

**Kennedy/Jenks Consultants**  
Engineers & Scientists

**COLORADO SCHOOL OF MINES**  
EARTH • ENERGY • ENVIRONMENT

**Argonne**  
NATIONAL LABORATORY


## Feasibility and Economic Analysis of Beneficial Use of Produced Water

Pei Xu, Xanthe Mayer, Katharine Dahm, Nathan Hancock, Katherine Guerra, Tzahi Cath, Jörg Drewes  
Colorado School of Mines

Jean Debroux, Dawn Taffler, Jim Graydon  
Kennedy/Jenks Consultants

Bob Raucher, Jim Henderson  
Stratus Consulting

The 17<sup>th</sup> International Petroleum & Biofuels  
Environmental Conference (IPEC), September 1<sup>st</sup>, 2010 - San Antonio,  
TX



## Outline

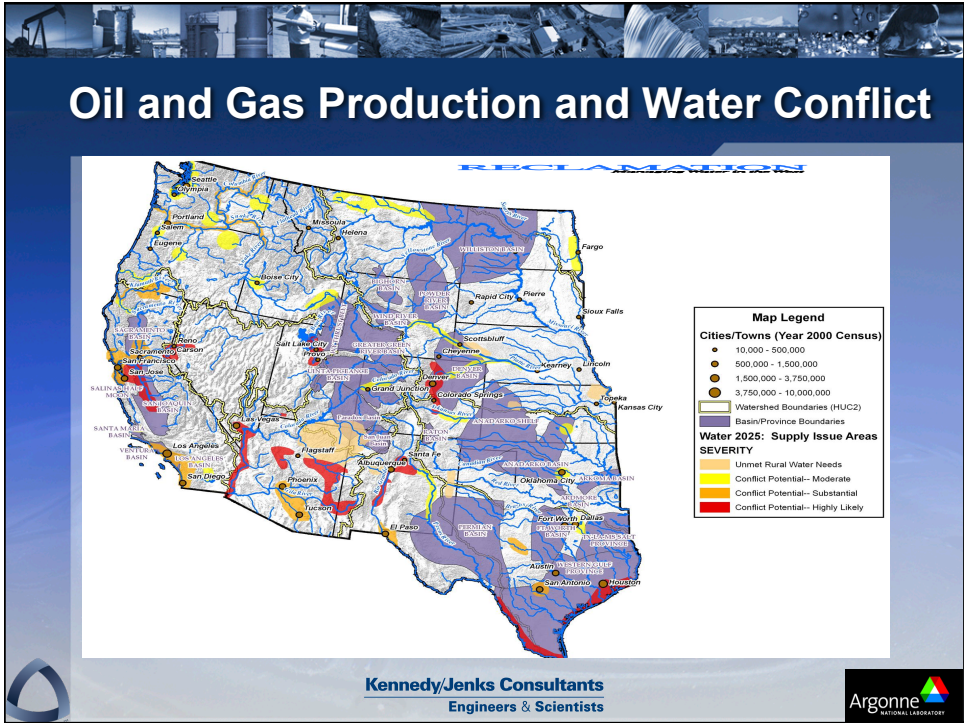
- ▶ Opportunities
- ▶ Beneficial use options
- ▶ Beneficial Use Screening Module
- ▶ Beneficial Use Economic Module
- ▶ Conclusions

**COLORADO SCHOOL OF MINES**  
engineering the way


**Kennedy/Jenks Consultants**  
Engineers & Scientists

**Argonne**  
NATIONAL LABORATORY

2




- 
- Potential Beneficial Uses**
- ▶ **Surface water discharge/instream flow augmentation**
  - ▶ **Aquifer recharge, storage and recovery (Class V well)**
  - ▶ **Agricultural uses**
    - Livestock watering
    - Crop irrigation
  - ▶ **Domestic/municipal**
    - Potable use
    - Non-potable use
  - ▶ **Environmental restoration**
    - Impoundments
    - Fisheries
    - Constructed wetlands
  - ▶ **Industrial uses during oil and gas production**
    - Dust control
    - Hydraulic fracturing
    - Drilling
- COLORADO SCHOOL OF MINES  
engineering the way
- Kennedy/Jenks Consultants  
Engineers & Scientists
- Argonne  
NATIONAL LABORATORY



## Produced Water Management & Beneficial Use

- Regulations and permitting
- Price of gas and disposal costs
- Produced water quality
- Costs of transportation and treatment
- End users
- Liability
- Water rights
- ....



