Water Reuse in the Petroleum Industry

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Why Water Reuse?

Thirsty Planet

- World-wide Water Shortages

Save Money/Save Energy/Sustainability

- Produce More Water Than Oil
- Water Treatment Influences Profitability
- Water Companies in Denial

Do More Than Just Check the Environmental Social Impact Assessment (ESIA) Boxes

- Environmental Stewardship
- Community Outreach
- Environmental Education
- Sustainability

Water Reuse Outline

Introduction to Water Reuse

- Water Sources
- Treatment
- Reuse Standards

Case Examples

- Applications
- Upstream
- Downstream

Future of Water Reuse

- Ideas to Go
- Barriers and Fixes

Water Reuse Opportunity

Brief History of Petroleum Industry

- Kerosene replaces whale oil
- Light bulb replaces kerosene
- Fuel oil replaces coal in ships
- Crude refined into gasoline and lube oils
- Fertilizer and pharmaceuticals
- Water usually increases with age of field
- 0 to >100 bbl of water for 1 bbl of oil
- 1.3 million tonnes produced water per tonne of hydrocarbons produced

World-wide Water Shortage

- 70% earth is covered with water
- 97% saltwater
- 3% freshwater
- <1% freshwater is readily available
- Scarcity could limit growth

Human Population

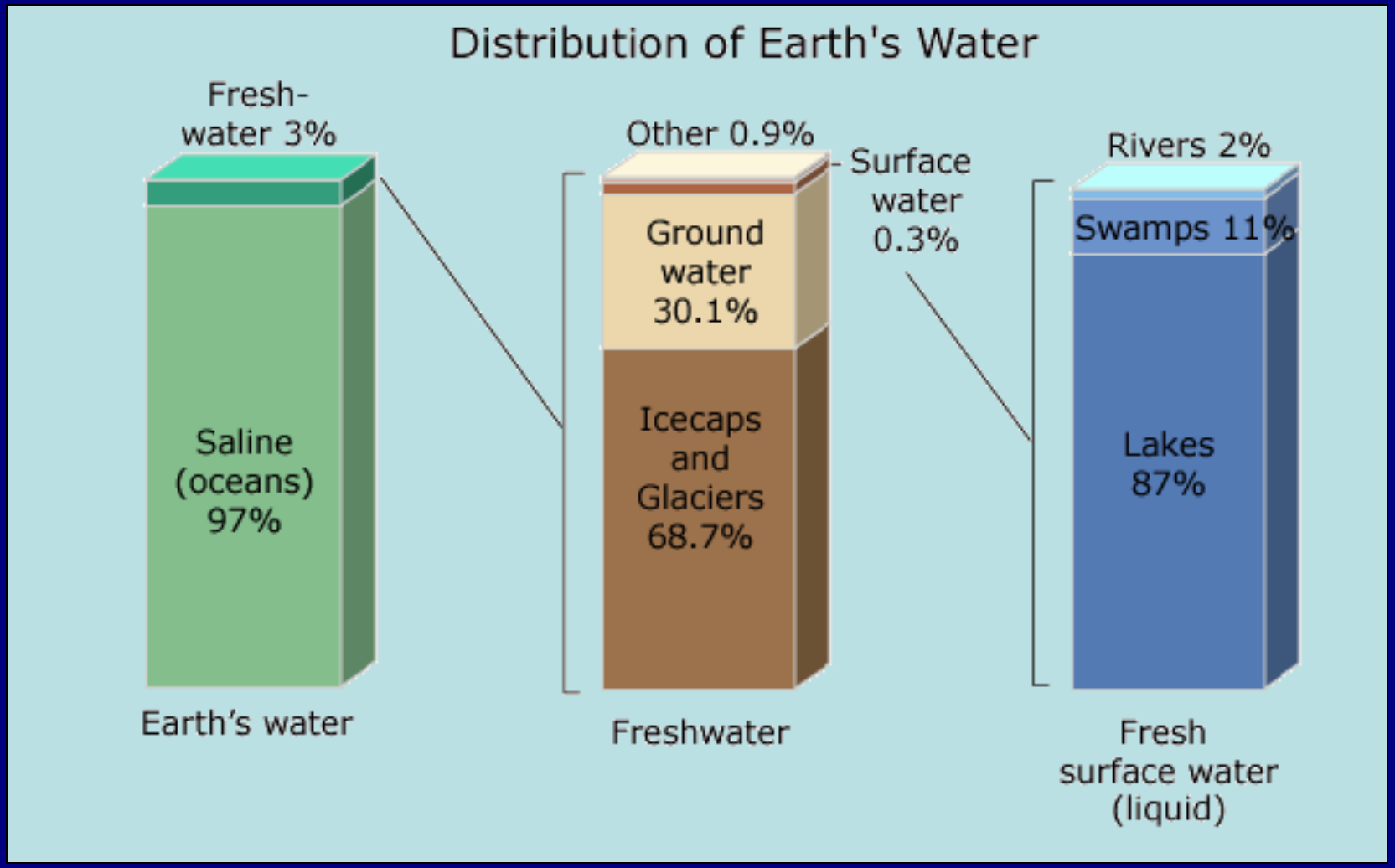
- 6.6 billion September 2007
- 9 billion 2050
- 40% short on water by 2050

Opportunity for Produced Water Reuse

- Typically produced water is found water not considered a water source
- Convert by-product into an asset
- Reuse water for agriculture
- Grow biofuels
- Sequester carbon

