Salt Partners

Solar Salt Ponds as a Clean Energy Bioreactors

Review of natural principles of high quality solar salt production

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Second Salt Workshop on Ecology and Economy of Solar Salt Production, Hotel Garbos, Mossoro, RN, Brazil, 23.-26.11.2010

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Salt Consumption World-wide

Salt user	Salt consumption
Chemical industry	155,000,000 t/y
Food	45,000,000 t/y
De-icing	30,000,000 t/y
Other	30,000,000 t/y
Total	260,000,000 t/y

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Main salt uses world-wide

Caustic / Chlorine	36%
Soda Ash	17%
Other Chemicals	3%
Human Consumption	22%
Road De-icing	12%
Other Uses	10%

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Salt Production World-wide

Salt type	World production
Solar salt	100,000,000 t/y
Rock salt	80,000,000 t/y
Brines	80,000,000 t/y
Total	260,000,000 t/y

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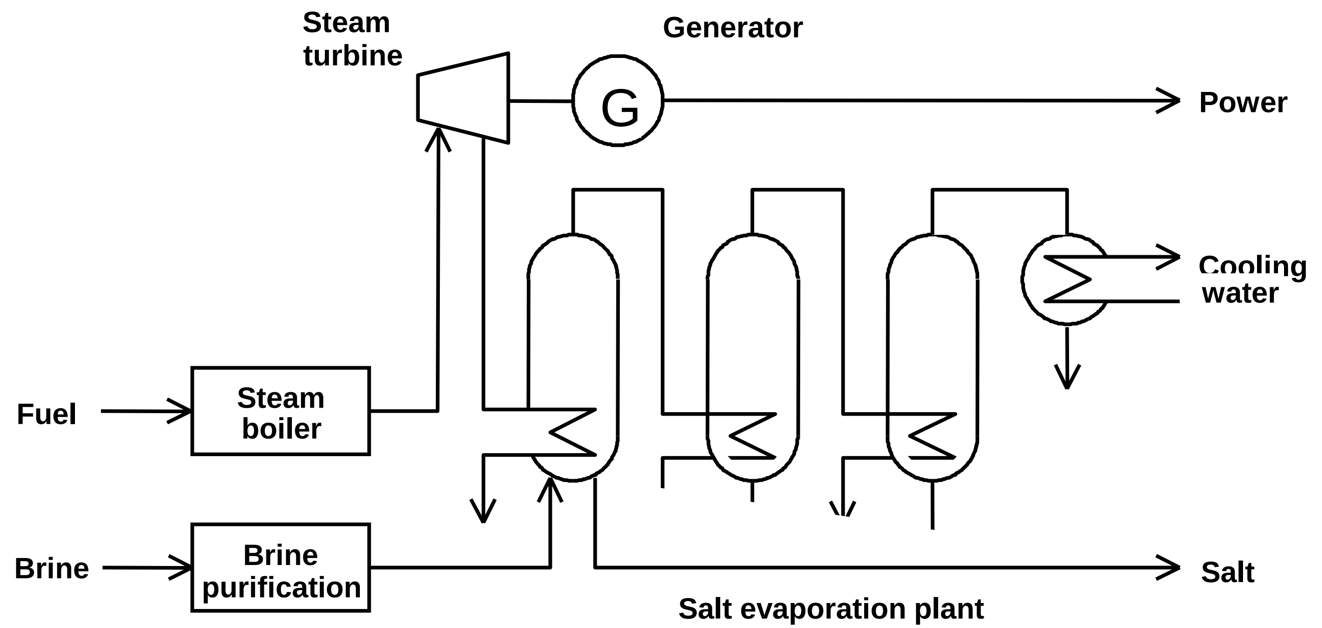
Multiple Effect Crystallisation



Vacuum salt production with cogeneration

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Prime energy consumption for multiple effect vacuum salt crystallisation

Water evaporation	3 t / t of salt
Steam to first effect	10 – 12 bar g
Number of effects	6
Steam consumption	0.62 t / t of salt
Boiler efficiency	85%
Prime energy consumption	420 kWh / t of salt

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Prime energy consumption for salt crystallisation by thermocompression with mechanical vapour recompression

Water evaporation	3 t / t of salt
Power consumption	160 kWh / t of salt
Power generation efficiency	38%
Prime energy consumption	420 kWh / t of salt

