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NH_3 as an energy storage medium - an Island experiment -

7th NH_3 Fuel Conference 2010

"NH_3 Fuel – the Key to US Energy Independence"

Romulus, MI

September 27th - 28th, 2010

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- Founded by the late Matt Simmons (1943 – 2010)
  - Founder of Simmons & Co Int'l.
  - Peak Oil – Author of **"Twilight in the Desert"**
- To utilize clean ocean energy to replace our dependency on declining fossil fuels
  - **40 MB / day new required by 2030**
  - Economics and security
- Water scarcity is also a global issue

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The Ocean Energy Institute is…

- A think-tank creating collaborative R&D teams for ocean energy projects
- A developer of ocean energy technology leading to the point of commercial feasibility
- A gathering place for ocean energy experts
- An ocean energy advocate, educating stakeholders

OEI's Charter

The development of ocean energy in all forms:

- **Energy Generation**
  - Wind (shallow and deep water)
  - Tidal / Current / Waves
  - OTEC (Ocean Thermal Energy Conversion)

  currently not included are Biofuels / Hydrates / Seeps

- **Secondary technologies of ocean energy harvesting**
  - Ammonia / Hydrogen
  - Desalination / SWAC (Sea Water based Air Conditioning)
- Focus on **GUST** (Generation, Use, Storage, Transmission)

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Locations of Energy Demand

Image courtesy of CEOE

Locations of current demand, degree of illumination is proportional to absolute Energy consumption

When China's and India's population gain more affluence they will begin to look more like the US, Europe or Japan

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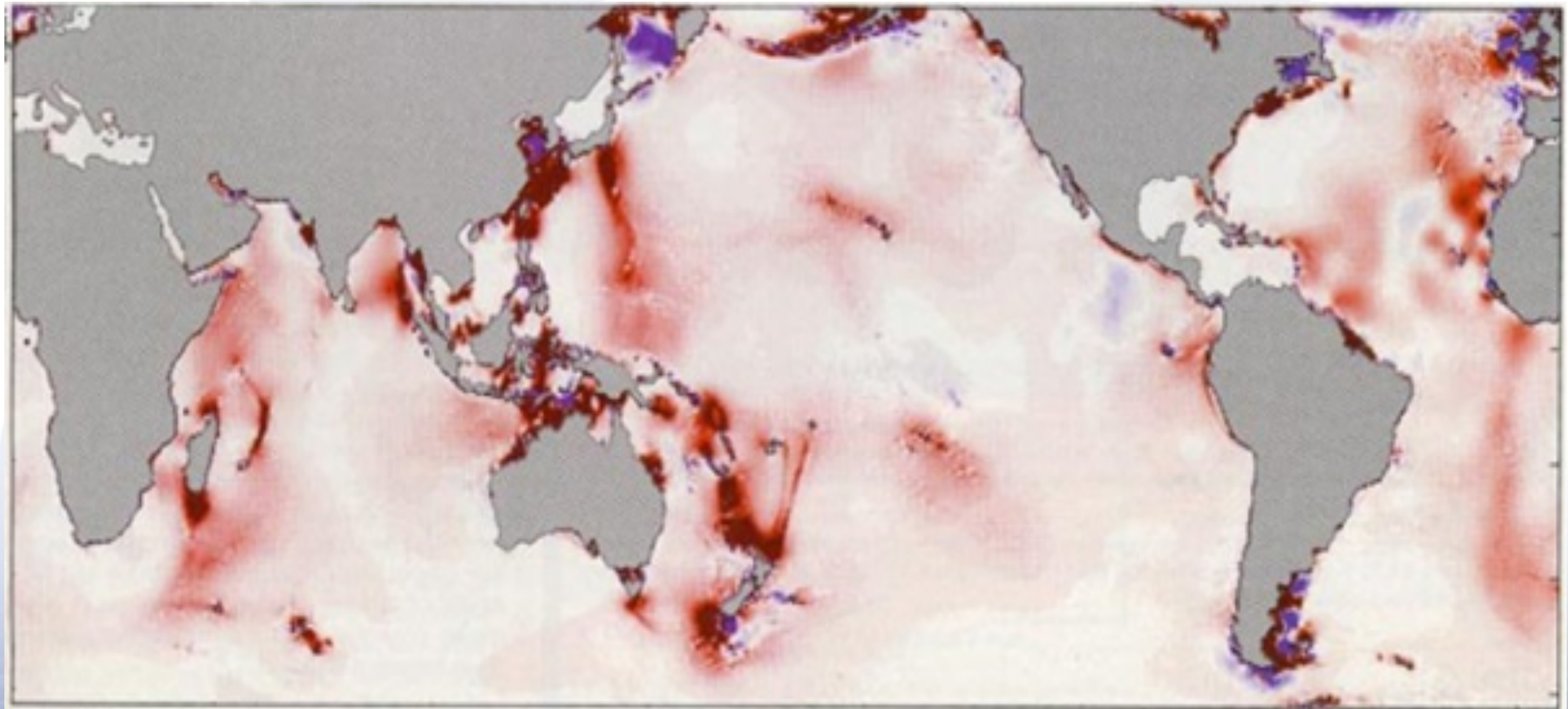
Locations of Renewable Energy Sources - Tides



