EFFICIENT SEAWATER AND BRACKISH WATER PURIFICATION
87% SEPARATION AND <300 PPM SALT IN PRODUCT
(WORK IN PROGRESS)

A unique, innovative and highly efficient desalination system is currently being developed by Enis WindGen™ Renewable Energy Systems LLC. This desalination concept is an outgrowth of a patented Transportable Compressed Air Energy Storage (T-CAES) system that is being evaluated for full-scale application to store excess wind energy for a wind turbine and at a wind farm. In addition to electric power, the T-CAES system produces highly chilled air as a byproduct. This chilled air is the basis for the innovative desalination concept under development.

Several options are available for the operation of T-CAES, depending on the specific requirements: (1) Generate electric power, while minimizing the production of the chilled air byproduct, thus increasing the efficiency of electric power production Generate electric power with highly chilled air as a byproduct, or (2) Generate highly chilled air with electric power as a byproduct, or (3) No electric power is generated, only chilled air. We are discussing the third option.

A wind turbine, power from the electric utility grid, or a diesel generator can drive the primary compressor. **In the case of the wind turbine, the T-CAES system will generate not only electricity but also co-generate the chilled air (RECOMMENDED SYSTEM).**

At the extreme cold temperatures of the order of –120^{o}F to –170^{o}F, the chilled air can be mixed with a droplet spray of seawater or brackish water to generate ice (pure water when thawed), salt and chilled air at about –6^{o}F so that the –6^{o}F air can be further used by air conditioning systems

ELECTRICAL POWER REQUIRED
TO PURIFY A UNIT FLOW OF PRODUCT
(PURIFICATION EFFICIENCIES NOT RANKED)

	KEY COMPONENT kW/(#/min)	COMPLETE SYSTEM kW/(#/min)
MULTI-FLASH DISTILLATION		**2 TO 4.4**
REVERSE OSMOSIS	**0.02**	**0.08**
SCRAPED SURFACE DISTILLATION*		
$NaNO_3$	**11.5**	
$CuSO_4.5H20$	**8.6**	
CRYOTEC*		**0.66 TO 0.86**
EFC-SPRAY CHAMBER (NaCl)*	**7.27**	
WTG/T-CAES/EFC-SPRAY CHAMBER*	**0**	

*** EUTECTIC FREEZE CRYSTALLIZATION (EFC)**
WIND TURBINE GENERATOR (WTG)
TRANSPORTABLE COMPRESSED AIR ENERGY STORAGE (T-CAES) SYSTEM
and food storage lockers.

The chilled air is available for “free” as a co-generated output of the T-CAES system.

Figure 1 Comparison of System Efficiencies of Desalination Processes

The first two systems in Figure 1 are the desalination systems most often used worldwide along seacoast installations where rainfall is in short supply.

Although eutectic freeze crystallization (EFC) process uses more power, the higher purity and the handling of food products makes it of more use in the food processing industry. The reverse osmosis systems just do not apply to the food processing industry.

For example, consider the 2.5 MW wind turbine on an island. Our T-CAES system will store and release 500 kW-hrs to 1,000 kW-hrs during long periods of wind speed lulls, and permit even better savings when there are short periods of wind speed lull. Each time we supply 500 kW of electrical power…we also release 500 kW of chilled air (-140 to –170^{o}F) that will be used for desalination. The output from the crystallizer is at –6^{o}F, so that it can be further used for air conditioning. In this case there is **NO COST** of electrical power. This is the ultimate in cogeneration.

When we do not have the advantage of a wind turbine generator and there is 200-psia, compressed air available at the facility, the compressed air can be input to the turboexpander and the chilled air exhaust of the turboexpander released through the crystallizer. There results high purity slurry that is potable when thawed.

