Sinking Groundwater Cost of Energy in Saudi Arabia

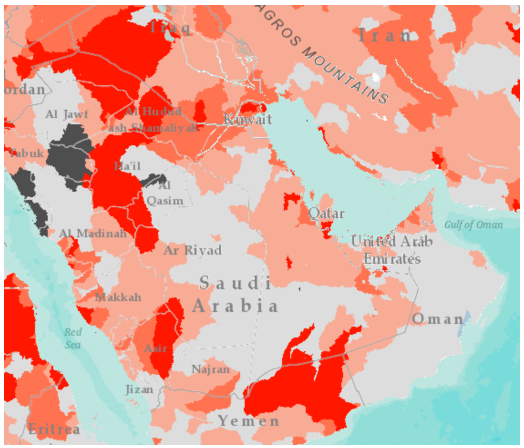
Groundwater Withdrawals & Alternatives for
Conventional, Unconventional, Power & Households

13/Feb/2020 | Water Arabia

Ridha H. Abbas

where energy is opportunity™

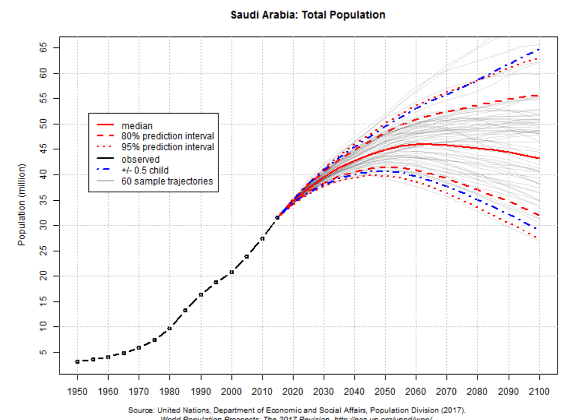
Water scarcity at the Kingdom of Saudi Arabia is projected to increase, entailing further groundwater extraction.



World Resources Institute

National Geographic

KSA population to grow 18% by 2030



U.N.

Water stress will increase across KSA by 2030.

Water stress across Saudi will increase by x(1.4 – 2.8) by 2030.

Water stress: ratio of total water withdrawals relative to available renewable water.

Groundwater (GW) is depleting at a high rate.

The estimated total of currently exploitable groundwater resources amount to 1,180 billion m^3. It would last 60 years at current rates, but 35 years at compounded annual growth rate of consumption.

Increasing population will drive further extraction.

KSA has world's 3rd highest per capita consumption of water at 265 L/day.

KSA population is projected to grow by 18% by 2030. This will drive further extractions.

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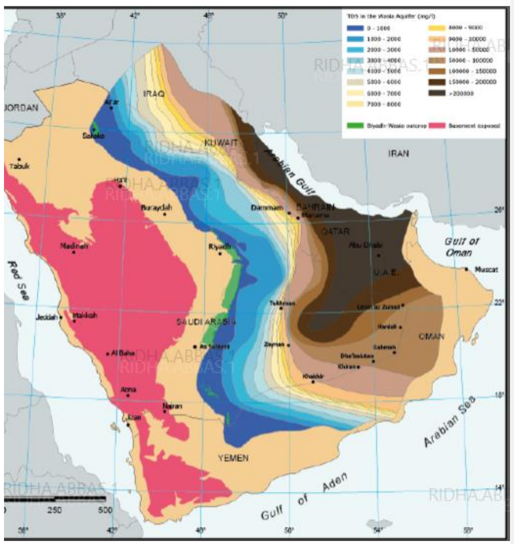
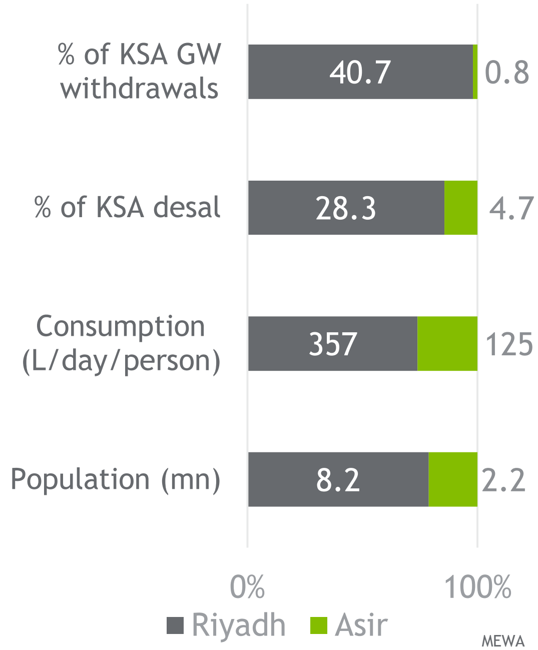
Insights on sinking groundwater consumption (and cost) for energy in this case study is subject to several limitations.