Highest tides worldwide in Bay of Fundy, New Brunswick, Canada. Strong resources in China Sea, Aleutians, UK, Ireland, Indonesia, Australia, Madagascar, Thailand, Malaysia, Hudson Bay

Image Courtesy of Science News Vol.158

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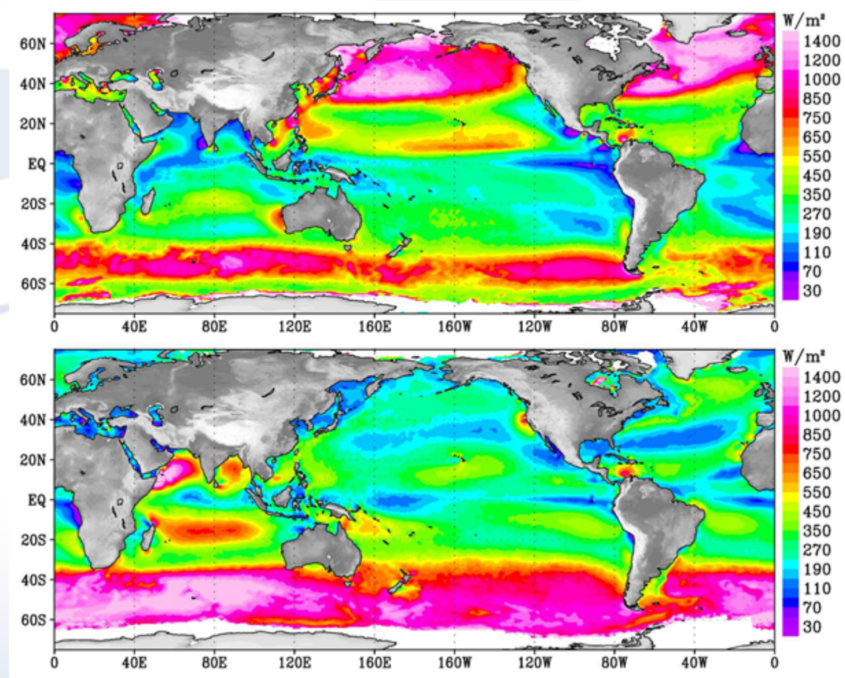
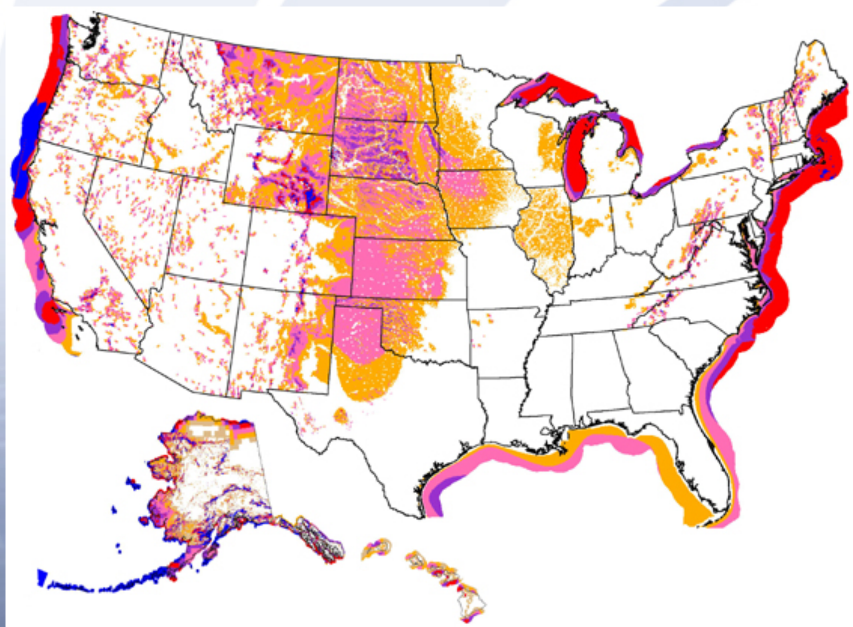
Locations of Renewable Energy Sources - Wind

Strong winds on the Oceans between 40^{o} and 60^{o} latitude, N and S
Upper chart shows Northern Winter
Lower Chart shows Northern Summer
Strong Winds produce high waves, especially 40^{o} - 60^{o} South





In the US wind is best harvested in the Midwest, the Great Lakes and off-shore the coastal regions. Especially the Gulf of Maine, the Great Lakes and the coast of Washington and Oregon have high quality wind.

