Produced water is a by-product of oil and gas recovery operations.

World average water to oil ratio (WOR) = 2 : 3

TDS = 12000 mg/L to 160000 mg/L (1.2% - 16%).

Sodium adsorption ratio (SAR) = 5 - >32

Oil and Grease = 25 mg/L to 5000 mg/L (0.0025 - 0.5%)

Typically found inorganics in produced waters include zinc, lead, manganese, iron, and barium.
MANAGING PRODUCED WATER

- Deep Well Injection
- Enhanced Oil Recover
- Water Treatment including:
  - Reverse osmosis systems (very costly)
  - Wetlands (sustainable and practical)

WET LANDS VS DEEP WELL INJECTION

- Energy consumption to treat produced water:
  - Wetland treatment = 0.06 kWh per m$^3$
  - Deep well injection = 3.6 - 5.5 kWh/m$^3$
- Saving of 98.3 - 98.9 %
- Reduction in CO$_2$ emissions
- Wetlands also provide a valuable habitat for migratory bird
The NIMR oilfield requires 250,000 m³/d of water to be managed.
One of the largest constructed wetland systems to manage more than 45,000 m³/day.
System consists of a passive oil-water separator:
- 234 ha of surface flow wetlands and
- 300 ha of evaporation ponds.
During 2012, 120 ha were added to wetland to increase the treatment capacity of the plant to 95,000 m³/day.
NIMR REEDBED WATER TREATMENT PROJECT

- Project is able to recover as much as >200 bbl/d of oil from the produced water
- The oil content in the produced water reduced from 400 mg/L to <0.5 mg/L
- Reduced the energy footprint by 80%
- Expected salt production of 0.21 million m³/year
- The wetlands provided a habitat for migratory birds of 100 bird species

DOES WETLAND PROVIDED FULL SOLUTION TO PRODUCED WATER PROBLEM?

- No! … Why:
  - Wetland treated the hydrocarbons but not the salinity leaving behind highly saline water
    - Incoming water salinity = 6180 mg/L
    - Outgoing water salinity = 10460 mg/L
    - 59% higher than the untreated water
  - For which evaporation ponds are used to evaporate the water.
WHAT TO DO WITH HIGH SALINITY PRODUCED WATER?

- Water is life and its value is tremendous in desert areas of the World
- It is “Blue Gold” if oil is “Black Gold”
- There are other uses of this water including
  - Aquaculture and
  - Production of halophytic plants (hydroponics or soil based production)

PRODUCTION OF HALOPHYTES BY USING PRODUCED WATER
HALLOPHYTS

Plants that naturally possess the traits needed to grow and reproduce on saline soils at 200 milli moles are termed as halophytes.

Plant Order: Caryophyllales

21.4% halophytic spp

Family: Amaranthaceae

Genus: Salicornia

SALICORNIA

Salicornia consists of highly salt tolerant annuals without salt glands/salt bladders (Flowers et al., 2010).

Salicornia has been "selectively developed" since early 1980's in Mexico's Sonora state, on the edge of the Gulf of California.
SALICORNIA

➢ Worldwide, there are 130x10^6 ha of land (0.5 x 10^6 miles^2) = land under conventional irrigation today, which can be brought under Salicornia cultivation.

➢ Salicornia crops had been grown successfully in trial plots in the United Arab Emirates, Egypt and Kuwait, as well as in Jubail, Saudi Arabia.

In Behar Project of Saudi Arabia about 100 tons of Salicornia crop was used as forage for dairy herds, and exploring the possibility of air-shipping the crunchy green tips of Salicornia to wholesalers.

Historically, Salicornia was known for its digestive and anti-flatulent properties. It also contains diuretic and depurative properties and is rich in I, P, Ca, Si, Zn, Mn and vitamins A, C and D.
SALICORNIA RESPONSE TO SALINITY

- In low salinity, the cell electro potential of Salicornia root cells were found to respond to inhibitors in a fashion similar to that observed in glycophytes.

- In high salinity, root cell membrane potential appears to be insensitive to bathing salinity and *m*-chlorocarbonylcyanide phenylhydrazone induces membrane hyperpolarization.

- Cl⁻ and Na⁺ are apparently accumulated at the expense of metabolic energy by Salicornia roots.

SALICORNIA GROWTH IN SALINE WATER

The halophytic species of the *Amaranthaceae* family have generally the highest Na⁺: K⁺ ratios, which are detrimental to most other species.

*Salicornia dolichostachya* possesses a mechanism to specifically absorb K⁺ in the presence of high external Na⁺ levels.