GW salinity can reach 50,000 mg/l, higher than close by seawater.

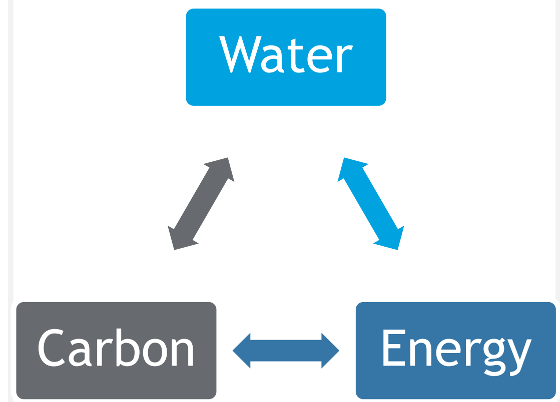


Kellter, 2017

Individual consumption is higher at arid Riyadh than water-rich Asir



MEWA



Consider water *quality* and renewability, not only *quantity*.

Analyze with higher spatial resolution due to water's local impact

Account for full Water-Energy-Carbon equation.

Insights can still provide value on groundwater use data, policy proposals and socio-economic considerations.

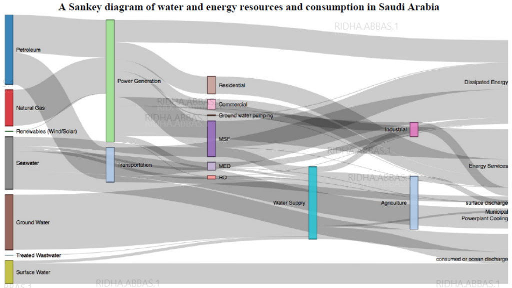
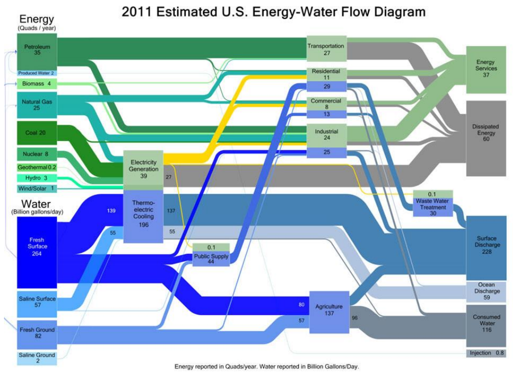


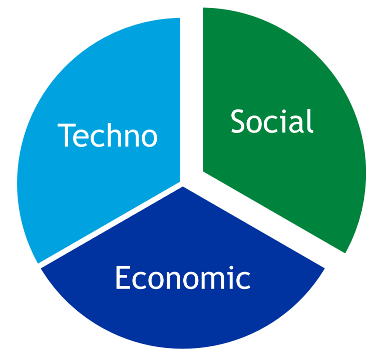
Figure 3: A Sankey diagram of water and energy resources, production, and consumption in Saudi Arabia. Created by combining multiple data sources for water and energy use and production, and making calculations with available data on system efficiencies[16][17] [18][19][20].

Rambo, 2017



Add accuracy to KSA's Energy-Water database (e.g., flow/Sankey diagram).

Propose policy on GW conservation aligned with Vision 2030.



Emphasize value/cost of water by social choice economics.

Social Choice Economics
What’s the true value of groundwater?