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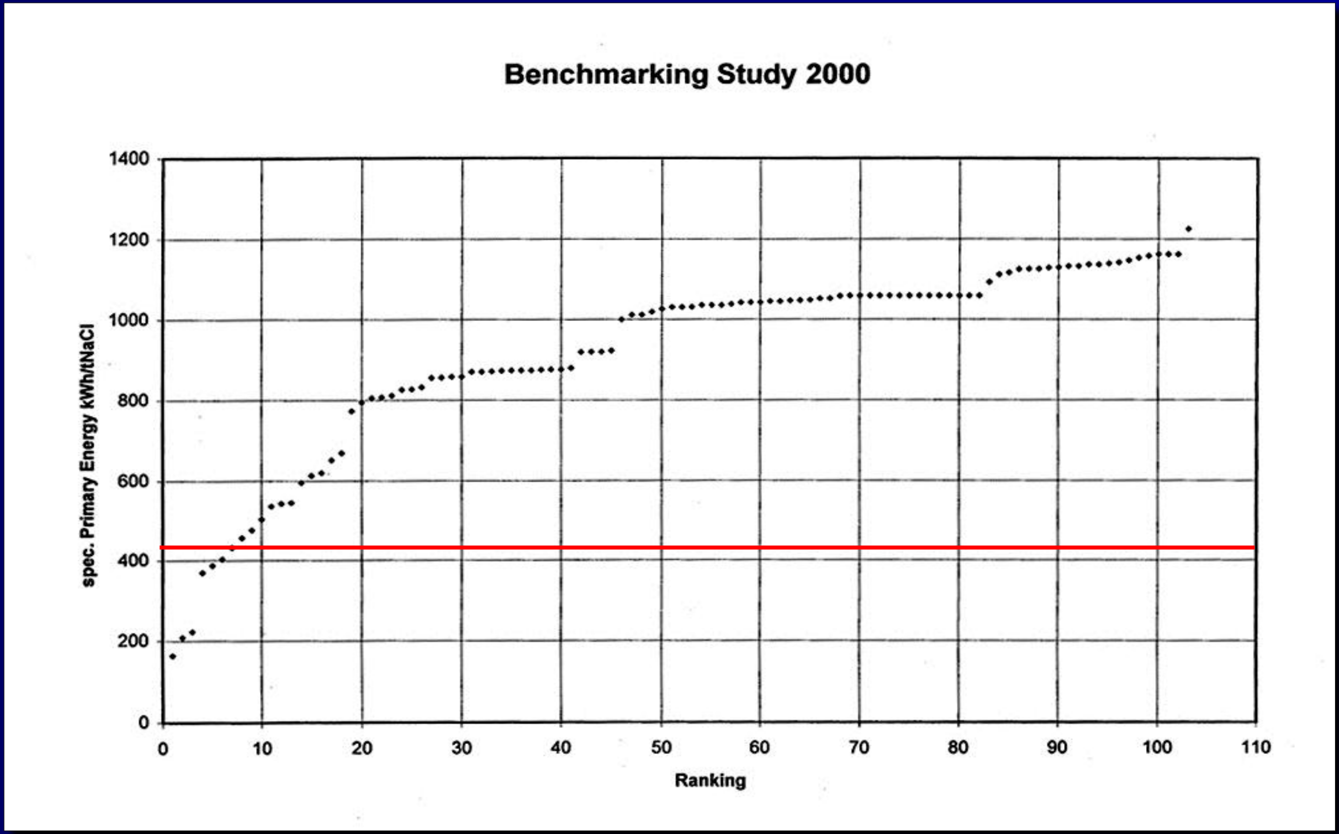
Energy Consumption Benchmarking Study



EVATHERM

96 out of 103 thermal salt evaporating plants use more than theoretical amount of energy.

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Air Pollution

In China, black coal is burned to make steam for vacuum salt production.

WU HONG / EPA

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Global Warming

Hurricane "Katrina" in the Gulf of Mexico on 29.8.2005.

NASA

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Destructive Climatic Change

Groenteman

Hurricane "Katrina" destroyed large parts of New Orleans and surroundings. Increased hurricane activity is believed to be caused by global warming.

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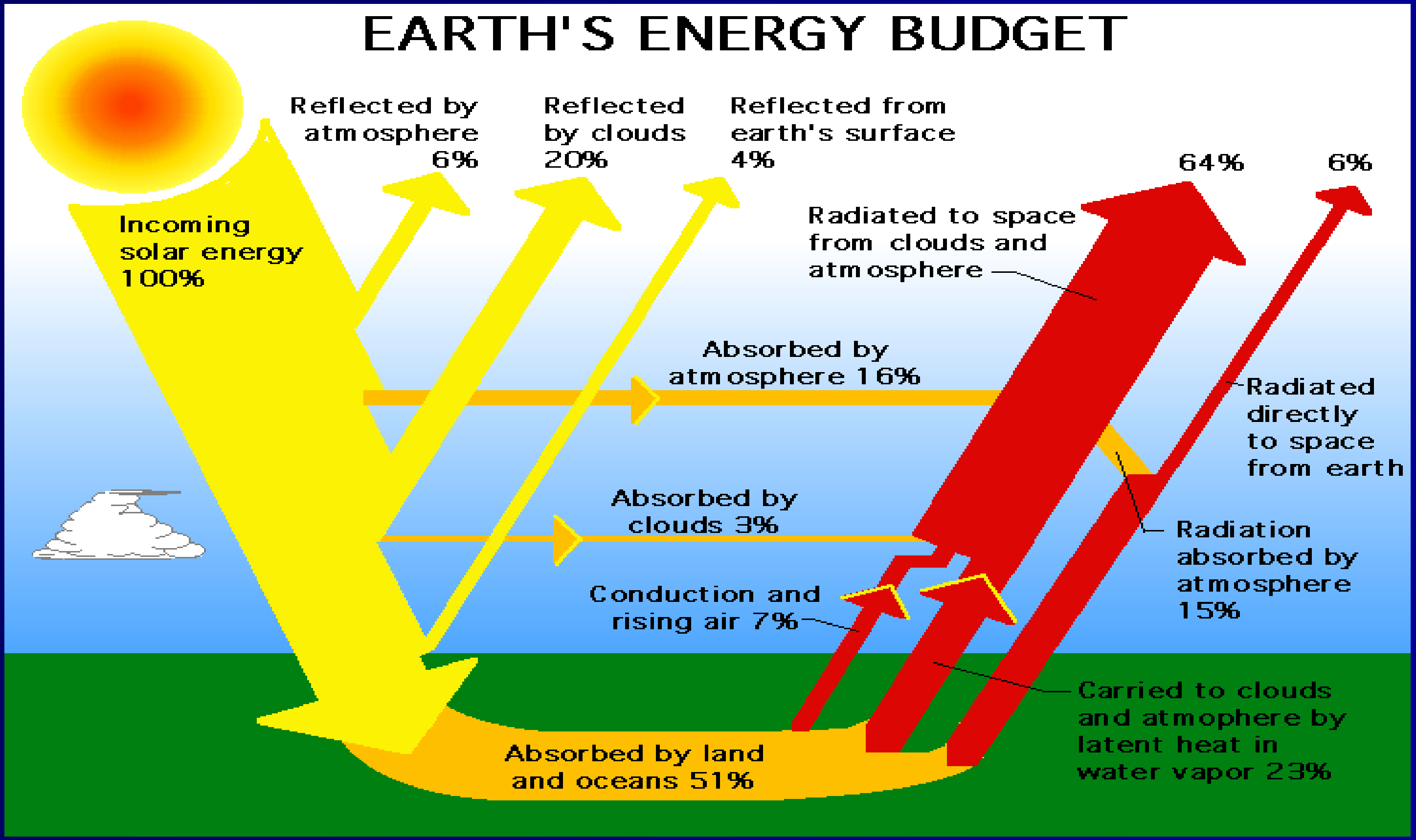
Earth’s solar energy budget



