An Update on Minimal and Zero Liquid Discharge Technologies

Mike Mickley, P.E., PhD
Mickley & Associates LLC
Bluetech Research

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An Interesting Story…

- **Impact of unconventional oil & gas operations on *high recovery technologies***

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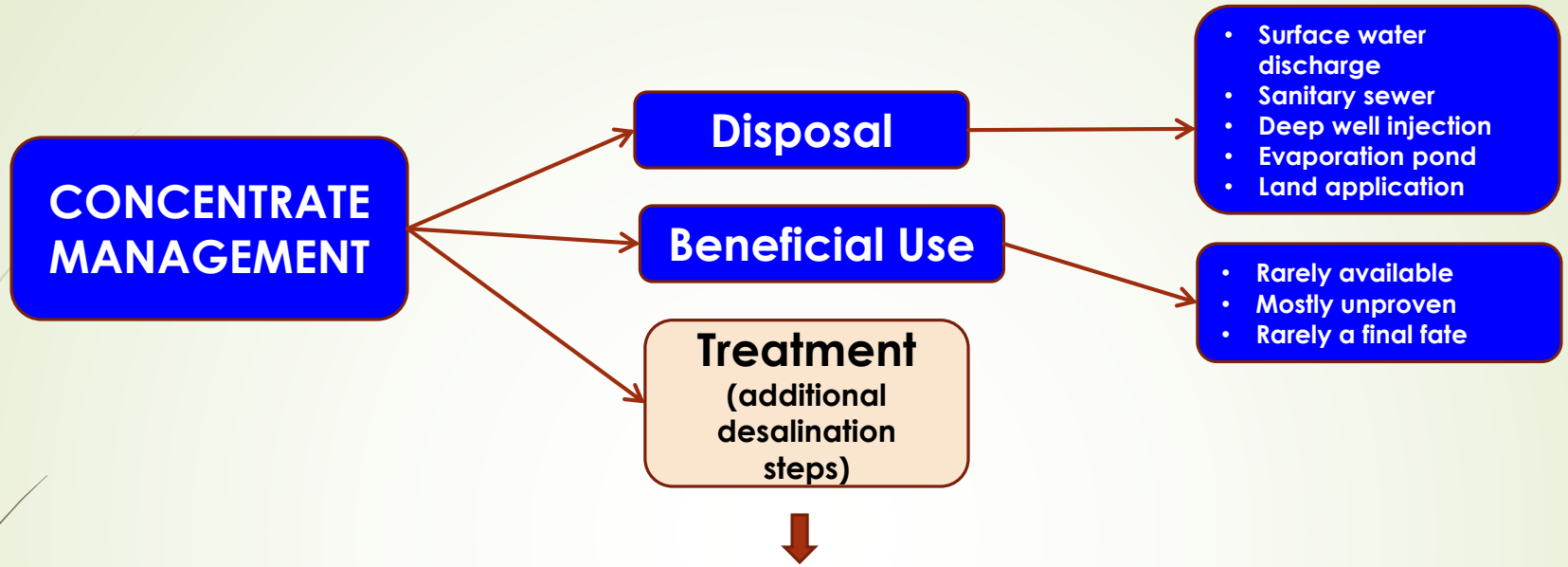
  - BlueTech Research

Concentrate Management



High recovery (incl. minimal & zero liquid discharge) processing

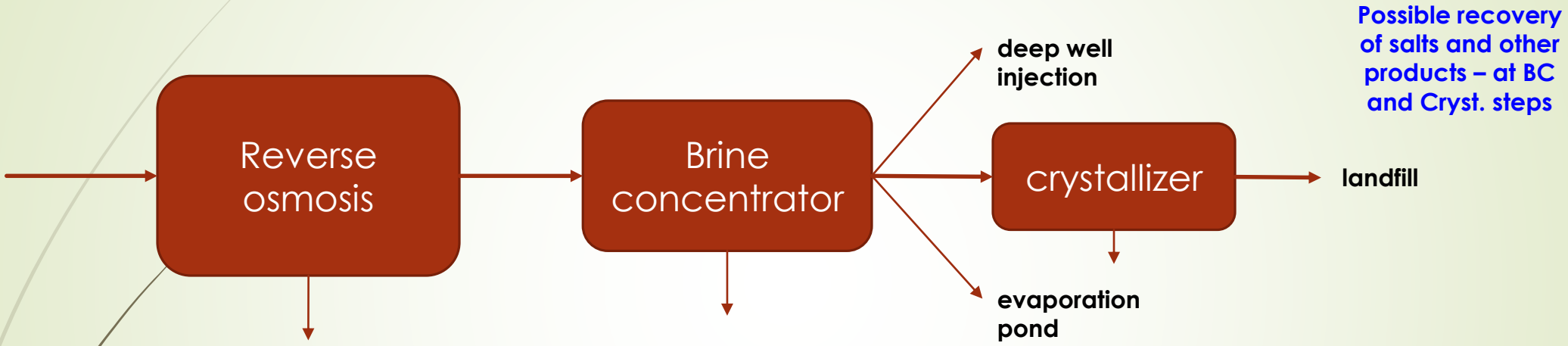
Brines:
- Desalination concentrates
- Produced water (conventional & unconventional O&G)
- Frack water
- Mine drainage
- Industrial wastewater
- Others