Convergence of Petroleum Industry, Water Shortage and Human Population

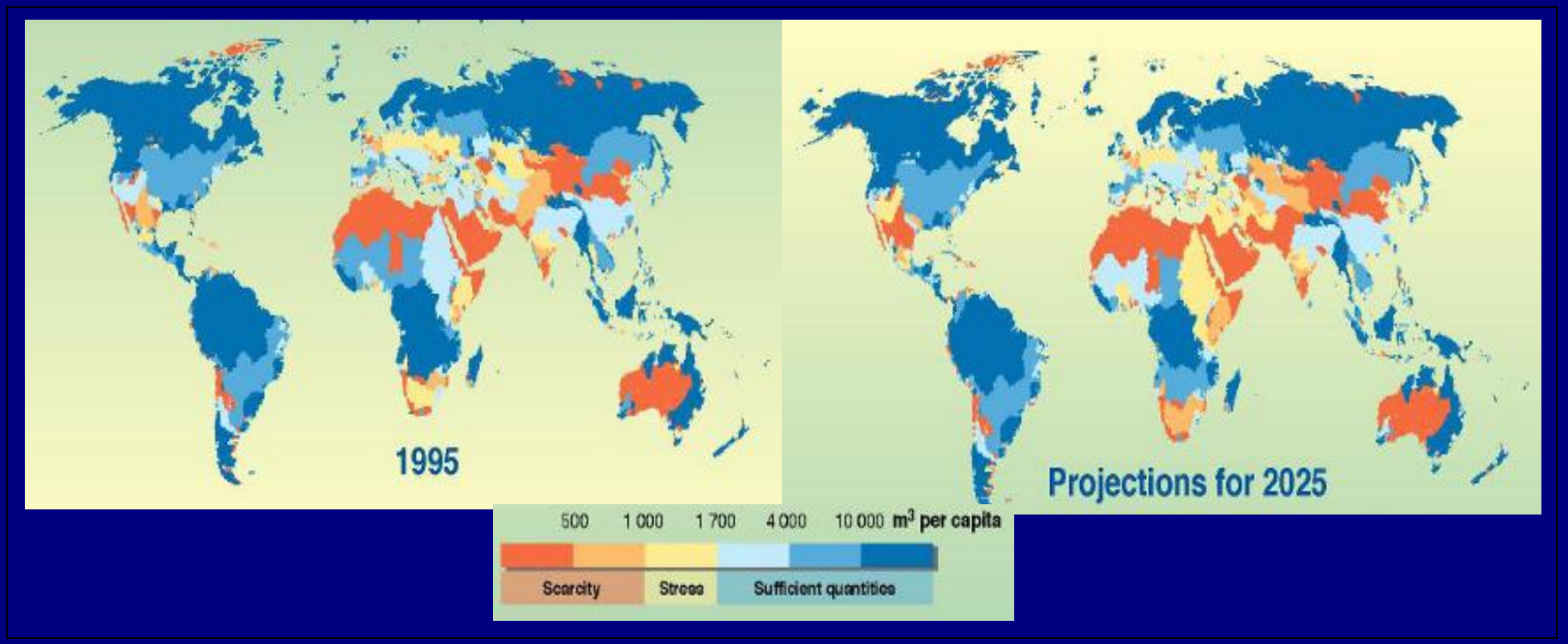
Water Sources



Easily accessible freshwater represents less than 0.01% of the earth's water.

USGS, 2005. http://ga.water.usgs.gov/edu/watercyclefreshstorage.html

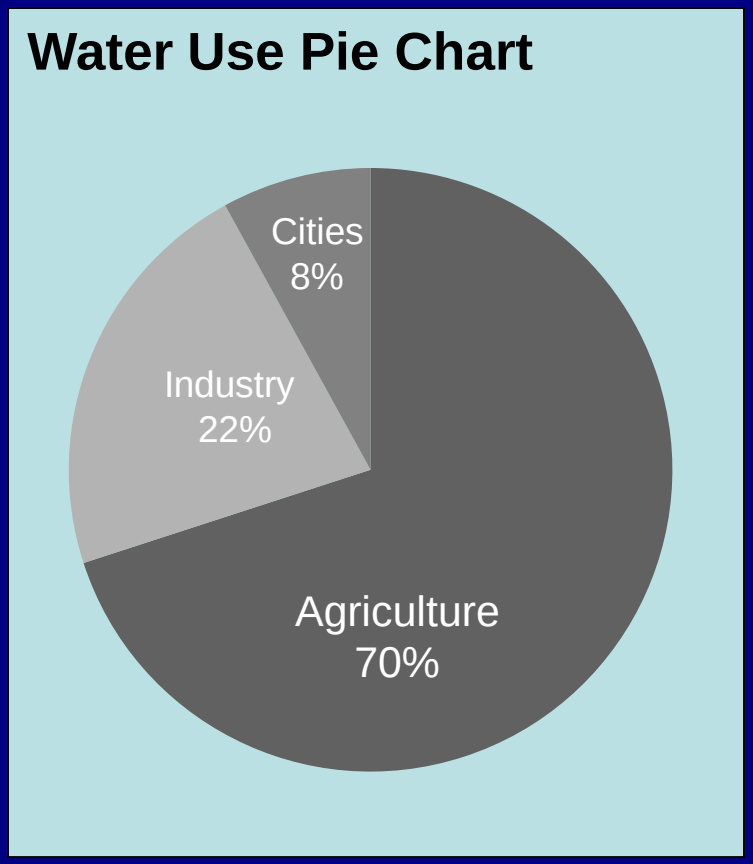
Projection of Drinking Water Availability



Red/Orange – Scarcity
Tan – Stress
Blue – Sufficient Water

Gleick, P. H., 1996: Water resources In Encyclopedia of Climate and Weather, ed. by S. H. Schneider, Oxford University Press, New York, vol. 2, pp.817-823