Images courtesy of DOE

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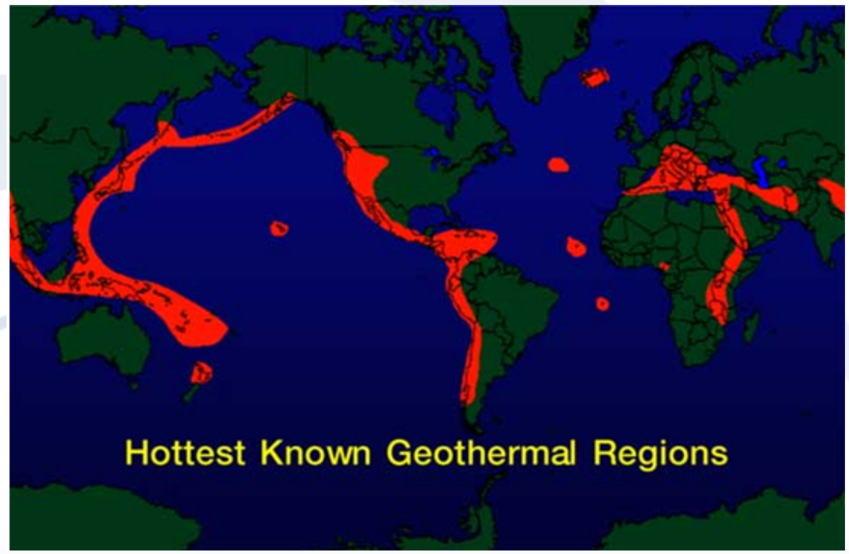
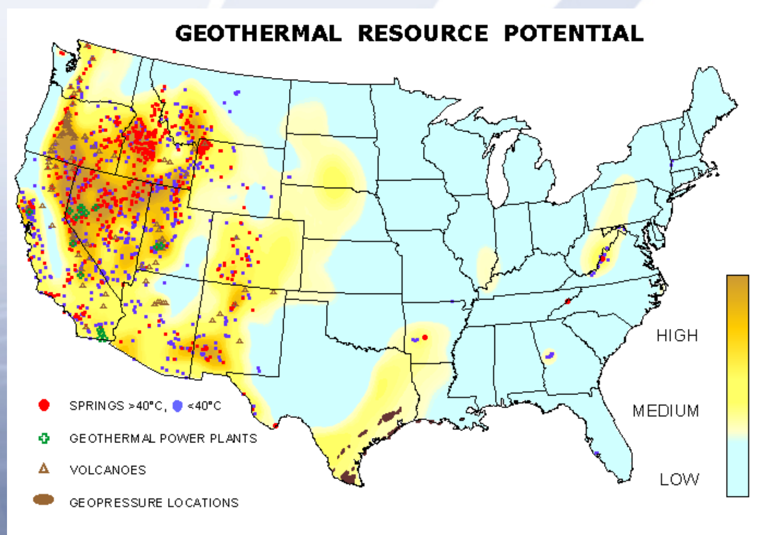
Locations of Renewable Energy Sources - Geothermal

Worldwide Locations of highest potential geothermal resources

Mostly along tectonic plate boundaries and subduction or rift areas or hot spots like Yellowstone

A lot of the potential is in the Oceans





In the US the concentration of Geothermal energy resources is in the West.

Especially in the range mountains and the Yellowstone, Snake River hot spot area

Image Courtesy of SMU, Dallas TX

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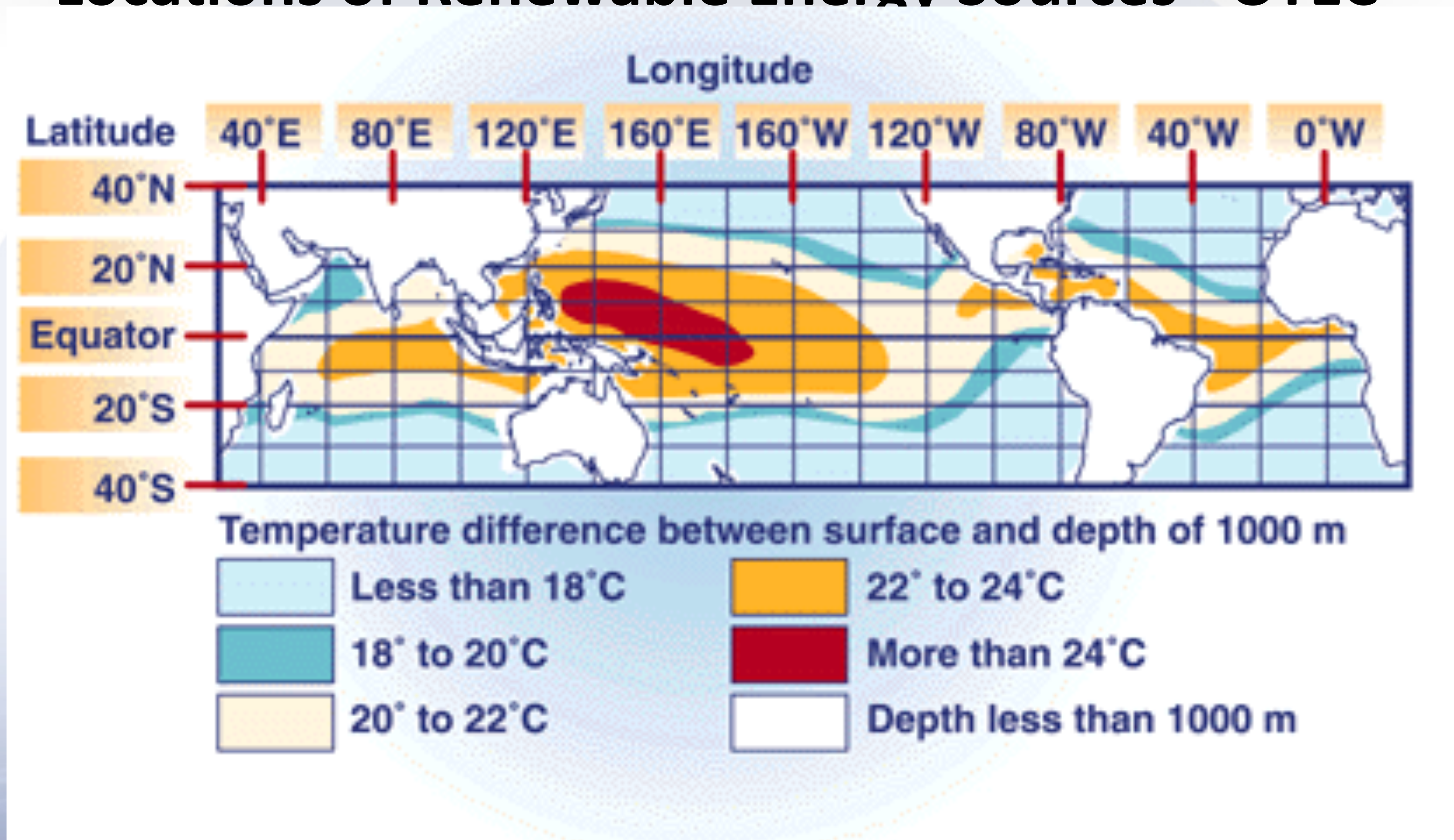
Locations of Renewable Energy Sources - OTEC