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Solar salt evaporation

Sea water density	3.85°Bè
NaCl content	30.09 kg NaCl / m3
Bitterns density	28.53°Bè
NaCl in bitterns	8.37 kg
NaCl crystallised	21.72 kg
Water evaporated	949.93 kg
Water evaporation	43.74 t H2O / t NaCl
Heat of water evaporation	0.675 kWh / kg H2O
Solar energy consumption	29’520 kWh / t NaCl

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Solar energy conversion into evaporation

Earth insolation	1.366 kW / m2
Surface insolation absorbed	51%
Solar energy absorbed in zenith	0.697 kW / m2
Daily solar energy absorption	5 – 7 kWh / m2 / day
Conversion efficiency	45%
Daily solar evaporation energy	2 – 3 kWh / m2 / day
Heat of water evaporation	0.675 kWh / kg H2O
Daily evaporation	3 – 5 kg H2O / day
Annual evaporation	1.1 – 1.8 m H2O / year

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Solar evaporation conversion into salt

Annual evaporation	1.1 – 1.8 m H_2O / year
Salt crystallised per tonne of sea water evaporated	22.86 kg / t H_2O
Corresponding salt production	27 – 44 kg NaCl / m2 / year
Crystalliser area	10%
Salt layer in crystallisers	270 – 440 kg NaCl / m2 / year
Salt layer density	2 t / m3
Salt layer thickness	13 – 22 cm

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Conversion efficiencies

Photovoltaic cells	8 – 15%
Solar collectors with stirling engine	30%
Super critical steam power plants	40 – 45%
Solar salt production	**45%**

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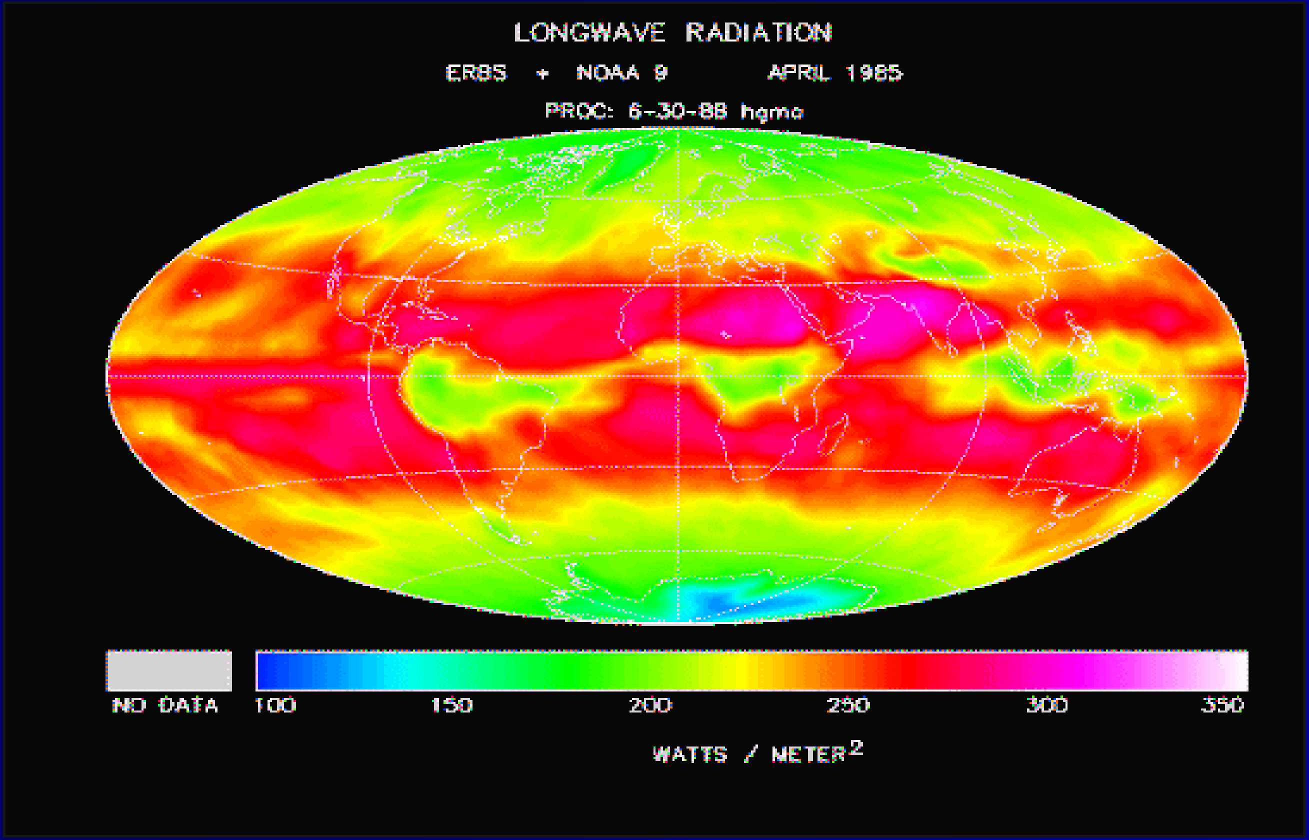
Solar Energy on the Planet Earth



NASA

Locations with highest rates of evaporation:

Caribbean Sea
South Aerica
North Africa
South Africa
Middle East
Western India
Western Australia

Other solar salt production areas receive only half the solar energy available at the most suitable locations.