Water Use and Cost

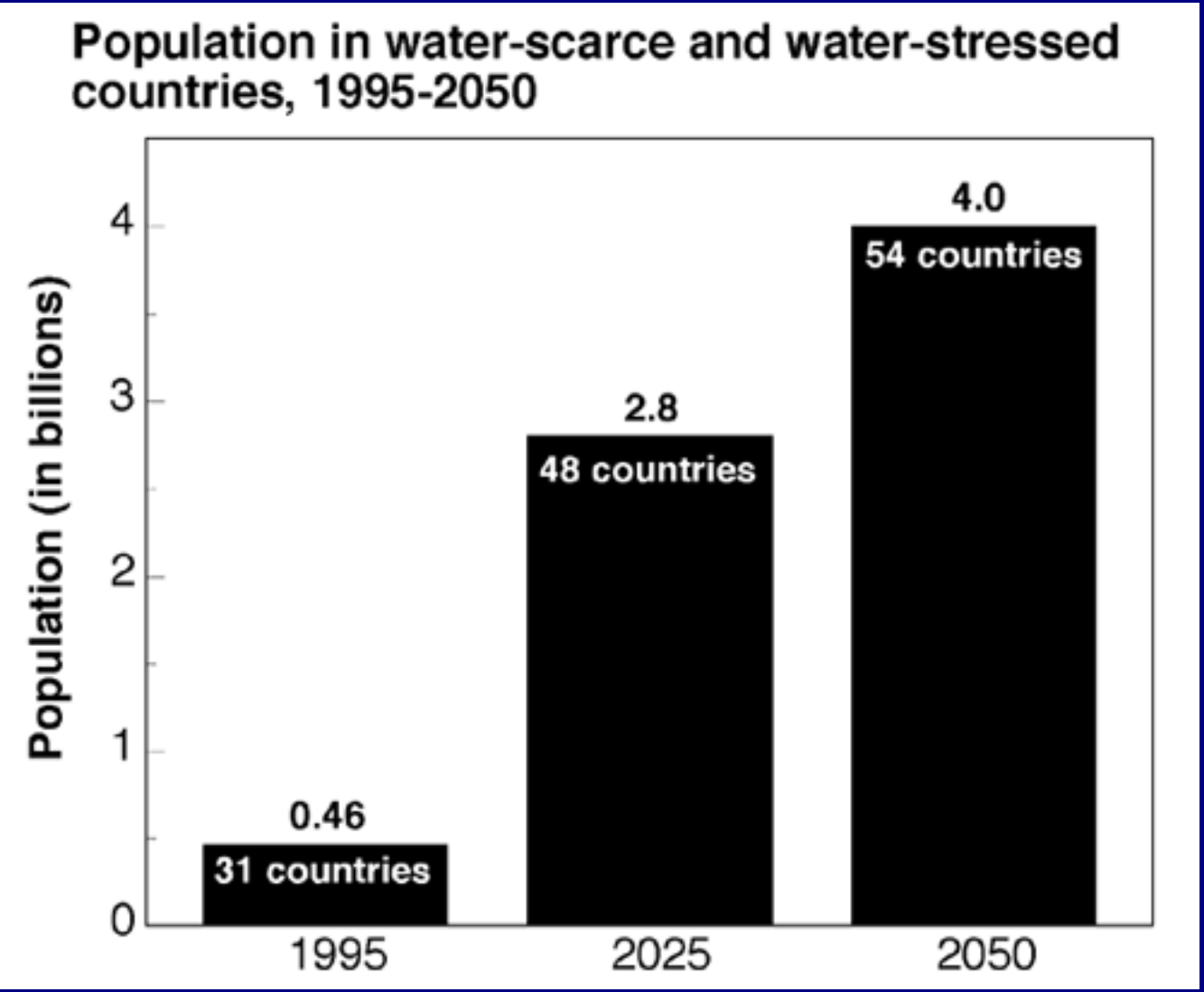


Whyte, Fergal, 2006, "Cities of the Future – Urban Sustainability & Water"

Acre-ft ~ 209 x 209 x 1 ft ~ 325,829 gal

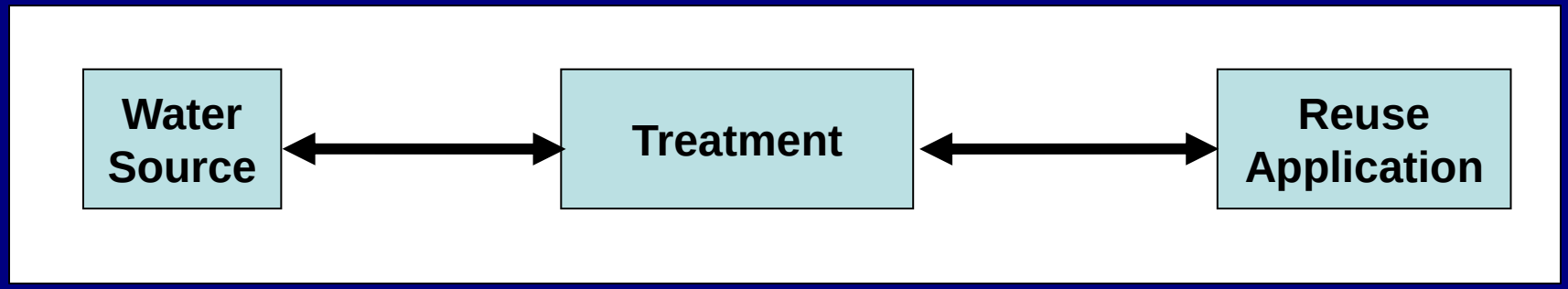
Water Source	Unit Cost	Cost ($/acre-ft)
Irrigation Water		
SE Texas		$10 to 100
California (wet year)		$100 to 150
California (dry year)		$200 to 500
US Cities ($/1000 gal)		
Low (Mississippi)	$ 0.80	$ 261
Average	$ 2.49	$ 811
High (West Virginia)	$ 5.61	$ 1,828
Treated PW (1 bbl)	$ 0.01	$ 78
	$ 0.02	$ 155
	$ 0.03	$ 233
	$ 0.04	$ 310
	$ 0.05	$ 388
	$ 0.06	$ 465
	$ 0.07	$ 543
	$ 0.08	$ 621
	$ 0.09	$ 698
	$ 0.10	$ 776
	$ 0.20	$ 1,552
	$ 0.30	$ 2,327
	$ 0.40	$ 3,103
	$ 0.50	$ 3,879
	$ 1.00	$ 7,758
16 oz Bottled Water	$ 1.00	$ 2,606,630

Human Population and Water



AAAS Atlas of Population and Environment, 1998. http://www.ourplanet.com/aaas/pages/natural03.html#

