CalWave was keen to keep their system operating autonomously around the clock. "Availability is the most important issue for us," says the CTO, adding, "with the Bachmann controller, we were able to achieve more than 99% total system availability during the 10-month pilot project under real conditions."

No interventions were necessary during the project, he adds. "Our mechanisms for drive control, power optimization and diagnostics proved to be reliable and robust; they worked completely autonomously," explains Boerner. Following the initial six months, CalWave decided to extend the project by an additional four months due to high reliability.

With a rated power of 15 kW, the xWave™ system is controlled with the MC220 processor module via a Bachmann master station, which is connected via FASTBUS to several remote drive substations. Communication to the drives is via EtherCAT. The GM260 network acquisition module quickly and reliably measures the relevant three-phase current variables. Finally, the processor load is cleverly distributed among the CPU's four cores. Boerner is impressed, "Despite complex controls requiring the exchange of more than 1,000 variables between parallel-running application programs, the MC220 CPU system load never exceeded the 50 percent mark, even when using just one of the four available processing cores."

CalWave kept a constant eye on the pilot plant's status: The Scope3 software oscilloscope was used to record and historize system data. Visualization with webMI pro enabled comprehensive plant diagnostics and targeted control of all important parameters, from any location. "Thanks to the 12-hour data sampling of all relevant signals, we were able to track the platform's processes quite easily and without post-processing," Boerner is pleased to report. "Of course, detailed analysis at a high data rate is always possible during post-processing."

### Challenging development conditions

However, the path to the pilot project was demanding from a development perspective, as the CTO emphasizes: "Testing a new type of system with multiple components on a large scale and under controlled conditions is highly complex. There are a great many factors that influence and sometimes reinforce one another. In addition, as much of the system configuration as possible had to be performed onshore, because offshore testing is very expensive. The development and optimization of drivetrain control strategies are good examples of this."

During the testing phase, the team further optimized the dynamic system with extensive simulations. They automatically generated code using M-Target for Simulink®, and were able to load it onto the controller at any point via the network. This was crucial for putting xWave™ through its paces (see article "In focus: model-based development" on page 29).

Another challenge was the complexity of the powertrain and controller system, as well as the signal and data organization. Here, it was an advantage that the Bachmann controller supports programming language C++ in addition to code compiled with Simulink. "This parallelism is already extremely strong. We are yet to find another platform that is so seamlessly integrated. It was very helpful," says Thomas Boerner.

### The development continues

As a next step, CalWave plans to build a 100 kW version of the xWave™ architecture. This is to be operated for two years at PacWave South – the first accredited, grid-connected and approved test facility for wave energy on the open ocean in the USA. From there, 20 megawatts of power will be fed into the mainland's local grid via pre-installed cables.

This time, CalWave also wants to work with a digital twin – a simulation model trained with data from the real system. The control and simulation model will then run in parallel in real time, with the results from the real system being compared with those of the simulation. "This will allow us to test different control concepts before they are deployed on the real system. This data-driven approach should ultimately enable us to monitor systems that are not equipped with sensors – and also to plan maintenance for the xWave™ predictively," explains Boerner. He expects to be able to accommodate the required computing power in parallel on his MC220 CPU.

The long-term goal is to achieve grid-serving power classes in the range of over one megawatt per system. Even if the drive systems are further scaled for this purpose, the control architecture based on the Bachmann automation system can essentially be adopted 1:1. "To this end, in future we also want to create a farm setup and bundle the units," says Boerner. But platforms with lower nominal power ratings, such as those in the pilot project, also have a role to play in wave power. They could be used in future, for example, as an energy supply for offshore measuring stations.

### CALWAVE POWER TECHNOLOGIES INC.

- Founded in 2014 in Oakland, California
- Employs seven people
- The company aims to harness the power of ocean waves to provide reliable and cost-effective access to sustainably-produced electricity

**https://calwave.energy**

## IN FOCUS: MODEL-BASED DEVELOPMENT

Calwave chose Simulink® for model based development. This allowed them to use a simulation model to precisely investigate the reciprocal influences of the mechanical and electrical components of waves. The necessary control algorithms, signal processing, and state machine were also designed in Simulink® at the same time. This made it possible to fully test the final machine control within the simulation, and to carry out proof of concept even before the first real components were available.

**The architecture makes the difference**

With M-Target for Simulink®, software applications for the Bachmann automation system could subsequently be generated directly from Simulink® and then processed on the Bachmann controller alongside other C++ programs. Within the Simulink® control program, sensor and actuator signals are connected directly via Bachmann hardware blocks. The drivetrain, connected to the mail server trigger via EtherCAT, is also integrated in the Simulink® model.

To maintain flexibility, the Simulink® control program was encapsulated in individual sub-applications. For this purpose, signal acquisition, machine control, the state machine and signal output were encapsulated in separate referenced models and accepted individually. From the M-Target library's referenced models, independent Bachmann software modules were generated and installed on the MC220 CPU using the Model Builder block.

This architecture proved to be a key advantage as the project progressed and during field testing. For example, it allowed CalWave to replace the existing control core with a newer, optimized version by reloading new software. All other software components remained unaffected by the change. Because the control system did not have to be restarted, the plant continued to operate.

**The future in sight**

In future, CalWave will simulate its machine model, which is built with SimScape blocks, on the Bachmann controller in real time. This will allow the model to be processed as a separate software module alongside the rest of the control code on the operating controller.

Among other things, Calwave expects this to provide decisive advantages for its hardware-in-the-loop (HIL) testing. Certain plant components, such as the drivetrain, are built in the real world and connected to the Bachmann automation system via the I/O interface. Non-physical components are simulated by the machine model.

In the next stage of expansion, this setup will be used to create a digital twin on which new controls, predictive maintenance concepts, or virtual sensors can be tested.