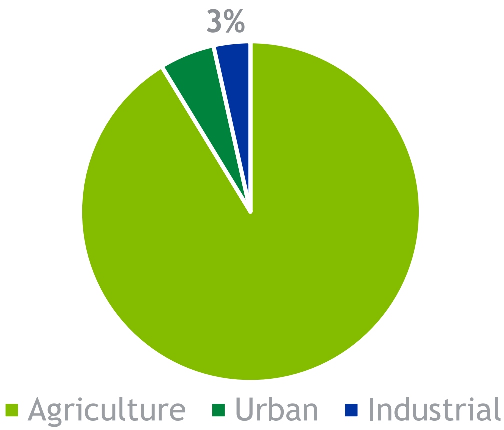
“Responsible management of water resources should recognize that water has an intrinsic local value and that each local stakeholder will value water differently.”

~ IPIECA

The global oil & gas industry association for environmental & social issues.

The water-energy landscape in KSA is unique, prominently featuring enhanced oil recovery (EOR) and desalination.

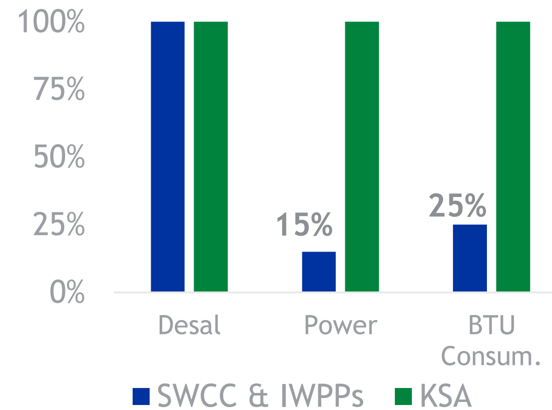
% Groundwater Withdrawal



MEWA

Qurayyah Sea Water Plant (QSWP)

Desal consumes up to 25% energy



ECRA.

Energy uses little GW but conservation is impactful

The entire industrial sector contributes just 3% of KSA's total GW consumption (2016). Further GW conservation for energy will have high impact, especially at the local level.

Aramco leads major GW avoidance for EOR.

Seawater treatment capacity of 14 million barrels per day, an annual GW avoidance equivalent to all annual industrial GW consumption at KSA.

Water provision by desal. high consumer of energy

Desalination by Saline Water Conversion Corporation (SWCC) and Integrated Water & Power Plants (IWPPs) accounts for 15% of KSA's power generation capacity and 25% of consumed energy, measured in BTU.

A simplified view of the water-energy nexus in KSA.

Produced Water Trt

Power Generation

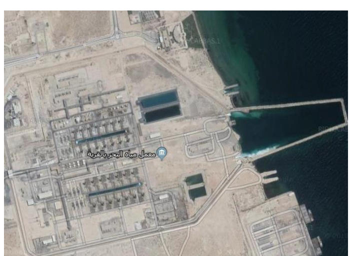
Wastewater Treat.

Seawater Desal.