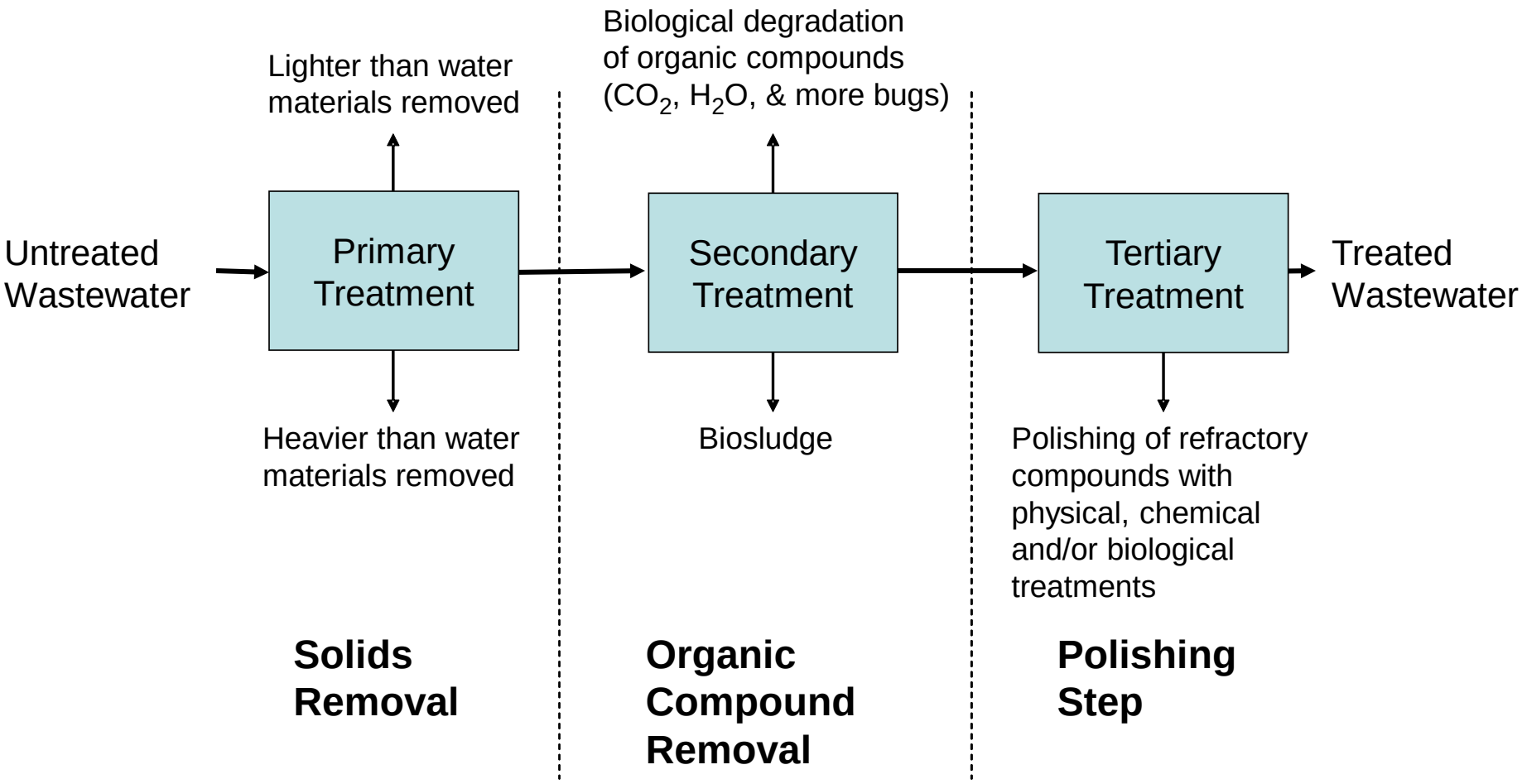
Water Reuse PFD



- Simple as A-B-C, 1-2-3 or "1st name, middle name, last name"
  - Lots of Water Sources
    - Produced Water, Refinery Wastewater, Marketing Terminal Water, Ground Water, Storm Water, Parking Lot Runoff
  - Plenty of off-the-shelf Treatments
  - Unlimited Supply of Applications