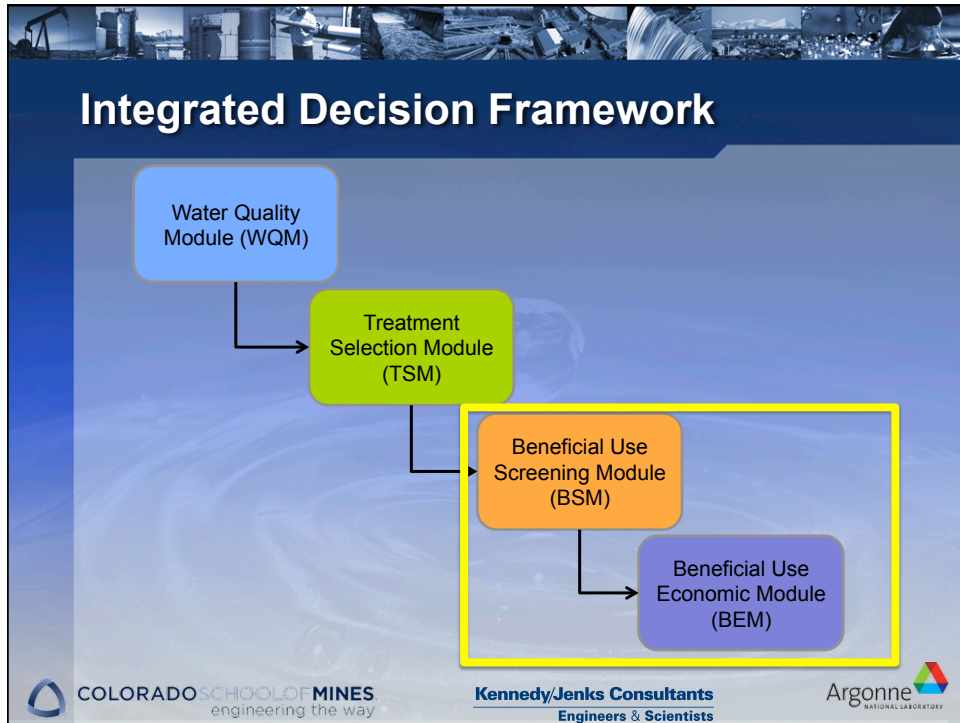
*Constructed Wetland*



## Integrated Decision Framework

- ▶ **Objective:** To provide producers, potential users, or other stakeholders an integrated decision framework to promote treatment, handling, disposal, and beneficial use of produced water.





- 
- The slide is titled "Stakeholder Advisory Committee (SAC) and Industry Advisory Committee (IAC) Input". It lists four key events and topics:
- ▶ **September 2008, SAC and the project team met for Workshop #1**
  - ▶ **August 2009, IAC, SAC and project team met for Workshop #2**
  - ▶ **Opportunities**
  - ▶ **Issues**
  - ▶ **Screening criteria**
- The background of the slide features a blue gradient with a faint image of water ripples.
- COLORADO SCHOOL OF MINES**  
engineering the way
- Kennedy/Jenks Consultants**  
Engineers & Scientists
- Argonne**  
NATIONAL LABORATORY



## Screening Criteria

- ▶ **Water Quality** – treat produced water (if necessary) to meet requirements of beneficial uses
- ▶ **Water Quantity** - volume of water produced over a relevant time interval (e.g., daily, seasonally, annually)
- ▶ **Supply Timing and Reliability** - supply does (or does not) match with the needs of the potential user, in terms of consistency through the year, meeting seasonal demands, and so forth.
  - Influenced by energy prices
- ▶ **Duration of Supply** - how many years the produced water supply is likely to last.