Urban Use

Unconventional

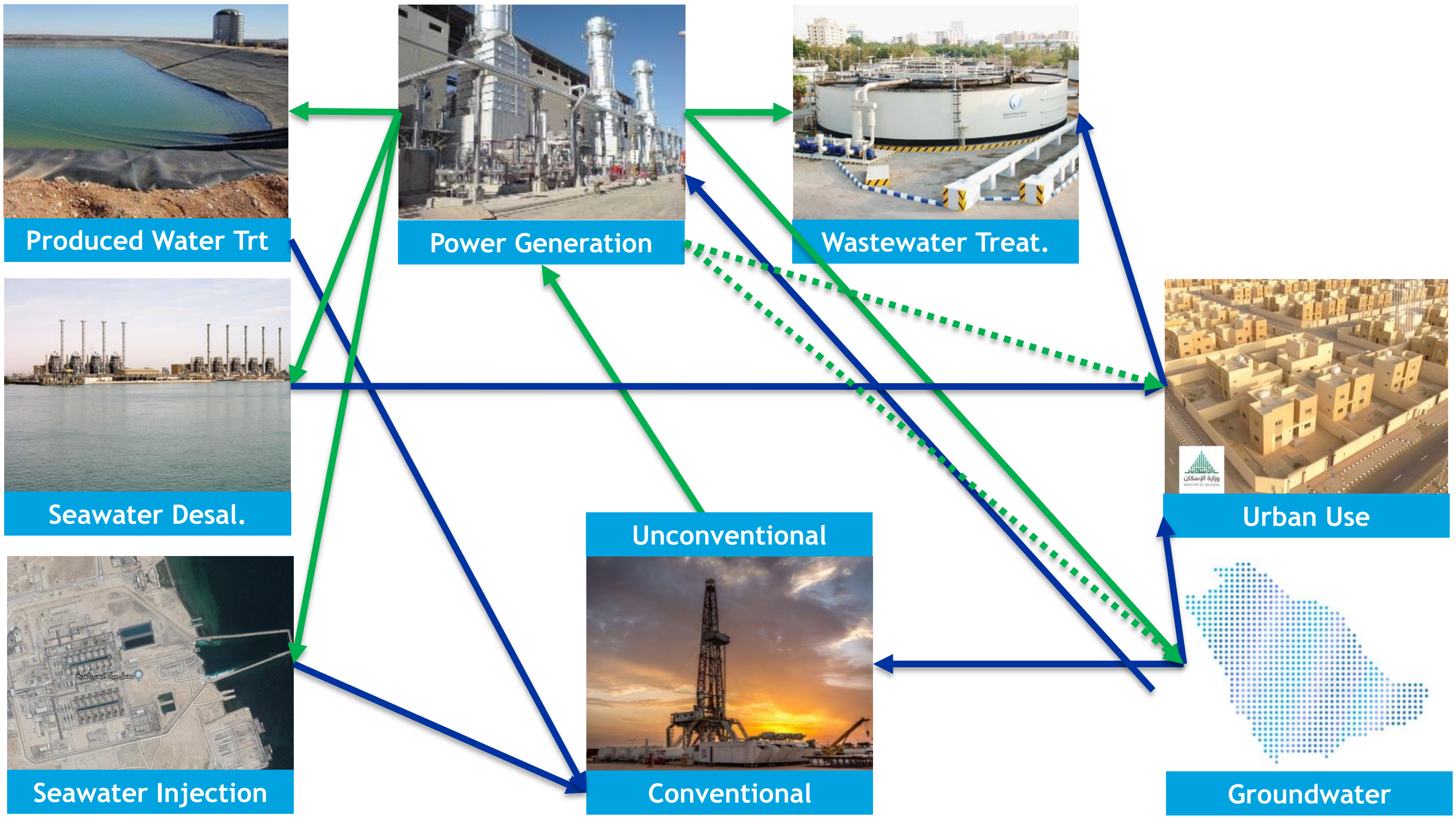
Conventional



Seawater Injection

Groundwater

Major players in KSA's water-energy landscape are interdependent and have potential synergies.