There is plenty of high quality OTE, but all in quite some distance from the major demand regions.

The problem

- **The best, most concentrated ocean energy (wind, waves, tides, warm surface water) is located very remote from the centers of demand.**
- Ocean energy is intermittent, with the exception of ocean thermal energy and ocean based geo thermal energy
- To supplement fossil fuels with renewable ocean energy the ocean energy must be converted in a form that can be used in multiple ways. It must be safely transportable at low cost, and it must be storable at low cost
- The technology to accomplish that must be safe, scalable, simple, ecologically benign, low cost, low maintenance , readily available

In Search of a Solution

- Transmitting the harvested energy in form of high voltage electrical current (transmission cables and lines) is not practical for three reasons, capital cost, maintenance cost and transmission losses. No practical large scale storage technology available.

- Hydrogen is difficult to manage, low volumetric energy density, needs special steel (carbon free), high diffusion losses, wide range of explosion limits (4% - 74%), not detectable by odor, flame very hot and invisible, cannot be liquified easily

  T_c = 33°K (- 400°F) and P_c = 12.8 bar

- Biomimetic technology (making hydrocarbons out of water, CO_2 and Energy) is not practical as CO_2 occurs only in relatively small concentration in the air and in sea water.

The Solution

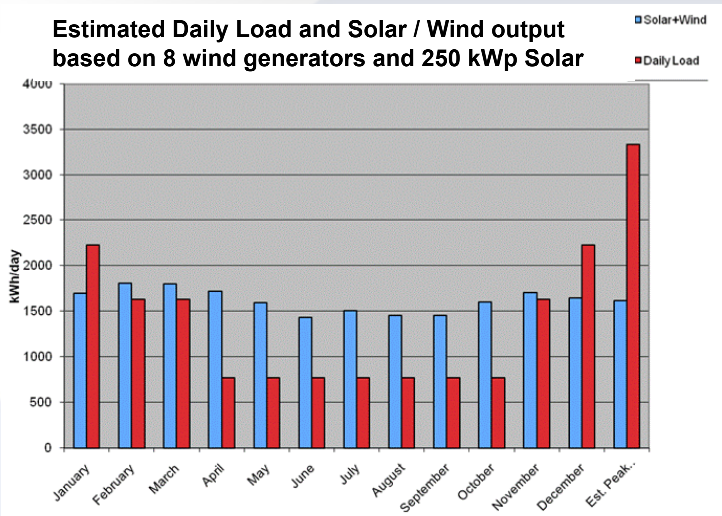
NH_3 - Fuel, Storage and Transportation medium

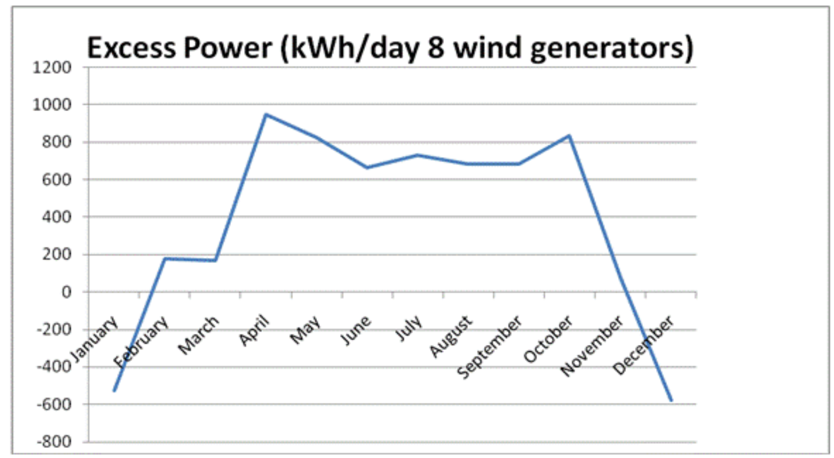
- Constituents readily available almost anywhere.
- Soon to be cost competitive with hydrocarbon fuels.
- Carbon-free energy cycle.
- Energy cycle inherently pollution free.
- Reasonably high energy density (Volumetrically ~ 50% of Diesel)
- Easy and proven handling, storing, and transportation.
- End-use in ICE, GT, fuel cells, or as raw material.
- Self-"odorizing" safety (you can smell it at 5 ppm, long term exposure limit is 25 ppm NIOSH – 50 ppm OSHA)