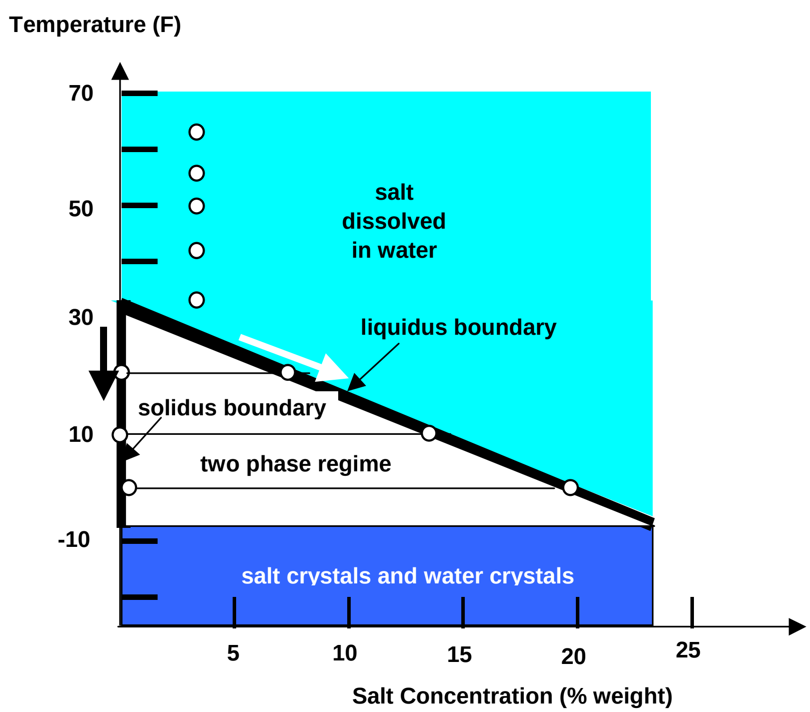

Figure 2 Water-Salt Phase Diagram

The proposed system has a convenient aspect in that the key moving component is the turboexpander that develops the chilled air and sees no corrosive elements. The turboexpander has operated in other scenarios for 40 to 50 years with only occasional maintenance for seals and bearings.

The basic principle for our innovative concept is the water-salt phase diagram. Figure 2 shows the sub-eutectic composition of the saltwater with 3% concentration at 65^{o}F. As the water is brought down the original saltwater in temperature the salt stays dissolved in the water as long as the temperature remains above the "liquidus boundary line".

When the temperature is dropped below the liquidus boundary line, the saltwater forms two phases. One portion of the original saltwater forms ice without any salt content, and as the temperature falls further and further, more and more ice is formed following the vertical solidus boundary line. The other portion of solution follows the liquidus boundary line and becomes more and more saline as the temperature is reduced. Since the concentrated salt water is much denser than the ice, the ice floats as a separate mass atop the salt water. The sequence of steps in the process of Eutectic Freeze Crystallization (EFC) occurs until lowest temperature possible for liquid salt solution is –5.98°F. It is not desirable to use temperatures lower than the eutectic temperature because a useless solid mass of salt crystals and water crystals form. The aim is to operate at about –4^{o}F so that the ice forms atop a boundary layer of dense saltwater.

The eutectic temperature of NaCl solution is –5.98oF and eutectic composition is 23.3%. Since the density difference between ice (57#/cu ft) and the salt solution (84 #/cu ft) is large, it is possible to separate both solids simply by force of gravity. The NaCl crystal weighs 135 #/cu ft.

In the EFC process, formation of ice crystals from aqueous solutions, such as saltwater, can be achieved in two different ways: (1) By Direct Cooling, or (2) By Indirect Cooling on a Chilled Surface. Direct Cooling is by far the more efficient process, and is the one used in our system. In this system chilled air (gas) is directly imposed on a droplet cloud of seawater.

The proposed desalinator, shown schematically in Figure 3, is a variation of the Direct Cooling Method described above, with several very significant and major differences.