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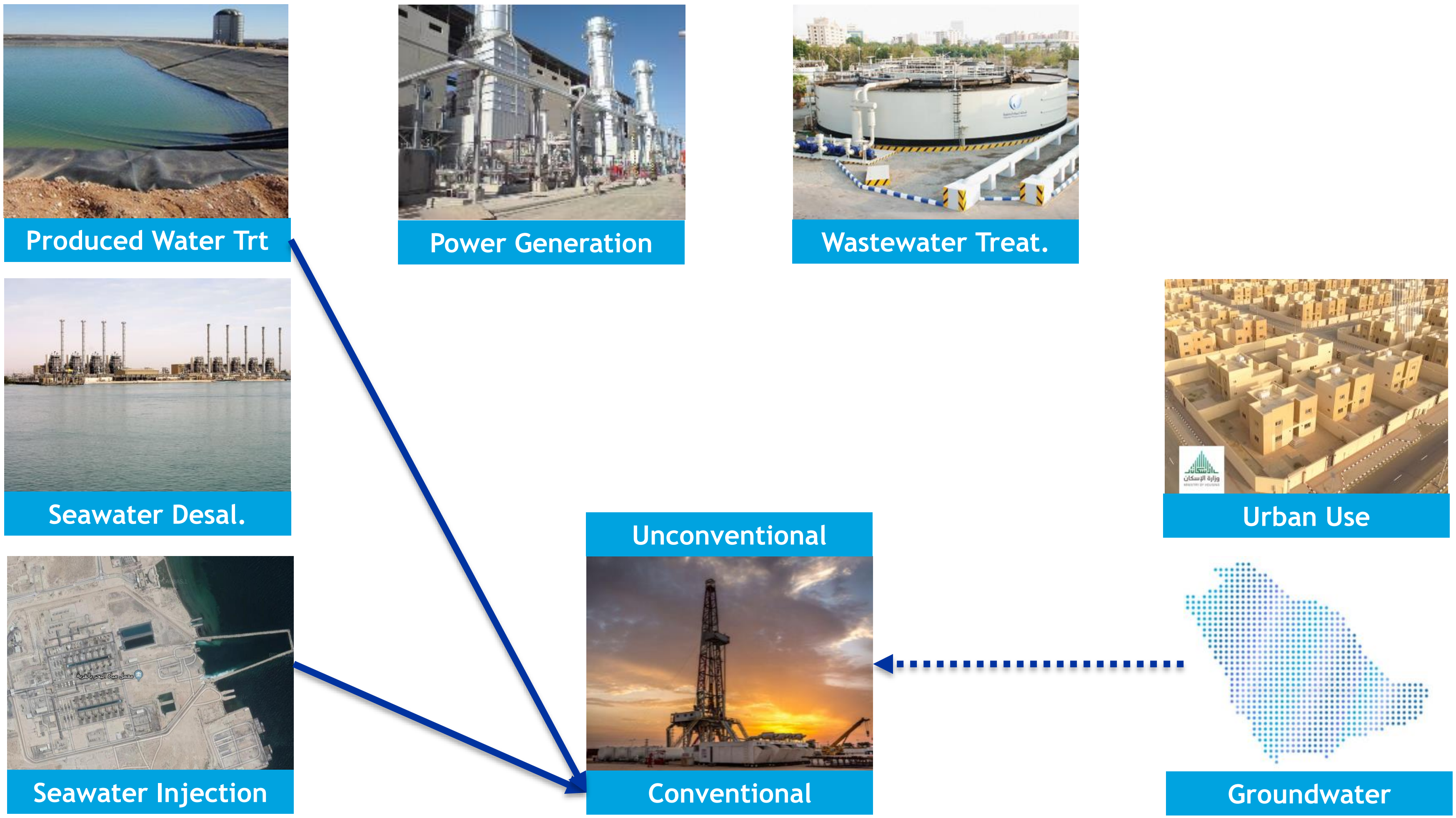
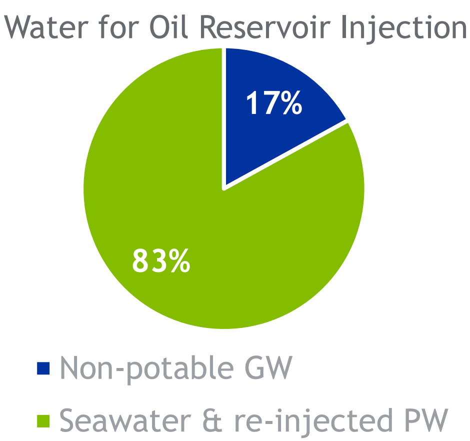
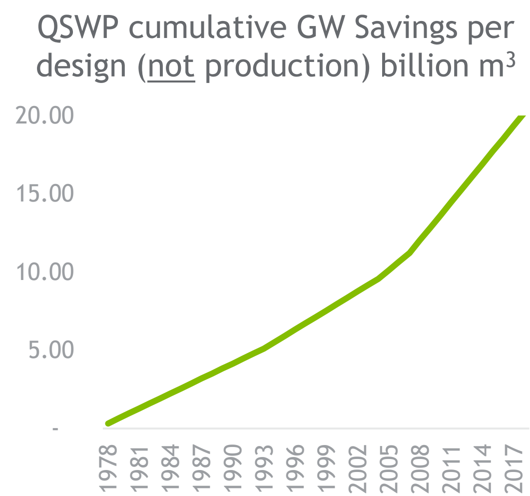
How may we reduce groundwater consumption for Conventional Resources?