Reasons/drivers for treatment:
- Regulations
- No other options
- Permitting time
- Cost (rarely)
- Maximize use of water resource
- Recovery of salts, products
- Minimize corporate risk
- Combination of above

Conventional markets:
- Overwhelmingly industrial
- Steady, slow growth
- 10-20 major systems /year
- MAJOR PLAYERS: GE (RCC), Aquatech, Veolia (HPD)
- Power: cooling water blowdown
- Power: flue gas desulfurization
- Produced water
- Coal to liquid (China)
- Others

Conventional High Recovery Processing

(of wastewater)



Relative costs:

Cost Factor	Relative Level	Approx. Ratio
Nominal UNIT OPEX	RO < BC < Crystallizer	1: 5: 15
Nominal UNIT CAPEX	RO < BC < Crystallizer	1: 5: 20

Result:

- Low salinity feed water → RO costs predominate
- Very high salinity feedwater → crystallizer costs predominate
- Intermediate salinity feedwater → brine concentrator costs predominate

HIGH COSTS

(against that background)
The Interesting Story…

- **FOR YEARS**:
  - RO, ED, and evaporators technologies changed very little
  - ZLD markets were essentially all industrial and of slow growth

- **AND THEN:**
  - the advent of unconventional O&G
  - drought
  - increased sustainability and environmental concerns
  - Increased regulation

THIS SET THE CONTEXT FOR WHAT HAPPENED NEXT:

→ Perceptions:

Significantly Increased Markets

Costs would need to significantly decrease

New markets would open

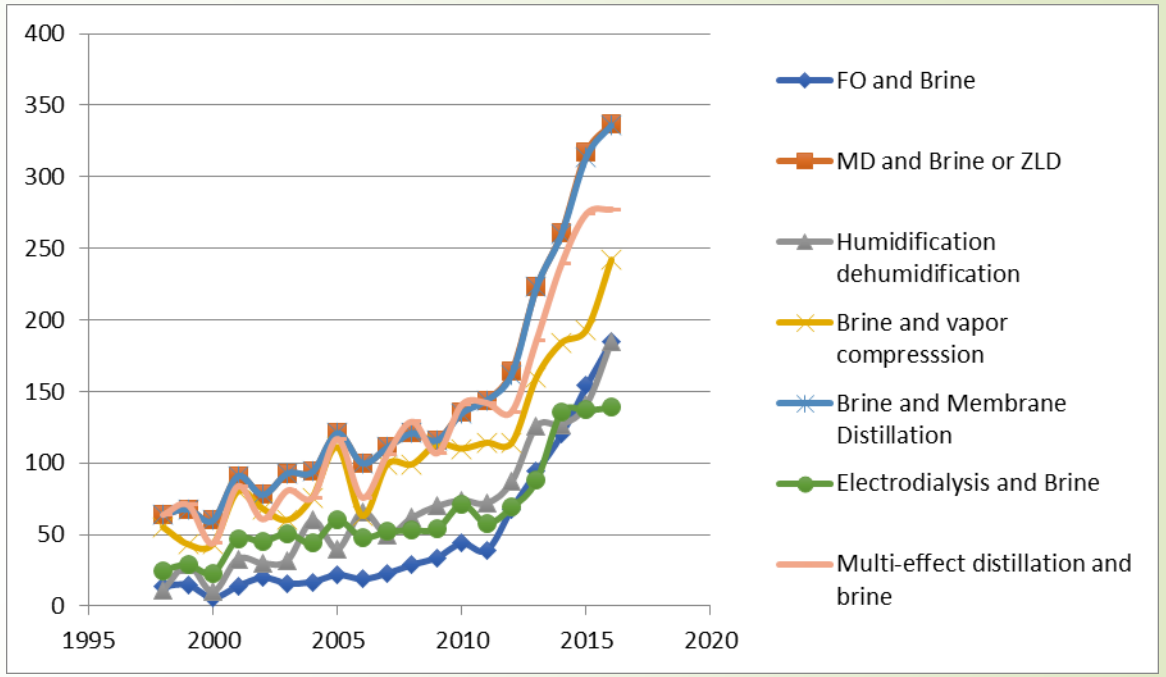
Existing markets would expand

→ Result

Interest in high recovery processing exploded

Indications of this Result…

- Increase in number of patents
- Increase in conference sessions
- Increase in the literature