COLORADO SCHOOL OF MINES  
engineering the way

Kennedy/Jenks Consultants  
Engineers & Scientists



## Screening Criteria (con't)


- ▶ **Economics** – Traditional cost/benefit analysis and Triple Bottom Line (TBL) analysis



COLORADO SCHOOL OF MINES  
engineering the way


Kennedy/Jenks Consultants  
Engineers & Scientists






## Screening Criteria (con't)

- ▶ **Institutional factors and associated uncertainty**
  - Legal
  - Regulatory
  - Public perception
  - Business operating conditions
  - Decisions for the suppliers or potential buyers




**COLORADO SCHOOL OF MINES**  
engineering the way

**Kennedy/Jenks Consultants**  
Engineers & Scientists



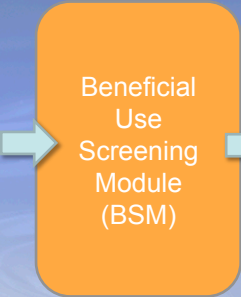
**Argonne**  
NATIONAL LABORATORY



## Beneficial Use Screening Module (BSM)

**Inputs:**


- ▶ Output from first two modules
- ▶ Economic data
- ▶ Current cost of disposal
- ▶ Produced water "Bin" values for screening criteria
- ▶ Beneficial use preference information



Beneficial  
Use  
Screening  
Module  
(BSM)


**Outputs:**

- ▶ Qualitative ranking of potential beneficial uses for a given produced water
- ▶ Value of treated produced water by beneficial use
- ▶ Possible environmental and social benefits



**COLORADO SCHOOL OF MINES**  
engineering the way

**Kennedy/Jenks Consultants**  
Engineers & Scientists



**Argonne**  
NATIONAL LABORATORY



## Bin values

### ▶ Water Quantity

- Bin 1- Base flow < 1,000 gal/day
- Bin 2- 1,000 gal/day < base flow < 10,000 gal/day
- Bin 3- 10,000 gal/day < base flow < 0.1 MGD
- Bin 4- 0.1 MGD < base flow < 1 MGD
- Bin 5- 1 MGD < base flow < 5 MGD
- Bin 6- Base flow > 5 MGD

### ▶ Supply timing and reliability

- Bin 1- Intermittent flow subject to stoppage
- Bin 2- Guaranteed intermittent flow for 5 years
- Bin 3- Guaranteed base flow for 1 year
- Bin 4- Guaranteed base flow for 5 years
- Bin 5- Guaranteed base flow for 30 years