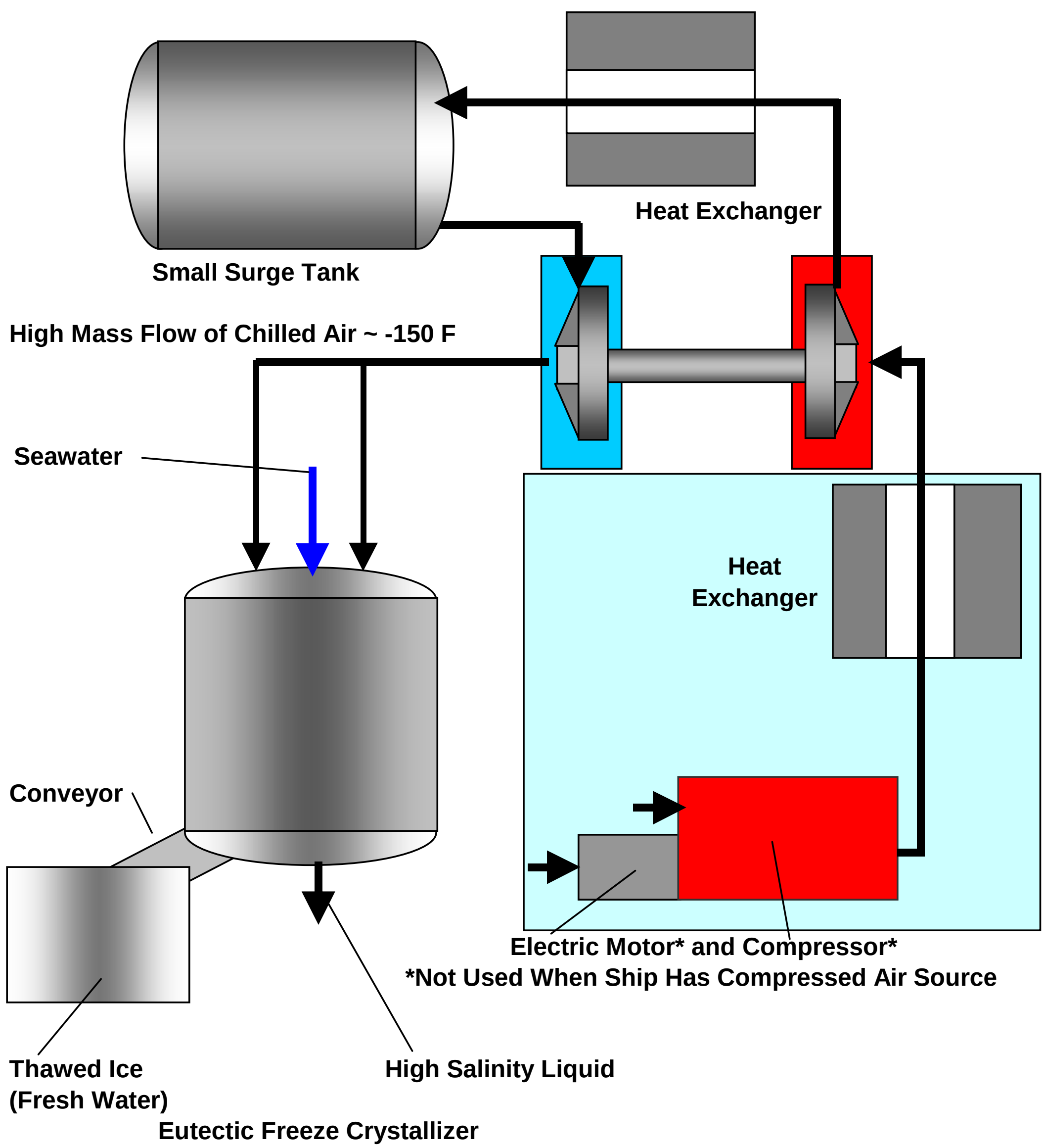

Figure 3 Schematic View of the Desalination System Under Development at Enis WindGen™ Renewable Systems LLC

- The proposed desalinator uses chilled air at temperature as low as ~ -150^{o}F. The air is clean and dry and poses no contamination threat to the clear water derived from the process.

- Wind power is used to produce the chilled air, with no polluting products to the environment.
- The chilled air is a byproduct of the energy storage system used in conjunction with a wind turbine.
- Dedicated production of chilled air can also be done with electric power from the power grid, as well as with a diesel generator
- The proposed desalinator will deliver efficiencies higher than any other operating or candidate system.
- The proposed desalinator system is compact in volume and is flexible in terms of application. It is ideal for application where there is access to saltwater; on an island, at the seashore, and aboard a ship or submarine.

In the configuration wherein the wind turbine generator produces electrical power and chilled air, the chilled air is sent directly to the crystallization chamber and the settling chamber for the desalination process. In the case where electrical power is available to drive the turboexpander, Figure 3 shows the desalination system.

Figure 4 shows the end product of the overall desalination, wherein 10,000 pounds of seawater resulted in 8,700 pounds of ice (pure water).

The ice (fresh water) is removed by a rotating screw surface maintained at –4^{o}F. The highly concentrated salt solution is drained. The –120^{o}F to –170^{o}F input chilled air that migrated through the saltwater droplets, exits the chamber at temperatures close to –4^{o}F. This chilled air is then used downstream in an air conditioning system.

The Wind Turbine Generator, T-CAES System for Desalination <u>and</u> the Electrical Driven Turboexpander for Desalination are being developed and a commercial partner is being sought.

STARTING CONDITION
3 % salt solution
9,700 pounds of fresh water
300 pounds NaCl

EUTECTIC CONDITION
23.1 % salt solution
1,000 pounds water in slurry
300 pounds NaCl in slurry
8,700 pounds of pure water as ice

87 % Desalination Efficiency

CONCLUSIONS
- **Our Direct Cooling Eutectic Freeze Crystallization (EFC) Method shows highest efficiciencyof all desalination systems currently in use**
- **For some applications the cooling medium (highly chilled air) is a co-generated byproduct of our T-CAES system, and is "free"**

Figure 4. Overall Desalination Efficiency

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