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Impurities in salt

	Rock salt	Sea salt	Lake salt	Brines
$CaSO_4$	0.5 – 2%	0.5 – 1%	0.5 – 2%	Saturated
$MgSO_4$	Traces	0.2 – 0.6%	Traces	Traces
$MgCl_2$		0.3 – 1%	Traces	
$CaCl_2$			Traces	
Na_2SO_4			Traces	
KCl	Traces	Traces	Traces	Traces
NaBr	Traces	Traces	Traces	Traces
Insolubles	1 – 30%	0.1 – 1%	1 – 10%	

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What impurities in salt cause in mercury and membrane cells employed in chloralkali industry

- Hydrogen evolution
- Mercury butter
- Membrane damage
- Incrustations
- Sludge deposits

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General Cost of Salt and Impurity Removal

	Cost of brine treatment and sludge disposal	Cost of salt, brine treatment and sludge disposal
	(USD / t salt)	(USD / t salt)
Minimum	1.50	10
Average	10	25
Maximum	30	50

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Relative cost of salt and brine purification in the chloralkali industry

	Cost of brine treatment as percentage of salt cost	Percentage of chloralkali production cost
	%	%
Minimum	120	3.6
Average	166	15
Maximum	256	37

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Conclusion:

Production of poor quality salt is undesirable

- **Impurities increase the cost of brine treatment in chloralkali plants**
- **Poor quality salts cause excessive contaminated effluent discharge**

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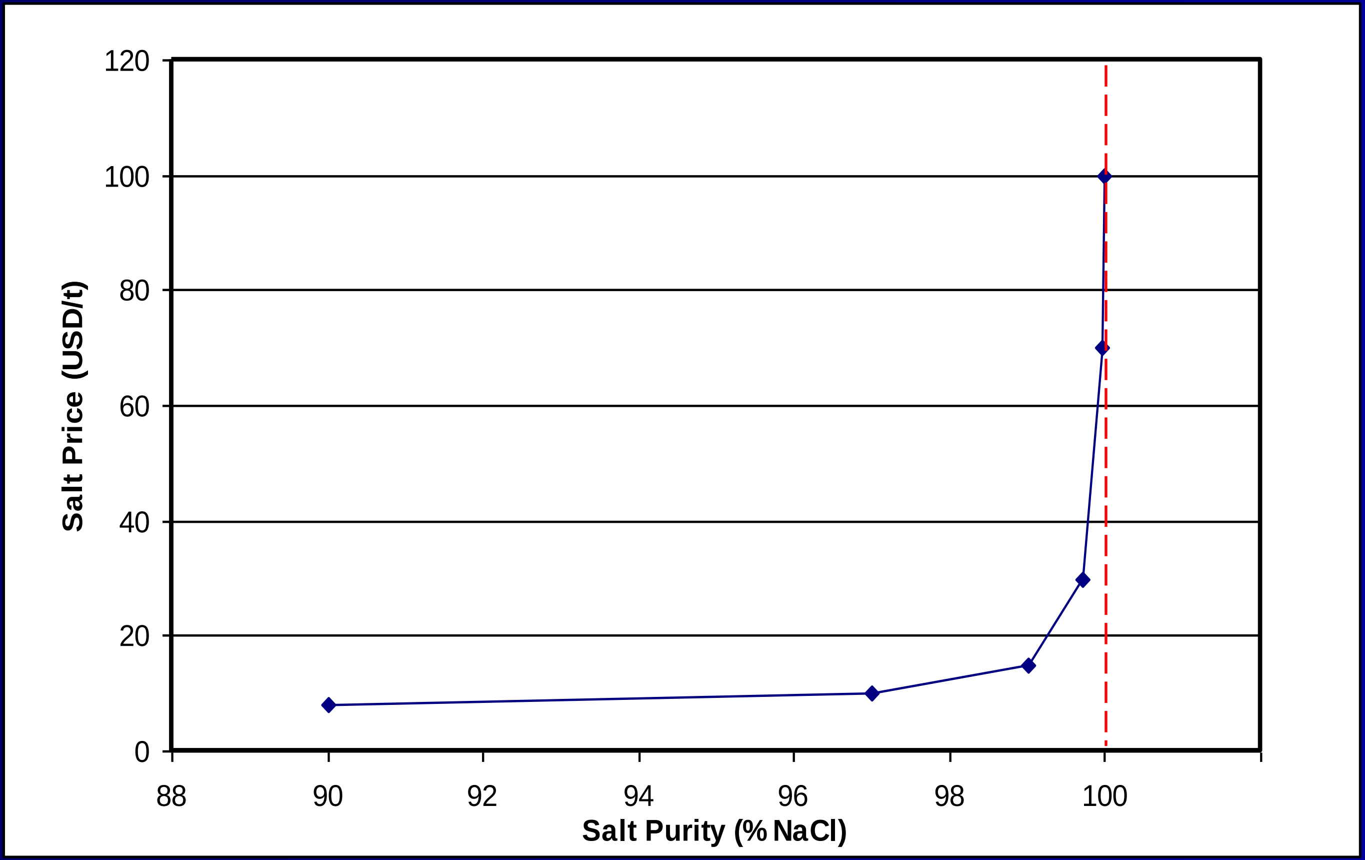
Salt Prices Depend on Salt Purity