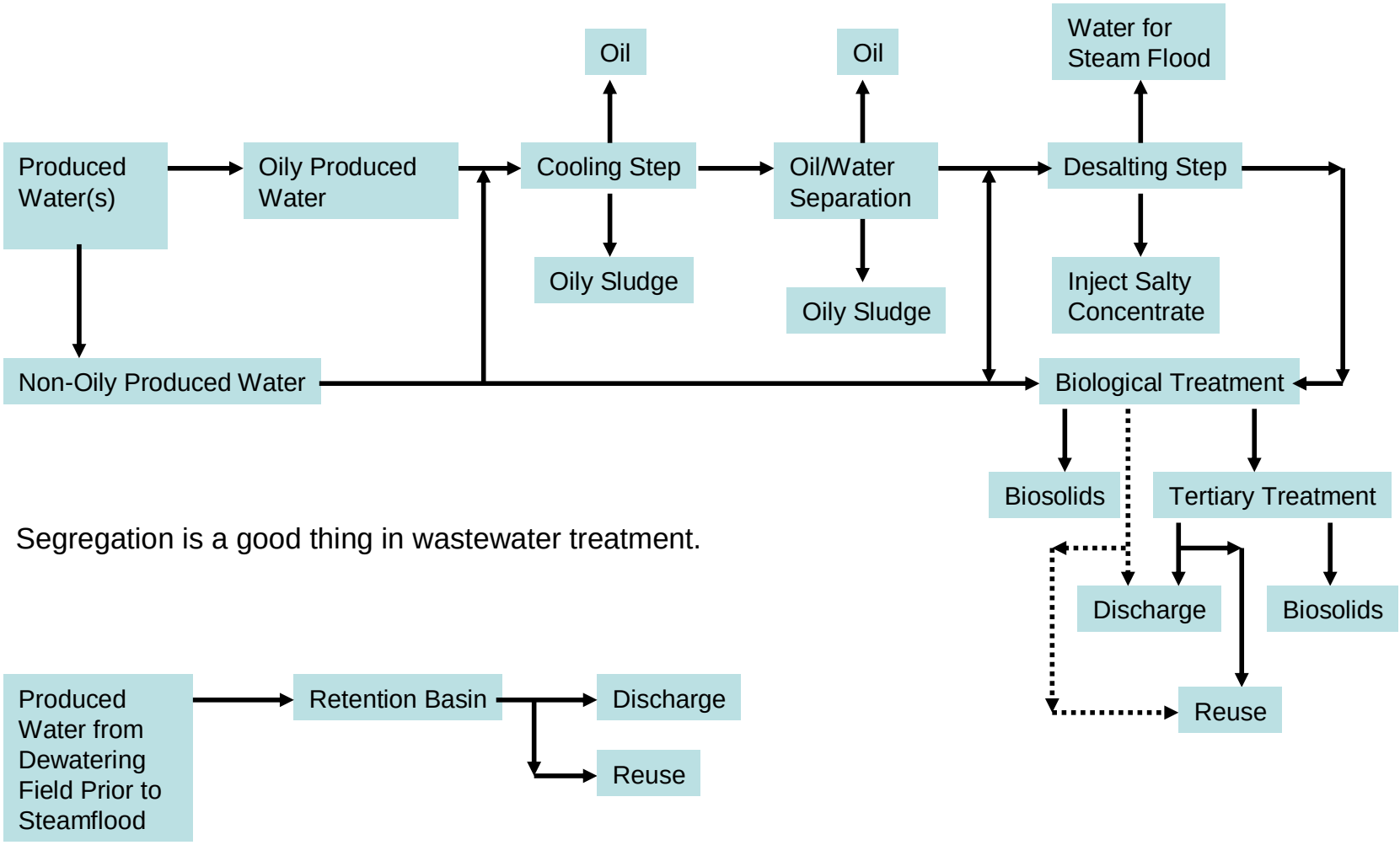
PFD – Process Flow Diagram

Typical Water Treatment PFD



PFD – Process Flow Diagram

Typical Produced Water Treatment PFD



1st Step in Design is to Create a Series of PFDs.

Water Treatment Technologies

Wide Selection – One Size Does Not Fit All

Water Treatment Grouped by Function	**Comment**
Primary Treatment - Oil/Water Separator - API* - CPI* - PPI* - DAF/DNF* - IAF* - Clarifier - Hydrocyclone - Treatment Wetland	Gravity settling of solids heavy than water. Float oils lighter than water. Entrain oil with air/gas bubbles. Use density differences to remove solids and oils.
Secondary Treatment - ASTU* - SBR* - Facultative Lagoon - RBC - Aerated Lagoon - Anaerobic Filter - Treatment Wetland - MBR* - Trickling Filter - GAC*	Biological treatment uses micro-organisms to consume organic compounds in an ambient temperature combustion reaction. Some of the treatments are energy intensive with small physical footprints. Others are not energy intensive but have large physical footprints.
Tertiary Treatment - Activated Carbon - Filtration - Chlorination - UV* - Chemicals (FeCl, O3, H2O2)* - Treatment Wetland	Polishing treatments remove the refractory compounds by physical, chemical and biological means.
Salts (desalting) - RO* - FO* - ED* - NF* - Freezing - UF*	Salt removal is typically to meet irrigation water standards (EC/TDS/salinity). Some of the membrane technologies require pre-treatment (solids removal) to avoid membrane fouling.

*SEE ACRONYM LIST – LAST SLIDE

Water Reuse Applications

Find Out What Local Stakeholders Need

Category	Typical Application
Agriculture	Crop irrigation, Commercial nurseries
Livestock	Cattle, Sheep, Pigs, Chickens, Waterfowl
Aquaculture	Fish, Shrimp, Frogs, Bait
Silviculture	Tree farming
Landscape Irrigation	Residences, Golf courses, Parks, Cemeteries, Freeway medians, Greenbelts, School yards
Industrial Recycling and Reuse	Boiler feed water, Fire protection, Cooling tower, Process water, Manufacturing, Vehicle washing, Dust control
Groundwater Recharge	Groundwater replenishment (water banking), Salt water intrusion control, Subsidence control
Recreation	Lakes, streams and ponds, Snow making
Wildlife Habitat	Marsh restoration, Habitat enhancement, Fisheries
Nonpotable Urban Use	Fire protection, Air conditioning, Toilet flushing
Potable Use	Blending in water supply reservoirs, Blending in groundwater, Direct pipe to pipe water supply

Brief Overview on Water Reuse Standards

Pick and Choose to Match Application

Reference	**Category/Comment**
Health Guidelines for Use of Wastewater for Agriculture and Aquaculture by WHO (1989)	Focus on helminth removal
Guidelines for Water Reuse by USEPA (1992)	Focus on municipal water
Water Reuse[13] (2007)	Compilation of municipal and agricultural standards
Water Encyclopedia[14] (2007)	Compilation of water standards
USA State Regulations on Water Reuse	Most have USEPA like standards
Forestry Standards (several sources & university papers)	Trees tend to tolerate lower quality water than other plants
Fishery Standards (several sources & university papers)	Focus is the taste of fish in commercial fish farming operations
AB (Alberta) Canada	Comprehensive lists including treatment technologies

WHO – World Health Organization USEPA – United States Environmental Protection Agency

Water Reuse Analytical Testing Parameters for Irrigation – Salt Focus

		Degree of Restriction on Use		
Irrigation parameter	**units**	**None**	**Slight to Moderate**	**Severe**
		Salinity		
EC	**dS/m**	**<0.7**	**0.7-3.0**	**>3.0**
TDS	**mg/L**	**<450**	**450-2000**	**>2000**
Sodicity				
SAR, 0-3 **3-6** **6-12** **12-20** **20-40**		**and EC ≥0.7** **≥1.2** **≥1.9** **≥2.9** **≥5.0**	**0.7-0.2** **1.2-0.3** **1.9-0.5** **2.9-1.3** **5.0-2.9**	**<0.2** **<0.3** **<0.5** **<1.3** **<2.9**
Specific Ion Toxicity				
Sodium (Na) **Surface irrigation** **Sprinkler irrigation** **Chloride (Cl)** **Surface irrigation** **Sprinkler irrigation** **Boron (B)**	**SAR** **mg/L** **mg/L** **mg/L** **mg/L**	**<3** **<70** **<140** **<100** **<0.7**	**3-9** **>70** **140-350** **>100** **0.7-3.0**	**>9** **>350** **>3.0**
Miscellaneous effects				
Nitrogen (total N) **Bicarbonate (HCO_3)** **(overhead sprinkling only)** **pH** **Residual chlorine (overhead sprinkling only)**	**mg/L** **mg/L** **s.u.** **mg/L**	**<5** **<90** **<1.0**	**5-30** **90-600** **Normal range 6.5-8.4** **1.0-5.0**	**>30** **>500** **>5.0**