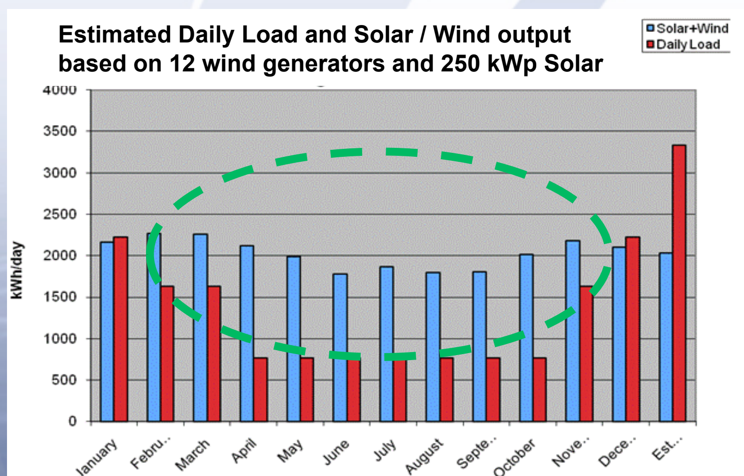
Testing the Solution

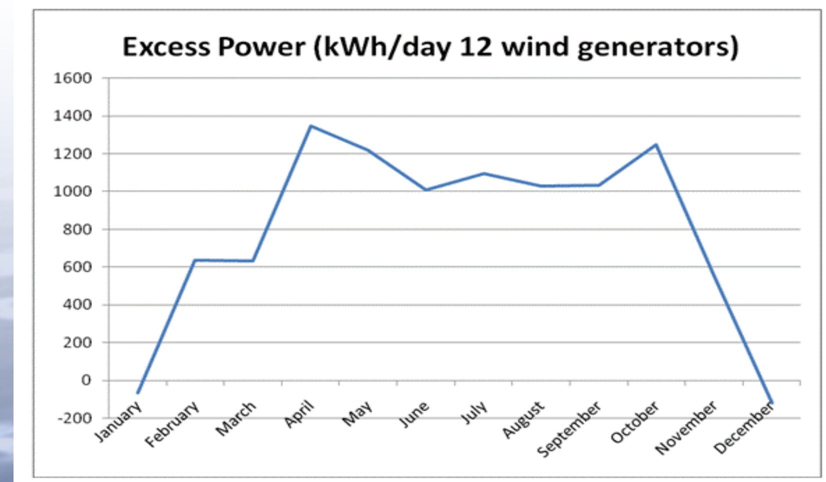
- **Location: An island in the Bahamas**
  - No grid connection
  - Diesel was the only fuel, needed to be shipped in, about $ 6 per gallon
- **The owner wanted the island 100% on green energy**
  - Installed 8 (soon to be 12) 15kW wind turbines – or even 1 additional 100kW turbine.
  - Installed 250 kW_p Solar PV panels
  - Installed 540 2000Ah 2V deep cycle flooded lead-acid batteries with a nominal storage capacity of approximately 1300 - 2000 kWh (variable, depends on age of battery and the characteristics of the charge discharge cycles)
- The solution reduced the Diesel consumption by more than 90%. Diesel is still needed in times when calm exceedes 6 hours during the months of February through November and to cover the systemic power deficit in December and January

Power generation and Demand on the Island









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Partial View of the wind farm and the solar PV array

Wind turbines
8 x 15 kW
(current)

Solar Array
250 kW_p

With 12 wind turbines and the solar PV array the excess power produced per year would be 290,000 kWh

Partial view of actual battery storage

Capacity_{nom} : 2000 kWh

Capacity_{pract} : 1300 kWh

Buffer time : 8 h $_{\text{max demand}}$

Battery Cost : $ 400k

Battery Life : est. 5 years

O & M p.a. : est. $ 30k

Annual storage cost per practical kW storage capacity, 5 yr life and a 20% reclaim value is ~ $ 72