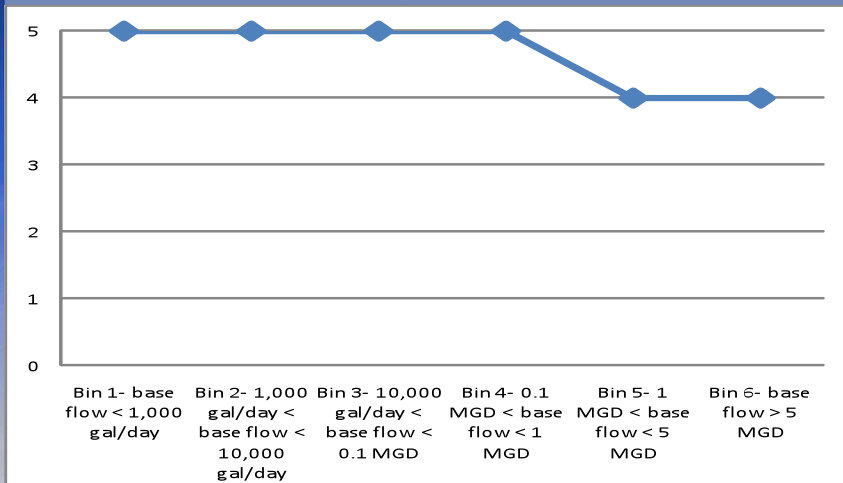
### ▶ Duration of supply

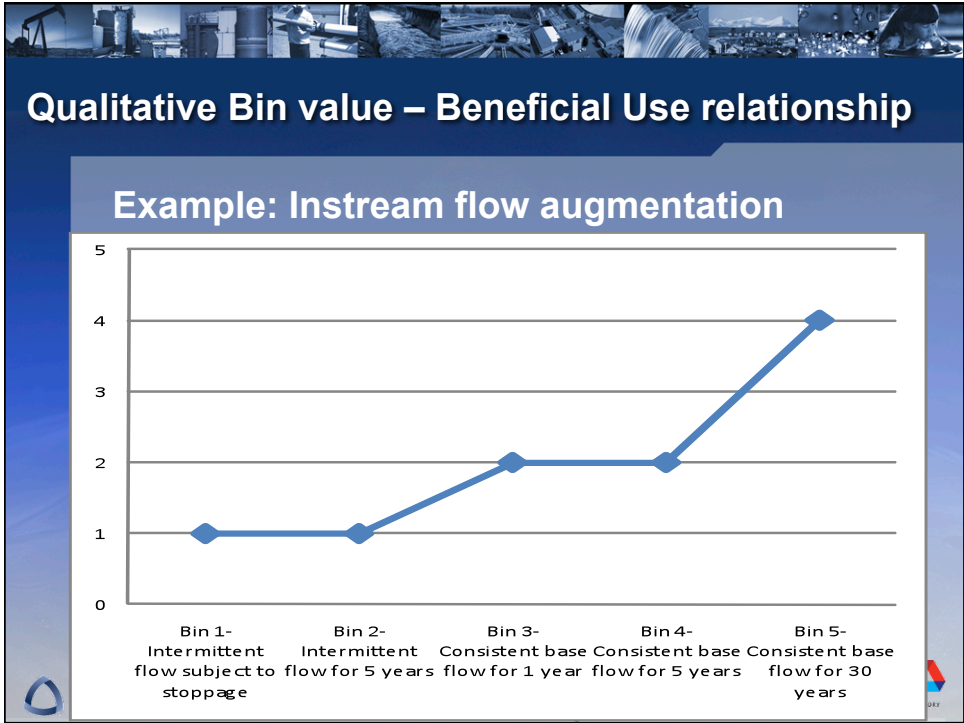
- Bin 1- Guaranteed base flow for less than 5 years
- Bin 2- Guaranteed base flow for at least 5 years
- Bin 3- Guaranteed base flow for at least 30 years



## Qualitative Bin value – Beneficial Use relationship

### Example: Instream flow augmentation





Sponsored by:

Research Partnership to Secure Energy for America

WQM

TSM

BSM

BEM

A Decision Framework to Assess Beneficial Use Opportunities for CBM Produced Water

← Back

**BSM User Inputs** ⓘ

Enter Current cost of disposal (\$/bbl, \$/gal, or \$/AF) \$0.900 \$/bbl choose unit from drop down menu

Enter Current Method of Disposal Deep Well Injection ⓘ

Please select range of below Screening Criteria from pull down lists associated with cells highlighted in yellow. The ranges are organized in Bins for computational uses in the model.

Water Quantity Range Bin 4- 0.1MGD < base flow < 1MGD  
2,400 bbl/day < base flow < 24,000 bbl/day  
110 AFY < base flow < 1,100 AFY ⓘ

Select Supply Timing and Reliability Range Bin 3- Consistent base flow for 1 year ⓘ

Select Duration of Supply Range Bin 1- Base flow less than 5 years ⓘ

**Add note regarding storage**

**BSM Screening Criteria** ⓘ

Please select relative importance of the screening criteria from the pull down lists below. If the User is uncertain as to the importance of the screening criteria in regards to the potential beneficial uses, leave all values at 5.

Importance of Screening Criteria (5 is extremely important; 1 is not important)

Water quantity	5
Supply timing and reliability	5
Duration of supply	5



# Outputs

## ► Qualitative weighted assessment of screening criteria

Project Feasibility Color Legend

Most Feasible (5) ..... (4) ..... (3) ..... (2) ..... Least Feasible (1)

Project Feasibility- Screening Criteria and Select Economic Information

Screening Criteria	Weighting / Importance <i>High (5) to Low (1)</i>	Bin Chosen	Beneficial Use Category 5		Beneficial Use Category 4		Beneficial Use Category 3	Beneficial Use Category 2	
			Potable use	Aquifer Recharge, Storage and	Surface Water Discharge/ Instream	Fisheries	Constructed Wetlands	Crop Irrigation	Non-Potable use
Water Quantity	5	Bin 4- 0.1 MGD < base flow < 1 MGD	3	5	5	5	5	5	5
Supply timing and reliability	5	Bin 3- Consistent base flow for 1 year	1	3	2	2	3	3	2
Duration of supply	5	Bin 1- Base flow less than 5 years	1	4	2	2	2	3	2
<b>Screening Criteria Summary</b>	<b>15</b>	Feasibility or Relative Complexity of Use	1.7	4.0	3.0	3.0	3.3	3.7	3.0