EC – Electrical Conductivity TDS – Total Dissolved Solids SAR – Sodium Adsorption Ratio

Petroleum Industry Water Reuse Case Examples

Case	Treatment	Reuse	Comment
California Produced Water[3]	Oil/Water Separation, Walnut Shell Filter, Cooling Pond	Agriculture	Chemical and mechanical treatment. Small footprint. Reused water grows >40 crops.
California Produced Water	Oil/Water Separation, Cooling, RO, CTW	Agriculture	RO for salt removal to meet irrigation water standards. Reused water recharges irrigation aquifer.
California Produced Water Demonstration Wetland	Oil/Water Separation, Walnut Shell Filter, Cooling Pond, Treatment Wetlands	Agriculture	Test program capturing data from multiple cells, plant species, planting densities and construction costs.
Ohio Closed Refinery Storm & Ground Water	Oil/Water Separation, GAC, Pond, CTW	Wildlife	Wetland is winning wildlife awards (pollinator and waterfowl). WHC certified wildlife management plan.
Kansas Refinery Wastewater	Oil/Water Separation, ASTU, Facultative Lagoon, CTW	Wildlife	Gravity fed CTW. Pump once. Let gravity do the rest. Large wetland is attracting wildlife use. IOGCC award. WHC certified.
Wyoming DOE CRADAs Pilot Studies	Oil/Water Separation, Cooling, Facultative Lagoon, CTW	Wildlife Agriculture Aquaculture	Series of pilot CTW studies. Reused water irrigates a normally dry stream creating grazing habitat for mule deer and elk.
Far East Produced Water Feasibility Study	Oil/Water Separation, Cooling Pond, CTW	Agriculture Aquaculture Silviculture	Several applications possible. Lack of infrastructure makes water hand-off challenging.
Africa Produced Water Feasibility and Pilot Studies	Oil/water Separation, Cooling Pond, CTW	Agriculture Livestock	Several applications possible. Lack of infrastructure makes water hand-off challenging.

RO – Reverse Osmosis CTW – Constructed Treatment Wetland GAC – Granular Activated Carbon ASTU – Activated Sludge Treatment Unit
DOE – Department of Energy CRADA – Cooperative Research and Development Agreement

Water Reuse Case Example

Refinery WWTP PFD

FORM	Oil/Water Separation Solids Removal	Activated Sludge Facultative Lagoon	**Treatment Wetland**
FUNCTION	Removal of Oil and Solids	Removal of Water Soluble Organic Compounds (WSO)	**Removal of WSO and Total Suspended Solids (TSS)**
OBJECTIVE	Setup for Biological Treatment	Meet Discharge Limits	**Meet Discharge Limits** **Provide Wildlife Habitat**

WWTP – Wastewater Treatment Plant
WSO – Water Soluble Organic Compounds
PFD – Process Flow Diagram
TSS – Total Suspended Solids

Water Reuse Case Example
Refinery Wastewater Treatment Wetland

- 90-acre Site in Mid-West
- Former Soybean Field
- 2 mgd Average Flow
- Multiple Cells
- Parallel or Series Flow
- Wastewater and Wildlife Balance
  - W-ditches, 6:1 & 4:1 Levees, Gravel/Grit, Hedgerow/Windbreak, Nesting Boxes, Biodiversity Increase (60 to 250 species)
- Interstate Oil & Gas Compact Commission (IOGCC) and Wildlife Habitat Council (WHC) Award

Refinery Water Reuse Example

Aerial View of Treatment Wetland

Refinery Water Reuse Example

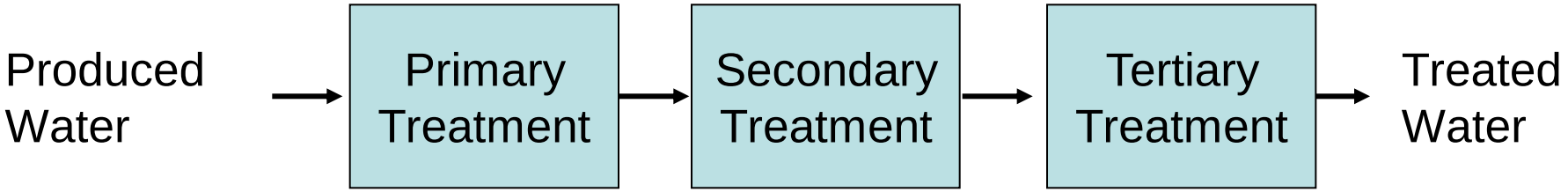
Mallard Landing on Cell Nos. 4 and 5

Water Reuse Case Example Department of Energy (DOE) Produced Water Wyoming

- 3 in Operation in the Western US
- Economics Good
- Wildlife Benefits Better
- Discharge Limits Met

DOE Wyoming Produced Water Reuse Case Example

Produced Water WWTP PFD



FORM	Cooling Tower Oil/Water Separation Solids Removal	Facultative Lagoon	**Treatment Wetland**
FUNCTION	Water Cooling Removal of Oil and Solids	Water Cooling	**Removal of WSO**
OBJECTIVE	Meet Discharge Limits Exclude Wildlife (nets)	Setup for Wetland	**Meet Discharge Limits** **Water Reuse for Wildlife**