Industrial salt prices vary between USD 10.-/t and USD 100.-/t depending on salt purity

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Three solar saltworks areas that are critical to production of high quality solar sea salt

- **Sea water pre-concentration area**
- **Solar salt crystallisation area**
- **Salt purification plant**

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Sea water pre-concentration area

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What to do and what to avoid in the sea water pre-concentration area

- Increase concentration gradually, avoid back-mixing
- Prevent seepage
- Cultivate dark pre-concentration pond bottom
- Maintain clear brine
- Avoid calcium sulphate over-saturation
- Allow nutrients in brine to get consumed

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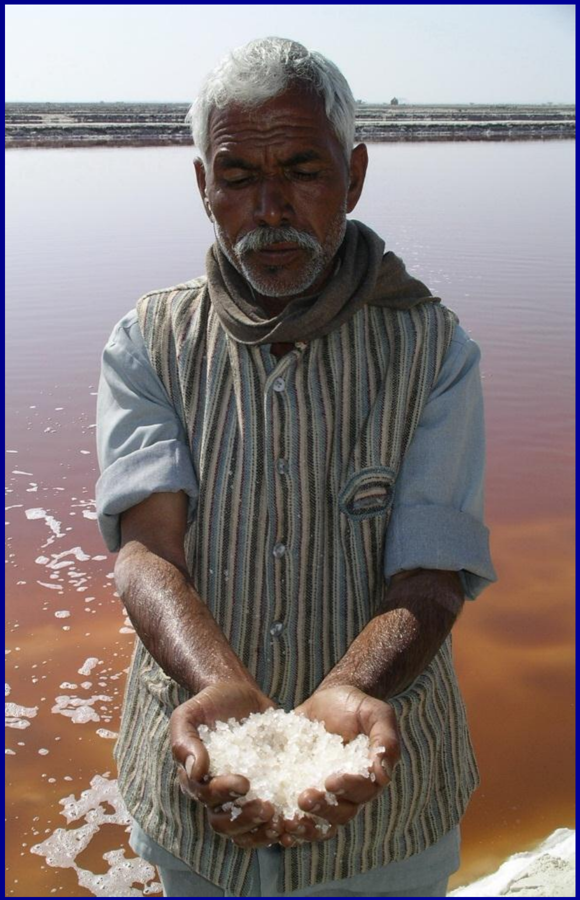
Solar salt crystallisation area

- **Employ crystallisers in series**
- **Drain 28.5°Bè brine**
- **Allow thick brine layer to avoid reflection of solar radiation**
- **Harvest under level control to avoid salt contamination with insolubles**
- **Support growth of *Halobacterium* that colours the brine red**
- **Avoid formation of organic material that causes growth of small crystal agglomerates**



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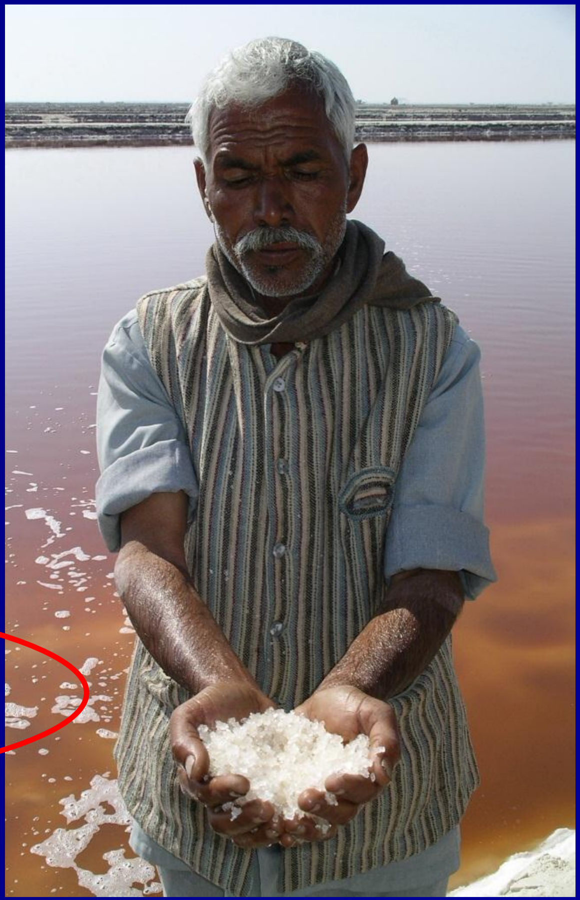