Alternatives to groundwater for conventional wells rely mostly on existing and planned expansion of seawater use …



EnviroNews



- Nano Filters for sulfate removal facilities.
- R.O. for utility water
- Pioneer biocides compatible with R.O. membranes

Alternatives to GW are main source for EOR.

Zero potable groundwater is used for enhanced oil recovery (EOR).

Seawater and re-injected produced water carry the main burden.

Use of both is being increased.

Aramco's QSWP achieved major GW avoidance.

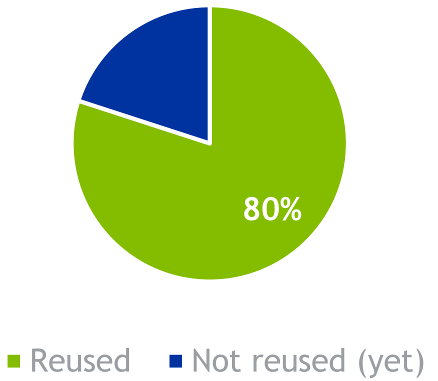
QSWP cumulative design capacity, amounts to approx. 15% of Wasia aquifer, and over 12 times the total actual production of all KSA's desalination plants during 2017, thereby avoiding energy for desal.

Further use of seawater to avoid GW is underway.

Unprecedented biocide formulations to be compatible with Reverse Osmosis and Nano Filter membranes while also protecting extensive seawater injection pipeline network.

… and further produced water treatment and reuse, and transitioning from groundwater in processing facilities.

80% of Produced Water is Reused



Aramco, 2016

Inland refinery does not use GW

Incompatibility of seawater with reservoir

GW with challenging quality, limited socio-economic value

Social choice economics may influence future decisions.

Further treatment of produced water for reuse

Exploring technologies for produced water not yet treated for reuse due to challenging characteristics (e.g., TDS up to 200,000 mg/l).

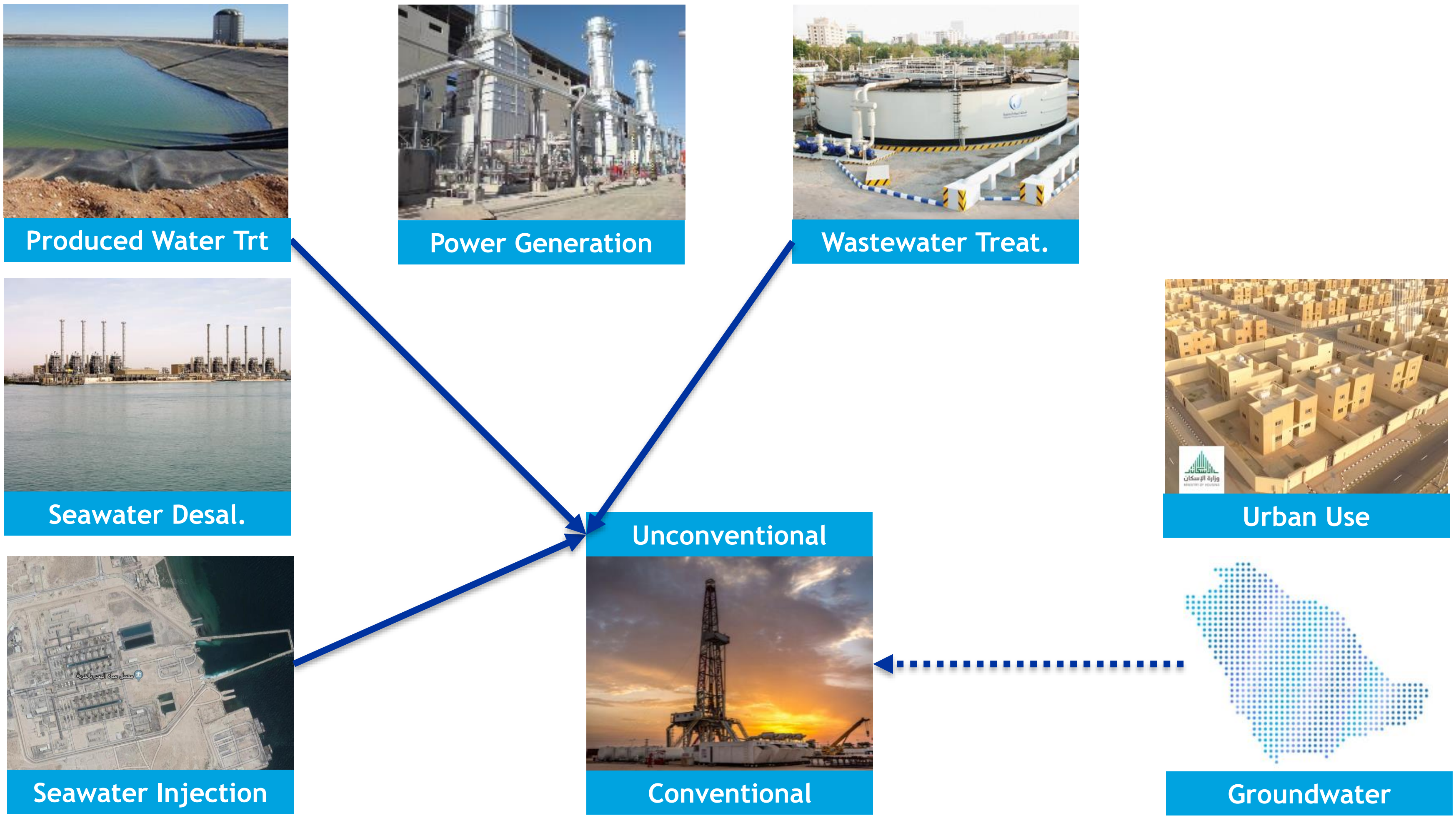
Zero groundwater used for refining.