WWTP – Wastewater Treatment Plant PFD – Process Flow Diagram

DOE Wyoming Produced Water Reuse Beneficial Reuse for Wildlife

Water Reuse Ideas to Go
Water Reuse Justification Kit

Economics

- CAPEX
- OPEX

GHG Emission Reduction

- CO2, NOx, SOx, CO, PM, Energy Usage
- Soil Carbon Sequestration

ESIA

- Environmental
- Social
- Health

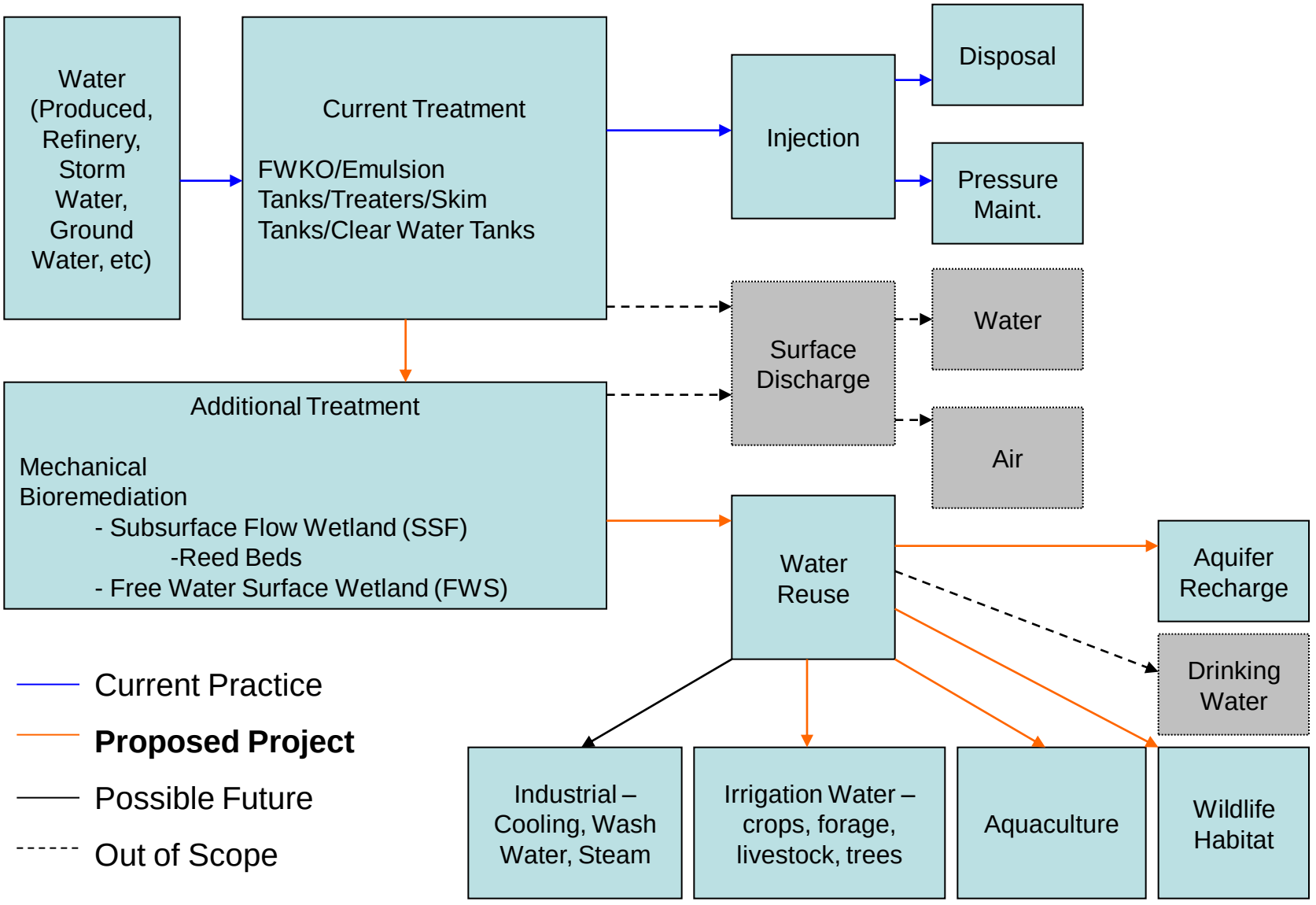
Business Development

- Political
- Regulatory
- Zero Water Footprint

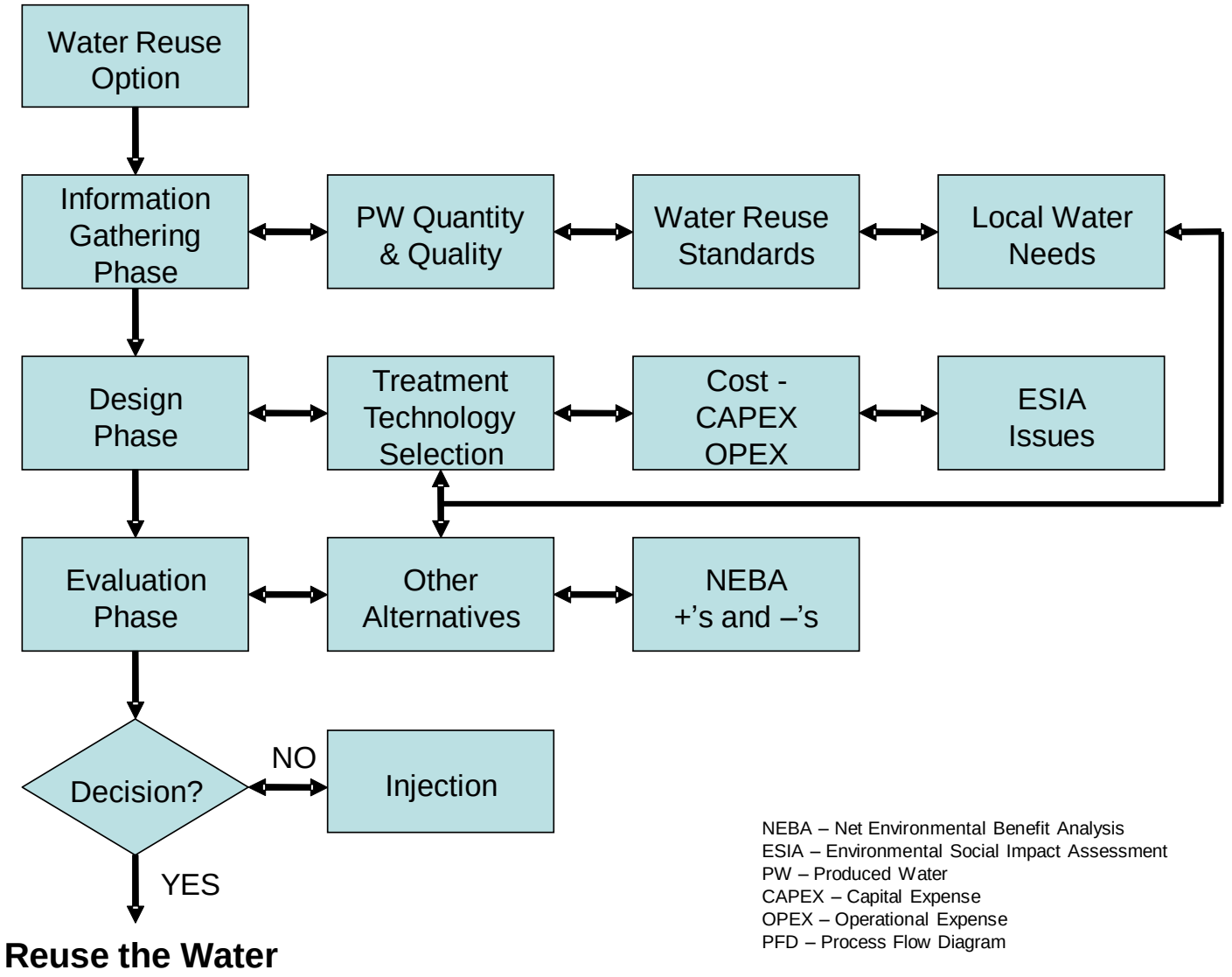
CAPEX – Capital Expense OPEX – Operational Expense GHG – Greenhouse Gases ESIA – Environmental Social Impact Assessment
CO2 – Carbon Dioxide NOx – Nitrous Oxides SOx – Sulfur Oxides PM – Particulate Matter