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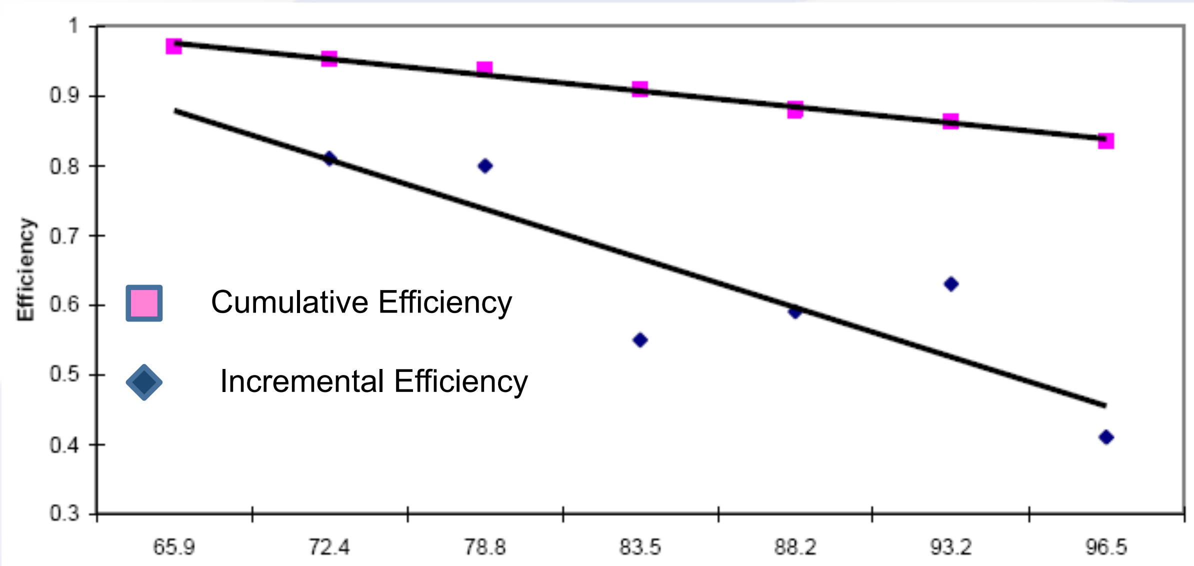
Efficiency of Lead – Acid Battery Storage



Ah out of nominal 100 Ah capacity

Cumulative efficiency for deep cycle between power in vs. power out ~ 85%
After 2000 cycles 80% depth of discharge attainable = end of life
Life expectancy = f(T) $L_{e\ 100^{o}F} = 40\%\ L_{e\ 77^{o}F}$

For longer life expectancy air conditioning in hot climates is advisable

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Current Lead – Acid Battery Storage Parameters

- Nominal 2160 kWh initial capacity, operating at typical 100°F
- Life time of cumulative 2000 60% discharge cycles, degradation to 1730 kWh storage capacity.
- With a 60% discharge cycle 1300 kWh can be extracted per cycle when new and 1040 kWh at the end of life. The charge power would be approximately 1400 kWh (93% efficiency when new).
- The inverter efficiency for both down and up conversion would be 92%.
- The conversion efficiency from wind power input to reclaimed AC output would be approximately 78% for the new condition and approximately 63% at the end of life.
- The cost of the initial battery system was $M 400 for the batteries alone. Nominal 6,800 kWh storage have recently been quoted for $ 1.45 MM
- The new set of batteries would be sufficient to store 3 days of average excess production of power in April and fill he power gap in December for 21 average days. In case of extended total calm, the batteries could supply power for about 30 hours maximum demand, with 12 hours support from solar system

Storage or use of the 290, 000 kWh annual excess

- **Batteries are not the answer**
  - Annual storage cost of 290,000 kWh with the current cost parameters for battery storage would amount to **$ 21.7 M**. The capital expense for the batteries would be **$ 53 M** (including a 15% volume price break), plus an estimated **$ 1.5M** for building and air conditioning.
  - There are currently no local user for the excess stored electricity. All current electrical power demand already satisfied by wind and solar output.

- Other alternative is to spill the excess energy as there is no other near-by user to whom it could be transmitted via cable. Underwater power cable cost would be in the range of **$ MM 14/GWmile for large scale (600 MW transmission) and about $ MM 230/Gwmile for smaller scale (5 MW transmission) ,** cost very variable based on terrain condition, currents, wave action

  Example: Neptune Cable LI – NJ 65 miles, 660 MW capacity, $M 600

- Third alternative is to manufacture a convertible fuel from the excess power in the months February through November.
  - All constituents for ammonia are readily available water, power and Nitrogen from air

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Small SSAS NH_3 generator for excess wind turbine output conditioned for an excess of 1400 kWh per day

- **1 RO** [Reverse Osmosis water purification] plant with 1 metric tons per day processing capacity
- **1 ASU**, [Air Separator Unit to generate Nitrogen] Maxiflow PSA unit (Pressure Swing Absorption) at 1.5 metric tons per day (for 99.9% pure N2). Would require compressed air at 7 bar. Oversized to cover for maximum production without need for N_2storage.
- **1 SSAS** [Ammonia generator] plant for output rate of .2 metric tons per day
- **1 refrigerated NH_3 Storage tank** for sufficient storage to cover six months of ammonia production
- **1 Water tank** for approx. 2 days run rate of RO water = .5 metric tons
- **Battery back up for approximately 20 kWh (exists already)**
- **NH_3 operated generator** for approximately 200 kW to max power need.