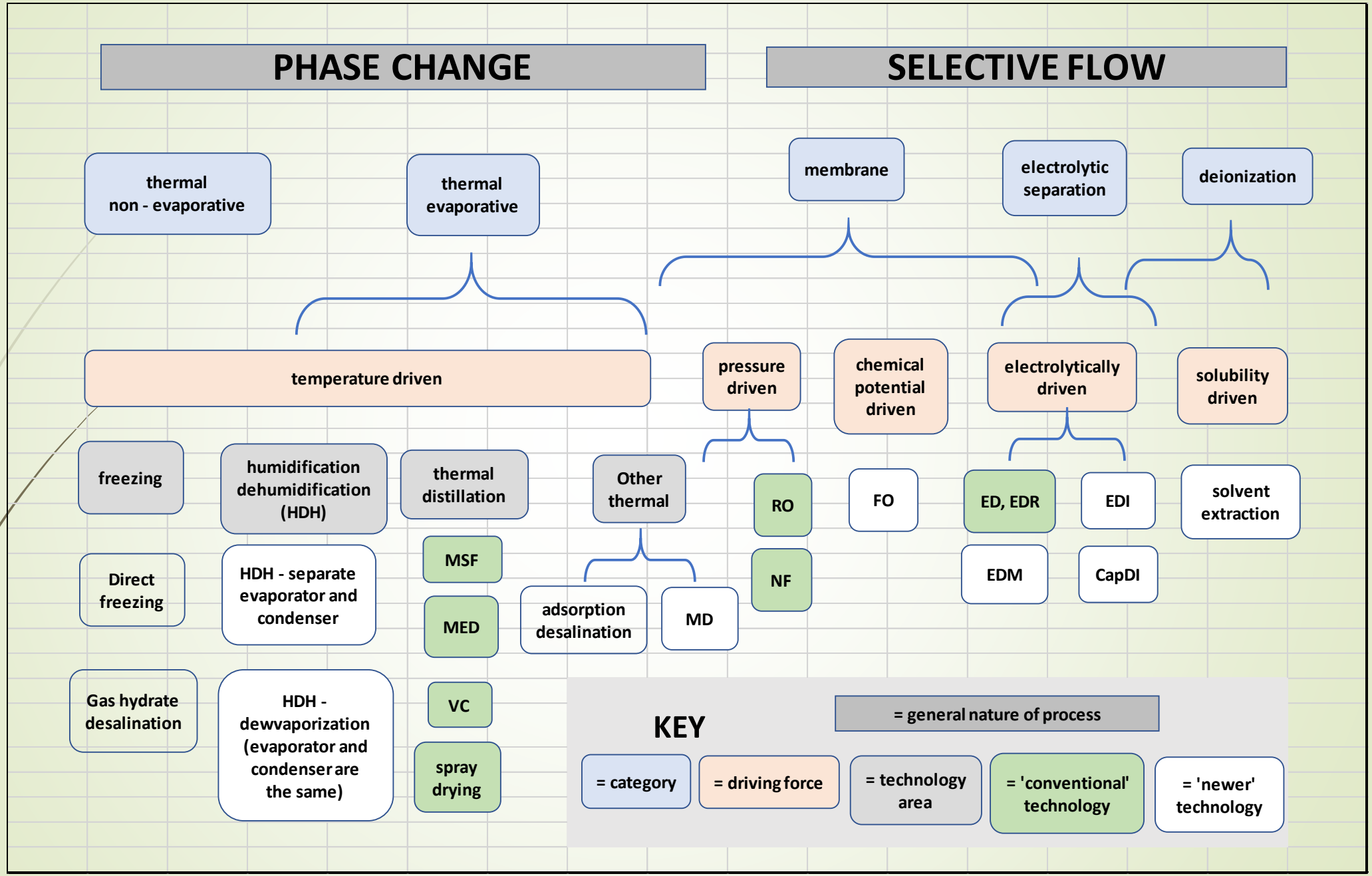


- AND Increase in the number of companies…

SELECTED EXAMPLES

Companies & Technologies Reviewed

- Non-Standard RP – NON-CASCADE SYSTEMS
  - ADEDGE: ROTEC RORO
  - PALL: Disk Tube Module
  - AQUATECH: HERO
  - DESALITECH: Closed-circuit RO
  - SALTWORKS: smart RO
  - NEW LOGIC RESEARCH: VSEP
  - EET Corp: High Efficiency ED
  - CH2M: MAX RO
  - OSMOFLO: Brine Squeezer
  - Kin Lee Technologies: Tandem RO
  - O'Brien & Gere: ARROW
  - HYREC: OARO – Osmotically Assisted RO
  - AVENG WATER: HIPRO
- Non-Standard RO – CASCADE SYSTEMS
  - BATTELLE: Cascade RO
  - GRADIANT: Counter Flow RO
  - NANYANG TECH. UNIV: EERO
- ELECTROLYTIC PROCESSES
  - SALTWORKS: EDR
  - FUJIFILMS: modified EDM
  - EVOQUA WATER TECHNOLOGIES: EDR/CEDI
  - BDL ENVIRONMENTAL TECH: high salinity ED
  - ATLANTIS TECH: RDI (radial deionization)
  - AQUA EWP: EWP CapDI
  - SUEZ-IONICS: RED
  - MEGA: high salinity EDR/low salinity EDI
  - VOLTEA B.V.: CapDI EDI
  - IDROPAN: CDI
  - ENPAR: ED (electrostatic deionization – CDI)


PHASE CHANGE
SELECTIVE FLOW
thermal non - evaporative
thermal evaporative
membrane
electrolytic separation
deionization
temperature driven
pressure driven
chemical potential driven
electrolytically driven
solubility driven
freezing
humidification dehumidification (HDH)
thermal distillation
Other thermal
RO
FO
ED, EDR
EDI
solvent extraction
Direct freezing
HDH - separate evaporator and condenser
MSF
MED
adsorption desalination
MD
NF
EDM
CapDI
Gas hydrate desalination
HDH - dewvaporization (evaporator and condenser are the same)
VC
spray drying
KEY
= general nature of process
= category
= driving force
= technology area
= 'conventional' technology
= 'newer' technology

EXAMPLES:
Single Evaporation Step Systems
(replace BC and XTALL)

- SALTTECH (Netherlands) – electrical MVR system
- HEARTLAND (USA) – single stage evaporator
- SALTWORKS (Canada) – HDH system
- GRADIANT (USA) – HDH system
- TPTEC (Switzerland) – MED system

Lower cost where waste heat is available

- General characteristics:
  - No heat transfer tubes
  - Low cost resin-based materials of construction
  - High but reduced energy requirement