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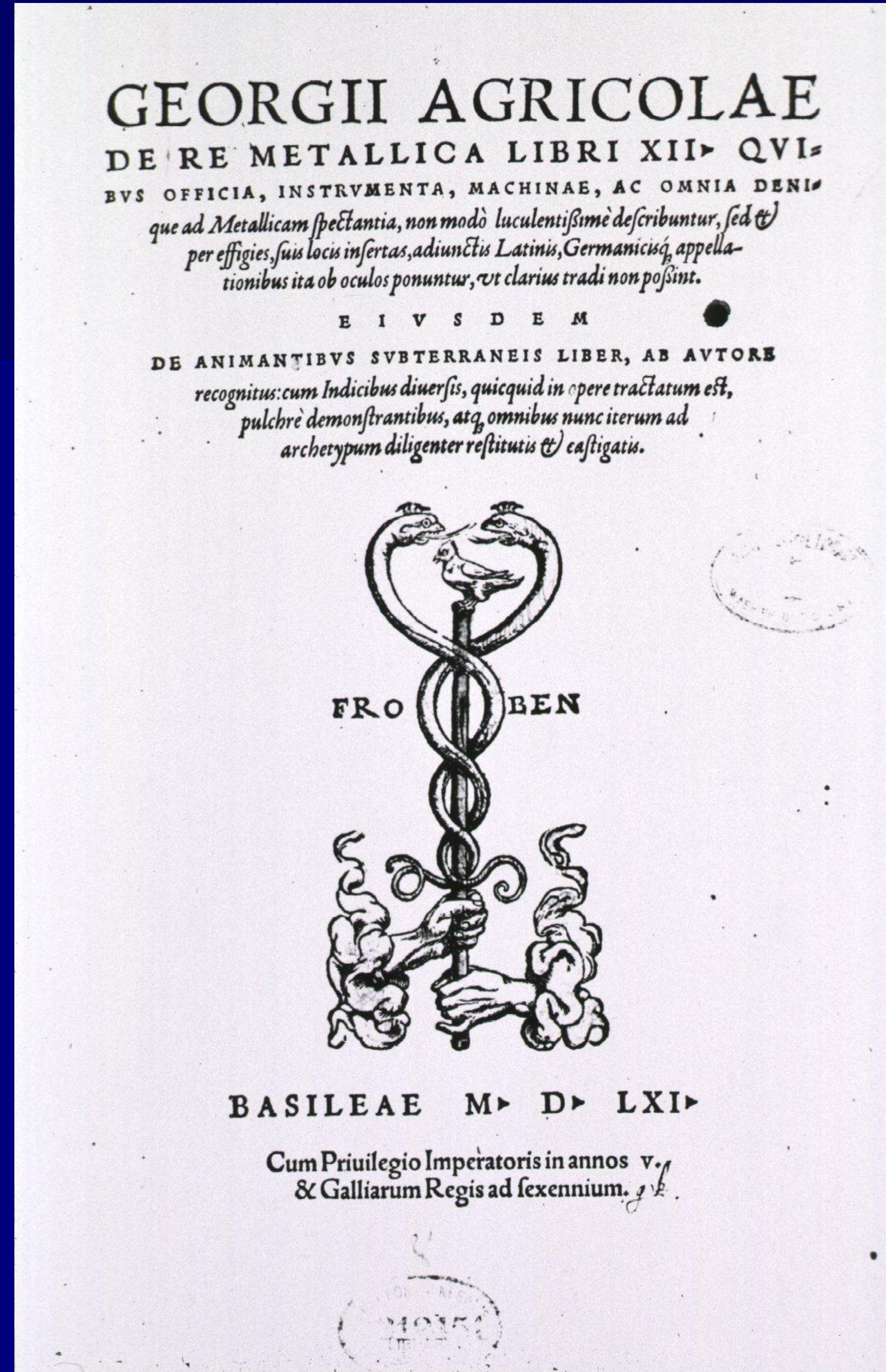
Already in 1556, Swiss scientist Georg Bauer, also known as Georgius Agricola, in his famous book De Re Metallica (About the Nature of Metals) indicated that the salt crystal growth can be influenced by addition of organic material of biological origin to the brine from which salt crystals are produced by evaporation.


GEORGII AGRICOLAE

DE RE METALLICA LIBRI XII. QVIBVS OFFICIA, INSTRVMENTA, MACHINAE, AC OMNIA DENIque ad Metallicam spectantia, non modò luculentissimè describuntur, sed & per effigies, suis locis insertas, adiunctis Latinis, Germanicisq; appellationibus ita ob oculos ponuntur, ut clarius tradi non possint.

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FRO BEN

BASILEAE M. D. LXI.

Cum Priuilegio Imperatoris in annos v. & Galliarum Regis ad sexennium.

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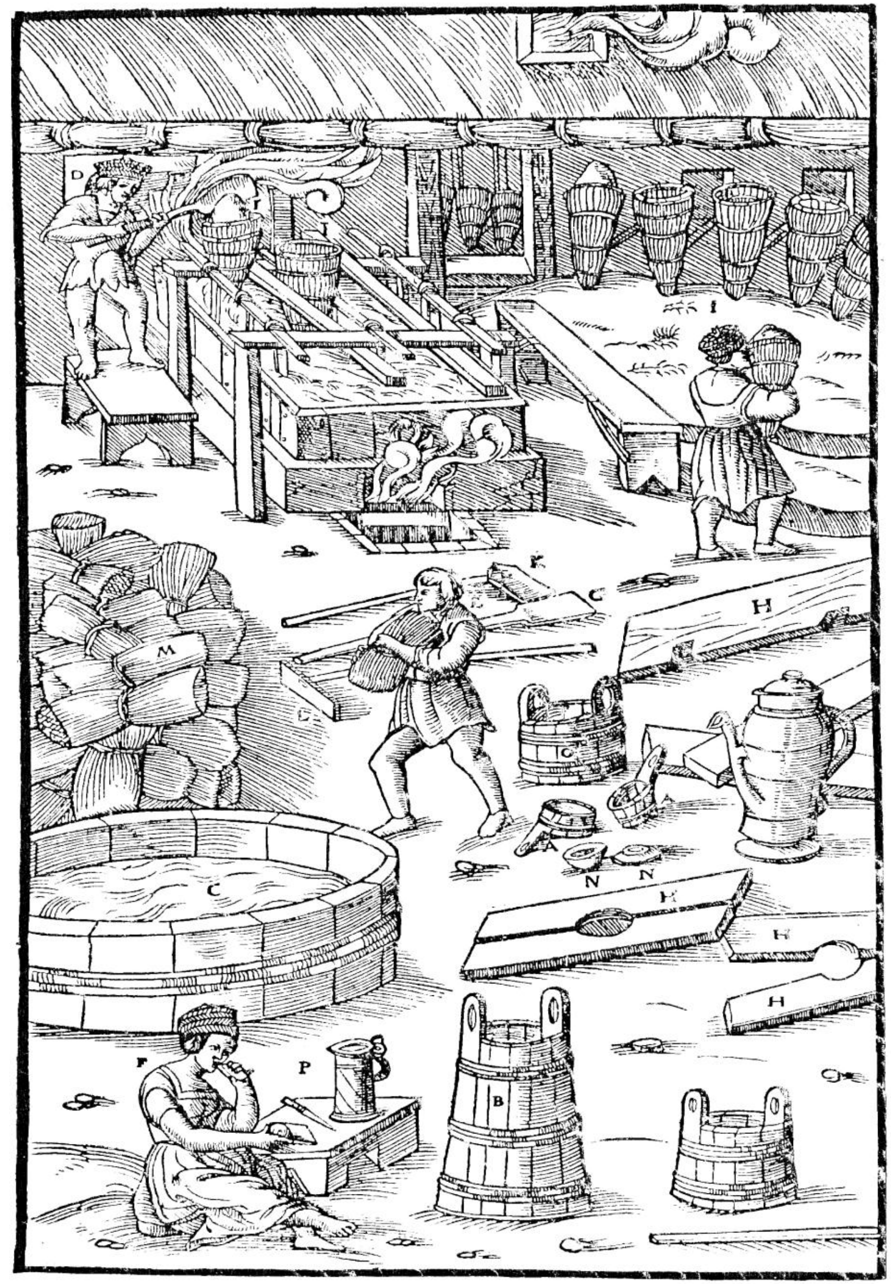
On this engraving, Agricola describes salt production in Switzerland where solar evaporation was not feasible. Brine was heated by burning straw and crystallised in an open pan by thermal evaporation.