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Process Flow diagram for a small NH_3 Synthesis Plant

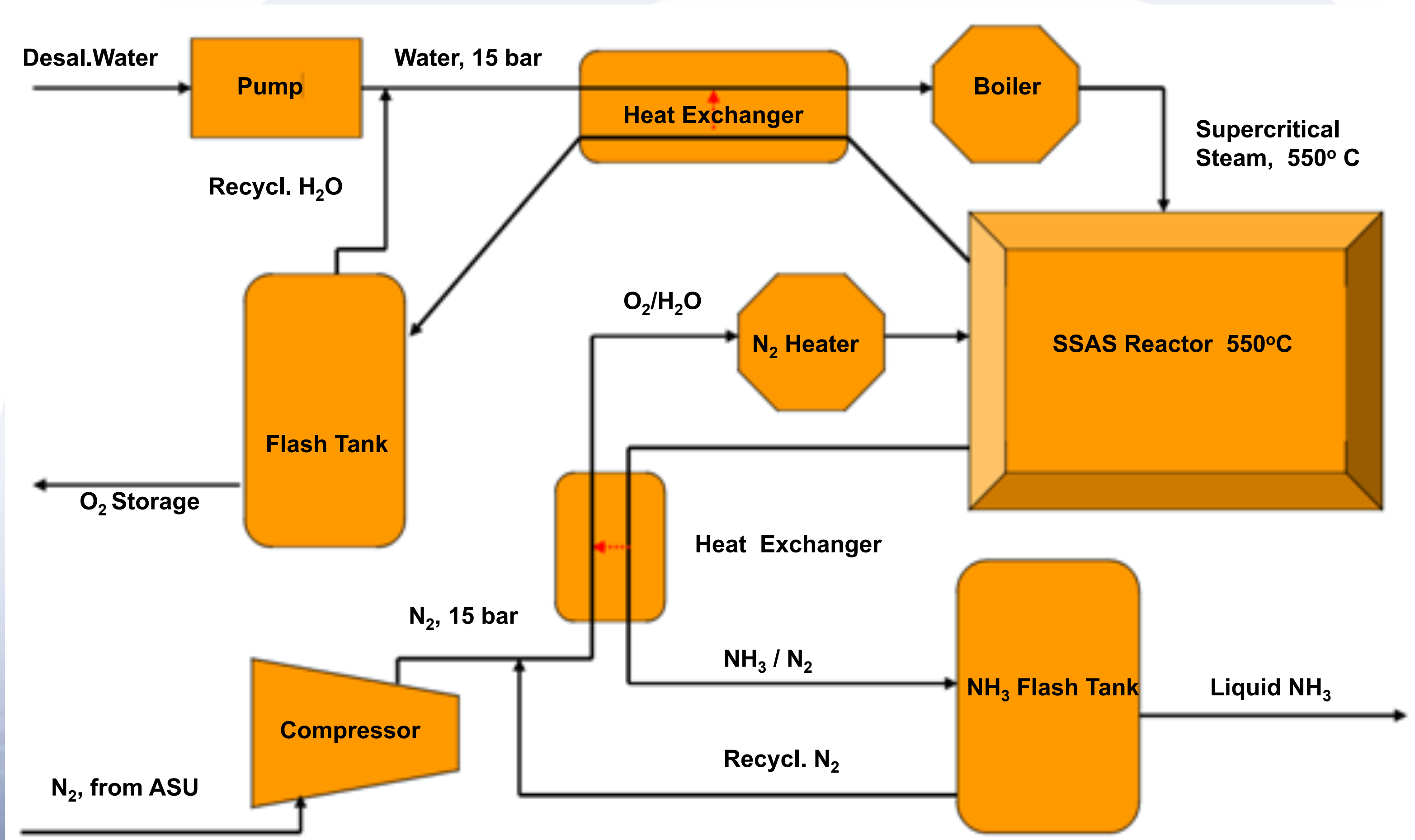
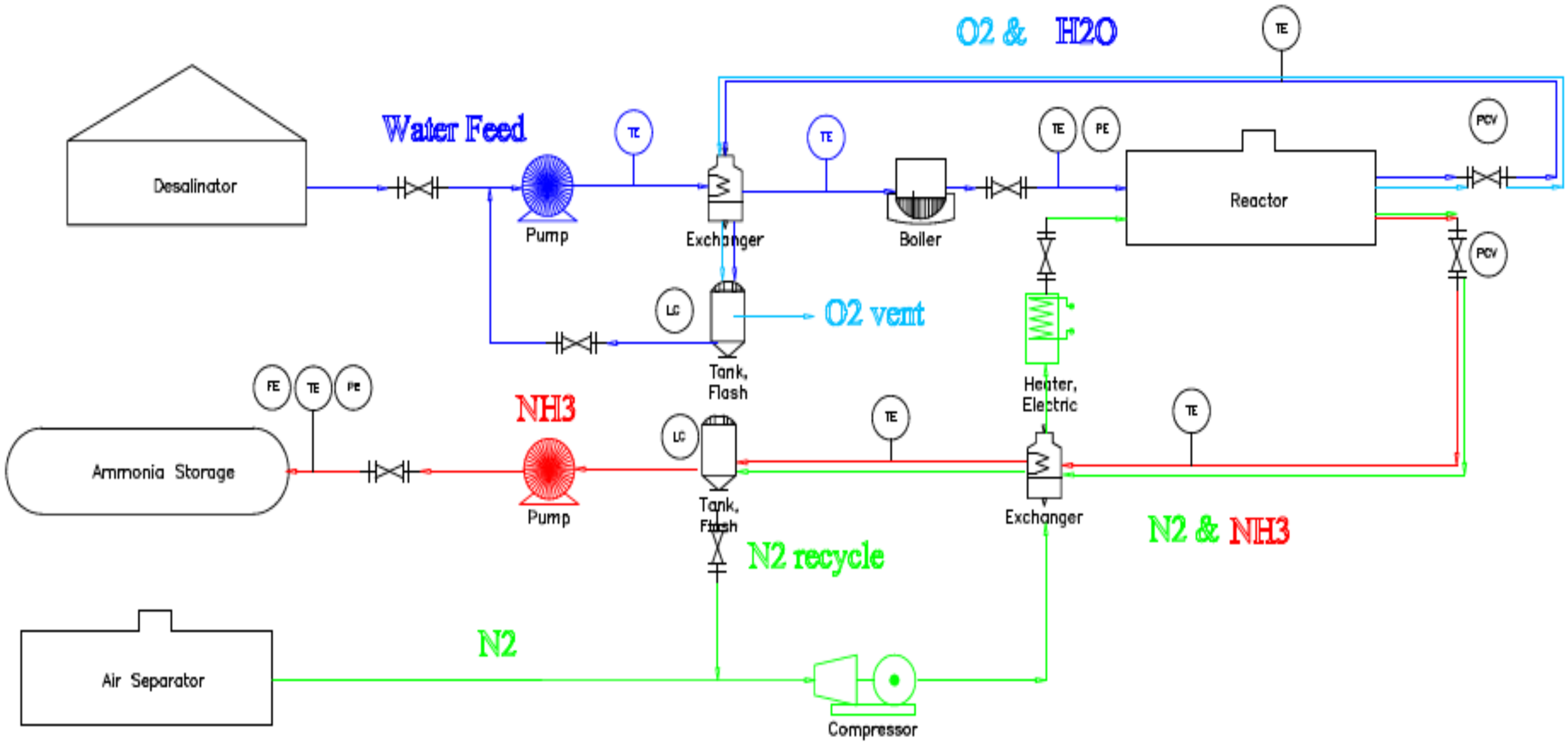