The only inland refinery at Riyadh achieved zero GW consumption by transitioning to 100% industrial wastewater reuse supplemented by TSE. This represents 4.45 MCM/year groundwater avoidance.

Modeling economic value of water in projects.

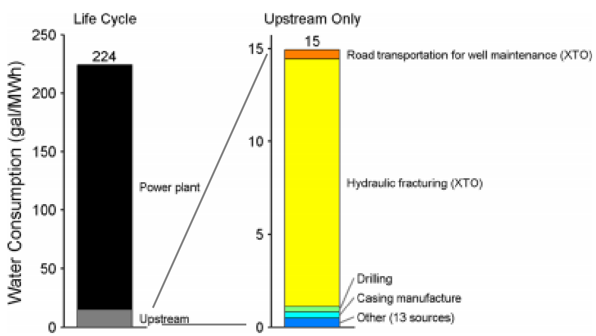
Aramco's guidelines for mega-projects assign an economic value of GW equivalent to the cost of desalinated seawater transported to the point of groundwater withdrawal. Economic value may be further refined.

How may we reduce groundwater consumption for Unconventional Resources?



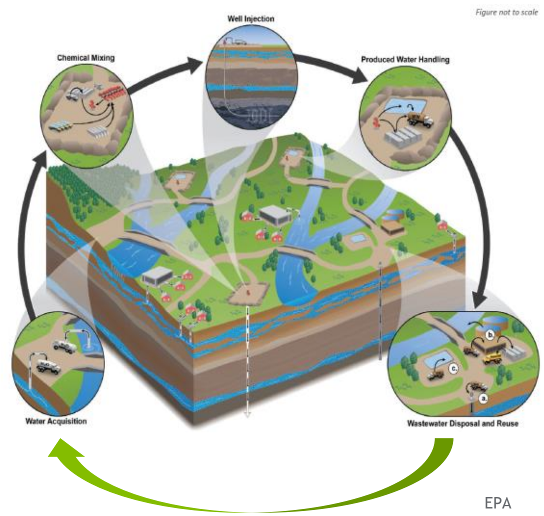
Alternatives to groundwater and treatment requirements have been researched, and Seawater R.O. will be used.

13.7 gal water for fracking/MWh



I.Laurenzi et. al.

Closing the fracking water cycle



EPA

Frack water sourced from upcoming desal. Plant.

Hydraulic fracturing is the main Upstream consumer of water for unconventional wells, though power plants consume far more. At Aramco, the CEO announced the Jafurah desalination plant will supply frack water.