Water Reuse Ideas to Go

Water Reuse Technology PFD



Water Reuse Ideas to GO
Produced Water Reuse Evaluation PFD



NEBA – Net Environmental Benefit Analysis
ESIA – Environmental Social Impact Assessment
PW – Produced Water
CAPEX – Capital Expense
OPEX – Operational Expense
PFD – Process Flow Diagram

Water Reuse Barriers

Barriers and Fixes

- **Barrier – risk aversion and "we have never done it that way before"**
- Fix – "Ask them what their 2nd answer is", education, economic evaluations, pilot studies, risk assessments and ESIA.
- **Barrier -1st to be 2nd to use a new technology mind set**
- Fix – Repackage off-the-shelf technologies and use water reuse best management practices (BMPs).
- **Barrier – Regulations do not encourage Water Reuse**
- Fix – Help change the regulations to benefit local stakeholders (farmers, ranchers, municipalities, etc).
- **Barrier – TMI overload and analysis paralysis**
- Fix – KISS principle (water source → treat → reuse)

ESIA – Environmental Social Impact Assessment BMPs – Best Management Practices TMI – Too Much Information KISS – Keep It Simple Stupid

Water Reuse Future

Water Reuse Train Has Left the Station

- **Voluntary – set your own terms**
- **Involuntary – do what you are told**

Regulations Encouraging Water Reuse

- **Incentives and Penalties**

Compilation of Water Reuse Standards

Regional Water Banks for Trading Water

Beg, Borrow and Steal BMPs from Existing Water Reuse Projects

Corporate Metrics Reporting Water Reuse

BMPs – Best Management Practices

Water Reuse Summary
What Does Water Reuse Do?

140,000 bwpd
Produced Water

44 hectare (108 acre) Treatment
Wetland (polishing treatment step)

890 hectare (2200 acre) Farm
Irrigated with 0.9 m/yr (3 ft/yr) water

Corn - 220,000 bu/yr (5,600 tonne/yr),
Peanuts - 200,000 bu/yr (3,000 tonne/yr),
Sorghum - 180,000 bu/yr (4,600 tonne/yr),
Beef - 1100 cow/yr (280 tonne/yr) or
Chicken – 880,000 chicken/yr (1,600 tonne/yr)

5,600+ tonne Food

5,000 to 10,000 or
more People Fed

Acronym List

ASTU – ACTIVATED SLUDGE TREATMENT UNIT
API – AMERICAN PETROLEUM INSTITUTE
CPI – CORRUGATED PLATE INTERCEPTOR
PPI – PARALELL PLATE INTERCEPTOR
DAF – DISSOVLED AIR FLOTATION
DNF – DISSOLVED NITROGEN FLOTATION
IAF – INDUCED AIR FLOTATION
RBC – ROTATING BIOLOGICAL CONTACTOR
RO – REVERSE OSMOSIS
FO – FORWARD OSMOSIS
NF – NANO-FILTRATION
UF – ULTRA-FILTRATION
ED – ELECTRODIALYSIS
SBR – SEQUENCING BATCH REACTOR
PFD – PROCESS FLOW DIAGRAM
MBR – MEMBRANE REACTOR
GAC – GRANULAR ACTIVATED CARBON
UV – ULTRAVIOLET
O3 – OZONE
FeCl – FERRIC CHLORIDE
H2O2 – HYDROGEN PEROXIDE
WWTP – WASTEWATER TREATMENT PLANT
EC – ELECTRICAL CONDUCTIVITY
TDS – TOTAL DISSOLVED SOLIDS
ESIA – ENVIRONMENTAL SOCIAL IMPACT ASSESSMENT
GHG – GREENHOUSE GASES
OPEX – OPERATIONAL EXPENSE
CAPEX – CAPITAL EXPENSE
USEPA – UNITED STATES ENVIONMENTAL PROTOTECITON AGENCY
SAR – SODIUM ADSORPTION RATIO
WHO – WORLD HEALTH ORGANIZAITON

CO2 – CARBON DIOXIDE
NOx - NIRTOUS OXIDES
SOx – SULFUR OXIDES
PM – PARTICULATE MATTER
BMP – BEST MANAGEMENT PRACTICE
TMI – TOO MUCH INFORMATION
KISS – KEEP IT SIMPLE STUPID
CTW – CONSTRUCTED TREATMENT WETLAND
CRADA – COOPERATIVE RESEACH AND DEVELOPMENT AGREEMENT
IOGCC – INTERSTATE OIL & GAS COMPACT COMMISSION
WHC – WILDLIFE HABITAT COUNCIL
WSO – WATER SOLUBLE ORGANIC COMPOUNDS
PW – PRODUCED WATER
NEBA – NET ENVIRONMENTAL BENEFIT ANAYLYSIS