Example for illustrative purposes only

# Beneficial Use Economic Module (BEM)

## Inputs:

- Select BU
- Project life
- Long-term interest rate
- Project details (conveyance, terrain, location, energy type, storage, other infrastructure.)
- Current disposal details
- User unit costs (if available)

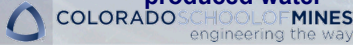
Beneficial Use Economic Module (BEM)

## Outputs:

- Engineer's planning level estimate of probable costs for selected BU
- Summary of range of potential costs and values for selected BU
- Comparison of multiple BU project scenarios or variation of one BU project

# Beneficial Use Economic Module Cost Template

- ▶ **Capital Costs**
  - ▶ Annualized Costs
  - ▶ Class 5 Level (planning-feasibility)
  - ▶ -30% to + 50%
  - ▶ Total and Annualized \$/unit produced water
- ▶ **O&M Costs**
  - ▶ Energy
  - ▶ Treatment
  - ▶ Labor
  - ▶ Land
  - ▶ Annualized \$/unit produced water



Approved by: **RPSEA** (Rocky Mountain Production Enhancement Agency) | A Decision Framework to Assess Beneficial Use Opportunities for CBM Produced Water | **COLORADO SCHOOL OF MINES** | **Kennedy/Jenks Consultants** | **STRATUS CONSULTING** | **Argonne**

**BENEFICIAL USE ECONOMIC MODULE**

**MINIEMRY PLANNING LEVEL ESTIMATE OF PROBABILE COST**

Project: **Class 5 Planning Feasibility Study** | Date Prepared: **05/01/2008**  
 Location: **CO, Basin, Permian** | 100 Units per Well: **100,000 bbl/d**  
 Description: **Class 5 Planning Feasibility Study** | Annual Unit Volume: **1,000,000 gal** | Estimated: **\$ 1.5**  
 Treatment: **Class 5 Planning Feasibility Study** | Peak Flow: **1.0 gpm** | Estimated: **\$ 1.5**  
 Revenue Type: **Class 5 Planning Feasibility Study** | Interest Rate: **10%** | Estimated: **\$ 1.5**