  - Very robust
  - Low pre-treatment need
  - May put high recovery RO/ED in front to reduce costs

Early commercial systems included:
- Aquatech's HERO process
- New Logic Research's VSEP system

EXAMPLES:
High Recovery RO-ED Systems
(replace conventional RO & perhaps BC)

Closed-Circuit RO
- DESALITECH = 100% closed; SALTWORKS and others <100% closed
- Smart systems – vary velocity and pressure → reduced energy requirement and higher recovery

Ultra-high Pressure RO
- Several companies
- → higher recovery; not limited by osmotic forces that limit 1000 psi operation

Systems allowing precipitation
- NEW LOGIC RESEARCH – VSEP: high shear; IDE – MAXH2O: smart system
- → higher recovery

Cascade (counter-current flow RO)Systems
- BATTELLE, GRADIANT, HYREC, NANYANG TECHNICAL UNIVERSITY
- → higher recovery, lower energy; some commercial sales

EXAMPLES:
Other Unique Technologies
(replace conventional RO & perhaps BC)

- **AQUAFORTUS**
  - Solvent extraction of water by an absorbent material
  - Release the held water by a small change in temperature
- **COLDSEPARATIONS**
  - Freezing of water yields water, solids, & very concentrated brines
- **ADIONICS**
  - Solvent extraction of salts by a proprietary organic cocktail
  - ion-specific resins hold cations and anions separately

General Status of Market Impact

CHALLENGES FOR COMPANIES DEVELOPING TECHNOLOGIES

- Wide range of possible applications – mostly industrial
- Company-related factors: management team, marketing strategy, funding
- Clients want full treatment solutions

LIMITED IMPACT TO DATE DUE TO:

- Market-related factors (until more recently: economy, low O&G prices)
- Some anticipated applications not yet realized
- Technology-related factors: hurdle of newer technologies getting accepted

- Costs are decreasing – SIGNIFICANTLY
- Direction is clear
- Largest area of impact will be with RO/ED related technologies
- The issue of impact is one of TIMING

The story continues…

Contact Information

President

Mickley & Associates LLC

Lafayette, CO

303 499 3133

mike@mickleyassoc.com

Technical Assessment Group

BlueTech Research

Cork, Ireland and Vancouver BC

www.o2env.com