*Salicornia dolichostachya* showed optimum growth at 300 mM NaCl in the root medium.
### SALT TOLERANCE OF SALICORNIA

<table>
<thead>
<tr>
<th>Plant Species</th>
<th>Salt Concentration (mM) at which germination reduced from 75 to 100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Salicornia brachystachya</td>
<td>240</td>
</tr>
<tr>
<td>Salicornia bigelovii</td>
<td>1000</td>
</tr>
<tr>
<td>Salicornia brachiata</td>
<td>600</td>
</tr>
<tr>
<td>Salicornia dolistachya</td>
<td>240</td>
</tr>
<tr>
<td>Salicornia europaea</td>
<td>850</td>
</tr>
<tr>
<td>Salicornia herbacea</td>
<td>1700</td>
</tr>
<tr>
<td>Salicornia pacifica</td>
<td>860</td>
</tr>
<tr>
<td>Salicornia patula</td>
<td>340</td>
</tr>
<tr>
<td>Salicornia persica</td>
<td>&gt;500</td>
</tr>
<tr>
<td>Salicornia rubra</td>
<td>1000</td>
</tr>
<tr>
<td>Salicornia virginica</td>
<td>600</td>
</tr>
</tbody>
</table>

Khan and Gull, 2006

---

### SALICORNIA PRODUCTION USING NIMR TREATED WATER

- Salinity of NIMR wetland project = 10140 mg/L which is approximately 1% salts or 174 mM.
- Seawater in the world's oceans has a salinity of about 35000 mg/L, or 3.5% (599 mM).
- Optimum growth of salicornia is achieved at 300 mM or 17529 mg/L or 1.75% salts.
- The above mentioned concentrations clearly show that the NIMR project treated water can successfully be used for *salicornia* production.
### SALINE WATER COMPOSITION

<table>
<thead>
<tr>
<th>Salinity</th>
<th>Sea Water</th>
<th>Produced Water NIMR</th>
<th>Optimum Salicornia Growth</th>
<th>Brackish Groundwater</th>
</tr>
</thead>
<tbody>
<tr>
<td>ppm</td>
<td>35,000</td>
<td>10140</td>
<td>17529</td>
<td>3000</td>
</tr>
<tr>
<td>%</td>
<td>3.5</td>
<td>1</td>
<td>1.75</td>
<td>0.3</td>
</tr>
<tr>
<td>mM/L</td>
<td>599</td>
<td>174</td>
<td>300</td>
<td>51.48</td>
</tr>
</tbody>
</table>

---

### SALICORNIA PRODUCTION SYSTEMS
**AQUACULTURE**

- The term aquaculture refers to the cultivation of both marine and freshwater fish species
- A rich protein food source for humans
- Aquaponics – Integration of Aquaculture with Hydroponics
- Enrichment of produced water with nutrients needed for plant production i.e. production of salt tolerant (halophytic) plants

**SMALL SCALE SALICORNIA PRODUCTION THROUGH AQUAPONICS**

Aquaponics = Aqua culture + hydroponics
SMALL SCALE SALICORNIA PRODUCTION

Green House Production

Bigger Green House

SALICORNIA BY DRIP IRRIGATION
LARGE SCALE SALICORNIA PRODUCTION

HYDROPONIC SALICORNIA
LARGE SCALE SALICORNIA PRODUCTION

Somalia  Eritrea

NUTRITIONAL VALUE OF SALICORNIA
### SALICORNIA COMPOSITION

<table>
<thead>
<tr>
<th></th>
<th>Crude protein</th>
<th>Ether</th>
<th>Crude fiber</th>
<th>Gross energy</th>
<th>Oil Content</th>
<th>Protein</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content</td>
<td>g kg⁻¹</td>
<td>MJ kg⁻¹</td>
<td>%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>340</td>
<td>64.5</td>
<td>36.0</td>
<td>19.4</td>
<td>26-33</td>
<td>33</td>
</tr>
</tbody>
</table>

*Attia F. M. Et al 1997*

### SALICORNIA VS OTHER OILSEED CROPS

<table>
<thead>
<tr>
<th></th>
<th>Salicornia</th>
<th>Cotton seed</th>
<th>Soybean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fatty Acids %</td>
<td>26-33</td>
<td>15-24</td>
<td>17-21</td>
</tr>
<tr>
<td>Salicornia fatty acid composition</td>
<td>polyunsaturated fatty acids</td>
<td>Oleic acid (Omega 3)</td>
<td>Linoleic acid (Omega 3)</td>
</tr>
<tr>
<td>19.98</td>
<td>12-17</td>
<td>76-80</td>
<td></td>
</tr>
</tbody>
</table>

*Elsebaie et al 2013*
MARKETING OF SALICORNIA PRODUCTS

SALICORNIA RECIPES
Questions
No question is a silly question

hafeez.chishti@Envirolead.ca
Tahir.Rashid@Envirolead.ca

Done

Thank You