Diagram Courtesy of Nigel Sammes
Colorado School of Mines and
Jason Ganley NHThree, LLC

Instrumentation Diagram for a small NH_3 Synthesis Plant



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Specific Capital estimate for components

- The cost estimates are on best effort basis for the location. Real cost may vary significantly based on local conditions, regulations and resource availability.

Capital Cost

SSAS: Equipment cost approximately output	estimated at $M 200 / ton per day
ASU PSA (pressure swing absorption)	estimated at $M 50 / ton per day
RO system	estimated at $M 1 / ton per day
Storage for Water	estimated at $M .5 / ton capacity
Storage for NH_3 refrigerated	estimated at $M 2.4 / ton
Pumps, Controls, valves, pipes etc.	estimated at $M 66 for the smaller systems

NH_3 Generator for 1400 kWh excess per day

• SSAS for max. output of .2 tons /day (Economy of Scale de-rating = 2)	$ 80,000
• PSA N_2 generator	$ 50,000
• RO system for 350 gallons / day	$ 1,400
• NH_3 refrigerated storage for 20 metric tons	$ 45,000
• Storage for water	$ 700
• Battery back up for instant protection of system (existing)	$ 5,000
• Ammonia operated generator 200 kW	$ 75,000
• Valves, pipes, controls	$ 81,000
• Compressors & pumps	$ 10,000
• Estimated Engineering and Installation	$ 150,000
• Hazop Study	$ 20,000
Total	$ 513,100

This system is estimated on the information provided about the currently installed excess capacity and the assumption to fully utilize the excess energy for NH_3 synthesis. The storage is dimensioned to store the ammonia generated throughout the months February through November. With about 35% reconversion efficiency in the generator we would expect to have an excess of 20 -24 tons of NH_3 per year

System cost would be about $513,100 capital cost, inclusive Engineering and Installation. Site prep and permitting would be extra.

The approximately 20 -24 metric tons of NH_3 per year excess could be used to fuel Internal Combustion Engines**. The equivalent savings in form of diesel oil would be about 4400 Gallons = $ 30K.**

Research in the green highlighted technologies is still ongoing

Project Objectives

- Convert excess island power economically into a fungible, transportable and storable form
- Demonstrate on a small, yet realistic scale the utility of NH_3 as a renewable fuel
- Collect data to reduce the cost of larger scale systems
- Formulate and test safety measures to prevent accidental release of ammonia
- Refine and collect data on the SSAS process to extend tube life, fine tune the properties of the catalytic layers, optimize processing conditions and obtain data pertaining to scalability.
- Use the system as a permitting base (data) for future SSAS systems
- Test and cost reduce the instrumentation for the system.
- Convert and test existing diesel generators for use with ammonia and study exhaust emissions under varying operating conditions
- Examine if engines with high compression ratios can use ammonia directly or require a thermal cracker for a 5-7% slipstream of Ammonia.

Thank you