Item No.	Description	Units	Qty	Units	\$/Unit	Total Capital Cost	Annualized Capital Cost	Remarks
<b>Activity Capital Costs</b>								
1.0	Permitting Fees	1	1		1,000,000	1,000,000	100,000	Permitting Fees for Class 5 Planning Feasibility Study
1.1	Engineering	1	1		1,000,000	1,000,000	100,000	Engineering Fees for Class 5 Planning Feasibility Study
1.2	Construction	1	1		1,000,000	1,000,000	100,000	Construction Fees for Class 5 Planning Feasibility Study
1.3	Electricity	1	1		1,000,000	1,000,000	100,000	Electricity Fees for Class 5 Planning Feasibility Study
1.4	Material Handling	1	1		1,000,000	1,000,000	100,000	Material Handling Fees for Class 5 Planning Feasibility Study
1.5	Production	1	1		1,000,000	1,000,000	100,000	Production Fees for Class 5 Planning Feasibility Study
1.6	Operations	1	1		1,000,000	1,000,000	100,000	Operations Fees for Class 5 Planning Feasibility Study
1.7	Storage Facility	1	1		1,000,000	1,000,000	100,000	Storage Facility Fees for Class 5 Planning Feasibility Study
1.8	Transportation	1	1		1,000,000	1,000,000	100,000	Transportation Fees for Class 5 Planning Feasibility Study
1.9	Buildings	1	1		1,000,000	1,000,000	100,000	Buildings Fees for Class 5 Planning Feasibility Study
1.10	New Surface Use Infrastructure	1	1		1,000,000	1,000,000	100,000	New Surface Use Infrastructure Fees for Class 5 Planning Feasibility Study
1.11	Production Facility	1	1		1,000,000	1,000,000	100,000	Production Facility Fees for Class 5 Planning Feasibility Study
<b>Additional Facility Costs</b>								
2.0	Site Development	1	1		1,000,000	1,000,000	100,000	Site Development Fees for Class 5 Planning Feasibility Study
2.1	Well Pads	1	1		1,000,000	1,000,000	100,000	Well Pads Fees for Class 5 Planning Feasibility Study
2.2	Production Pads	1	1		1,000,000	1,000,000	100,000	Production Pads Fees for Class 5 Planning Feasibility Study
<b>Subtotal Additional Facility Costs</b>								
						<b>\$1,000,000</b>	<b>\$100,000</b>	
<b>Activity O&amp;M Costs</b>								
3.0	Energy	1	1		1,000,000	1,000,000	100,000	Energy O&M Costs for Class 5 Planning Feasibility Study
3.1	Water	1	1		1,000,000	1,000,000	100,000	Water O&M Costs for Class 5 Planning Feasibility Study
3.2	Electricity	1	1		1,000,000	1,000,000	100,000	Electricity O&M Costs for Class 5 Planning Feasibility Study
3.3	Material Handling	1	1		1,000,000	1,000,000	100,000	Material Handling O&M Costs for Class 5 Planning Feasibility Study
3.4	Production	1	1		1,000,000	1,000,000	100,000	Production O&M Costs for Class 5 Planning Feasibility Study
3.5	Operations	1	1		1,000,000	1,000,000	100,000	Operations O&M Costs for Class 5 Planning Feasibility Study
3.6	Storage Facility	1	1		1,000,000	1,000,000	100,000	Storage Facility O&M Costs for Class 5 Planning Feasibility Study
3.7	Transportation	1	1		1,000,000	1,000,000	100,000	Transportation O&M Costs for Class 5 Planning Feasibility Study
3.8	Buildings	1	1		1,000,000	1,000,000	100,000	Buildings O&M Costs for Class 5 Planning Feasibility Study
3.9	New Surface Use Infrastructure	1	1		1,000,000	1,000,000	100,000	New Surface Use Infrastructure O&M Costs for Class 5 Planning Feasibility Study
3.10	Production Facility	1	1		1,000,000	1,000,000	100,000	Production Facility O&M Costs for Class 5 Planning Feasibility Study
<b>Subtotal Activity O&amp;M Costs</b>								
						<b>\$1,000,000</b>	<b>\$100,000</b>	
<b>Project Capital Cost Total</b>						<b>\$1,000,000</b>	<b>\$100,000</b>	
<b>Annualized Project Cost</b>						<b>\$1,000,000</b>	<b>\$100,000</b>	
<b>Annualized O&amp;M Costs</b>						<b>\$1,000,000</b>	<b>\$100,000</b>	
<b>Annualized Total Costs</b>						<b>\$2,000,000</b>	<b>\$200,000</b>	

# Beneficial Use Economic Module Summary

- ▶ **Summary of range costs and values**
  - Annualized project cost (cost template)
  - Current cost of disposal (user input)
  - Estimated value of BU (varies by location)
  - Estimated social / environmental value (qualitative or quantitative)

**RANGE = -30% to +50% Annualized based on Project Life and interest rate**

	Est Total \$/mil/year	Estimated Range of Project Annual Cost		
		Min \$/bbl	Ave \$/bbl	Max \$/bbl
Annualized Capital Costs	\$4.0	\$0.36	\$0.52	\$0.77
Annual O&M Costs	\$1.5	\$0.14	\$0.19	\$0.29
<b>Total Annualized Costs</b>	<b>\$5.5</b>	<b>\$0.50</b>	<b>\$0.71</b>	<b>\$1.07</b>
Current Cost of Disposal	\$3.0	\$0.38	\$0.38	\$0.38
Estimated Value for BU	\$1.8 - \$7.3	\$0.23	\$0.59	\$0.94
Estimated Social/Env Value	\$0.02 - \$0.04	\$0.002 - \$0	\$0.002 - \$0	\$0.002 - \$0





## Conclusions

- ▶ **Beneficial Use Screening Module** allows users to compare the feasibility, treatment complexity and capital cost, and triple bottom line (TBL) information to screen which beneficial uses may provide better opportunities than others
- ▶ **Beneficial Use Economic Module** allows users to develop a Class 5 Conceptual Engineering Estimate of Probable Costs to determine if a project is potentially economically viable.