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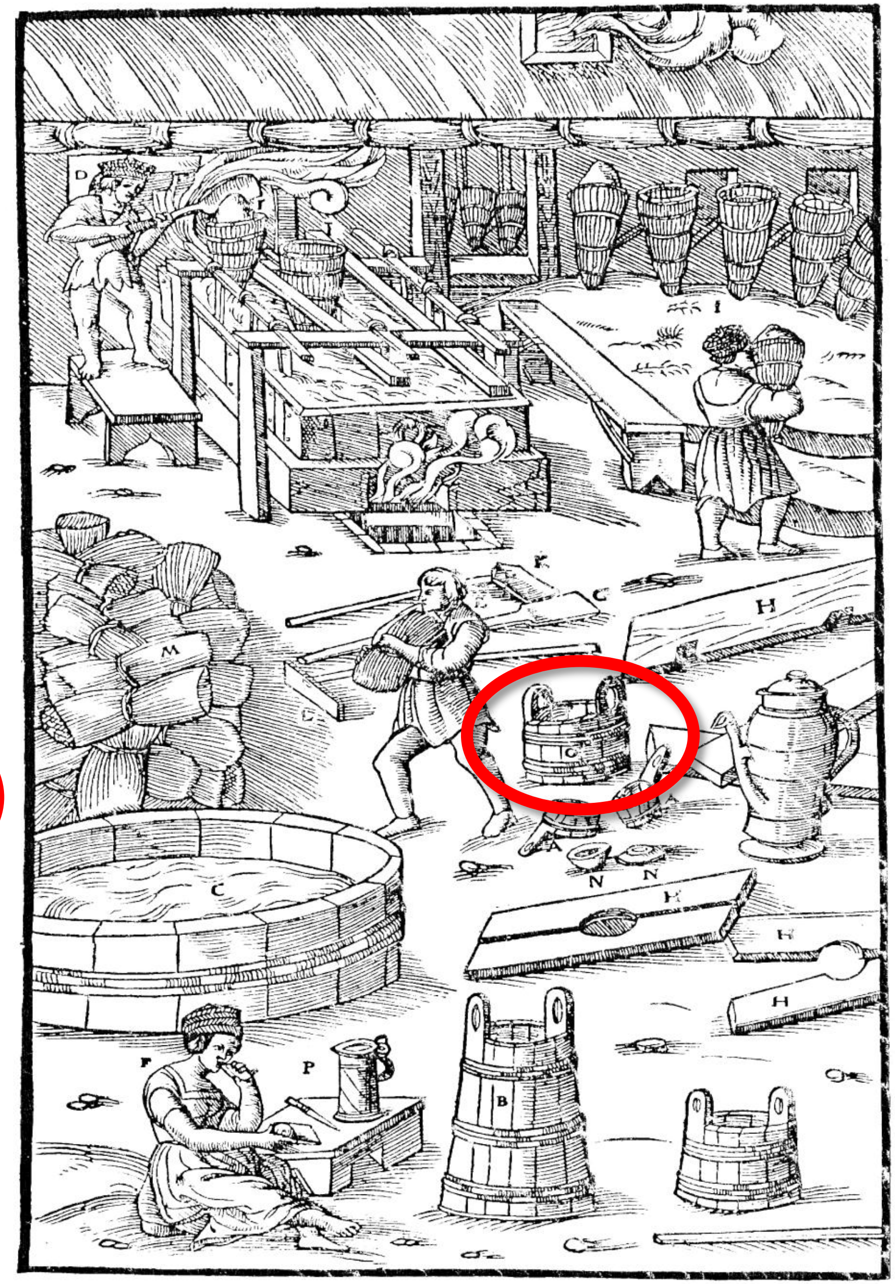
Look!

Gefäß mit Blut = vessel with blood



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Solar salt from poorly managed saltworks

Salt that looks like a crystal but it is an agglomerate of small crystals.

The agglomerate can be broken by hand.

Impurities are imbedded between the small crystals.

The salt is not well upgradeable.

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Solar salt from well managed saltworks

Hard, clear crystals, impossible to break by hand.

Impurities are only on the surface of the crystals.

The salt is very well upgradeable.

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Results of BIOSAL Biological Saltworks Management

	Raw salt 1996	Raw salt 2006	Impurity reduction
Ca	0.183	0.175	4%
Mg	0.527	0.097	82%
SO4	1.29	0.595	54%
Insolubles	0.04	0.02	50%
NaCl	97.052	98.96	65%

Raw salt quality improvement achieved by application of BIOSAL biological management techniques in Walvis Bay saltworks in Namibia

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Results of BIOSAL Biological Saltworks Management

	Upgraded salt 1996	Upgraded salt 2006	Impurity reduction
Ca	0.070	0.032	54%
Mg	0.020	0.008	60%
SO4	0.200	0.101	50%
Insolubles	0.02	0.01	50%
NaCl	99.66	99.84	53%

Upgradeability improvement achieved by application of BIOSAL biological management techniques in Walvis Bay saltworks in Namibia

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Results of BIOSAL Biological Saltworks Management

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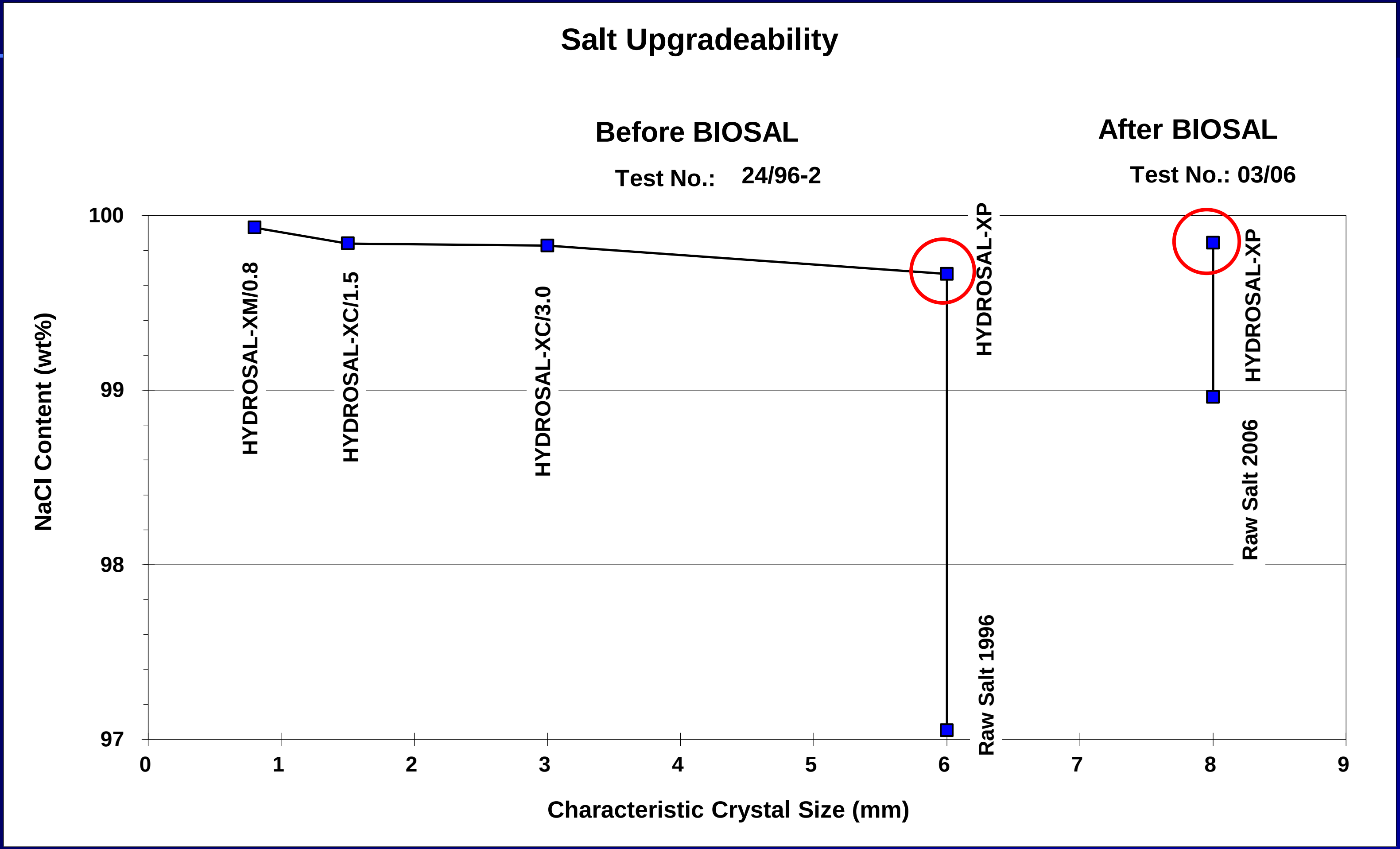
Salt Upgradability test Before and After BIOSAL



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Salt Partners Prospect New Solar Saltfields

Salt Partners assist their clients to prospect sites where new solar saltfields could be established.

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Salt Partners Modernise Solar Saltworks

ROV DURRANT

Salt Partners provide SOLARSAL technology to their clients to increase efficiency solar salt production.

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Salt Partners supply technologies for production of salt according to Australian standard:

Ca < 0.04%
Mg < 0.02%
SO_4 < 0.12%

Modern industrial salt upgrading plant in Spain. Capacity up to 700 t/h when operating with solar salt.

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Why not turn your salt into gold?

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