Potential produced water reuse in subsequent frack

Hydraulic fracturing cycle has five stages: water acquisition, chemical mixing, well injection, flowback and produced water, wastewater treatment and disposal. Cycle closed by reusing wastewater for acquisition.

TSE is potential but unnecessary alternative.

Pioneer Natural Resources has sourced treated sanitary effluent from the city of Odessa, TX, and won an award (Pioneer). However, TSE requires more treatment, especially disinfection, compared to seawater.

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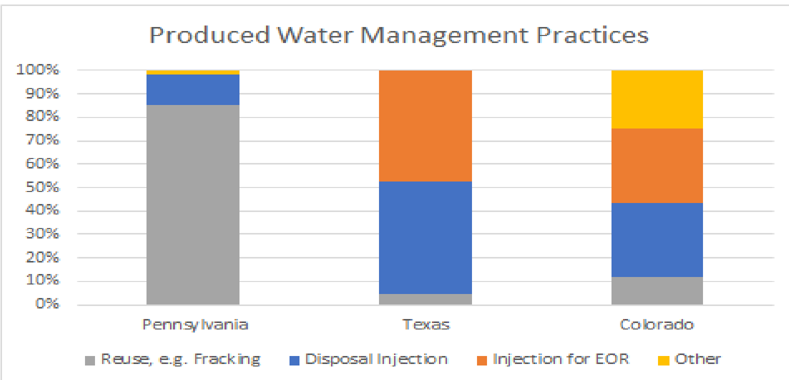
Decision to treat produced water from fracking for reuse is influenced by economic and operational factors.

% of reuse varies by state



Three PW Management options considered

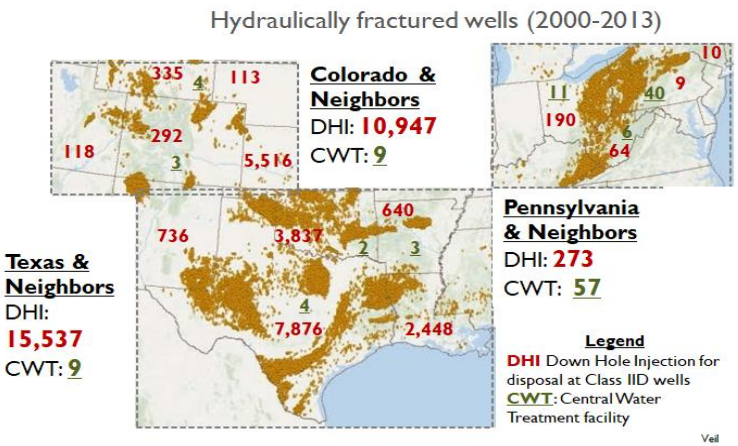
- Downhole injection for disposal.
- Onsite treatment.
- Central Water Treatment facilities.

Option depends on cost

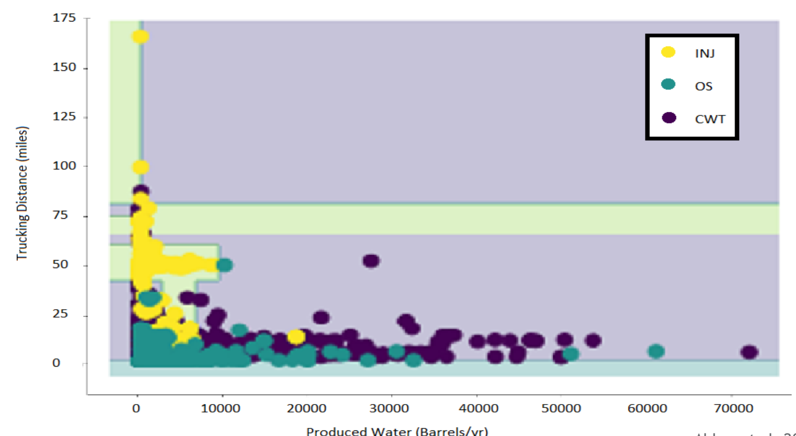
- Cost of trucking depends on distance and PW quantity.
- Comparative cost of onsite treatment and CWTs.

Policy can drive treatment and reuse

% of reuse affected by # of disposal wells



PW management options modeled



Abbas et al, 2018a

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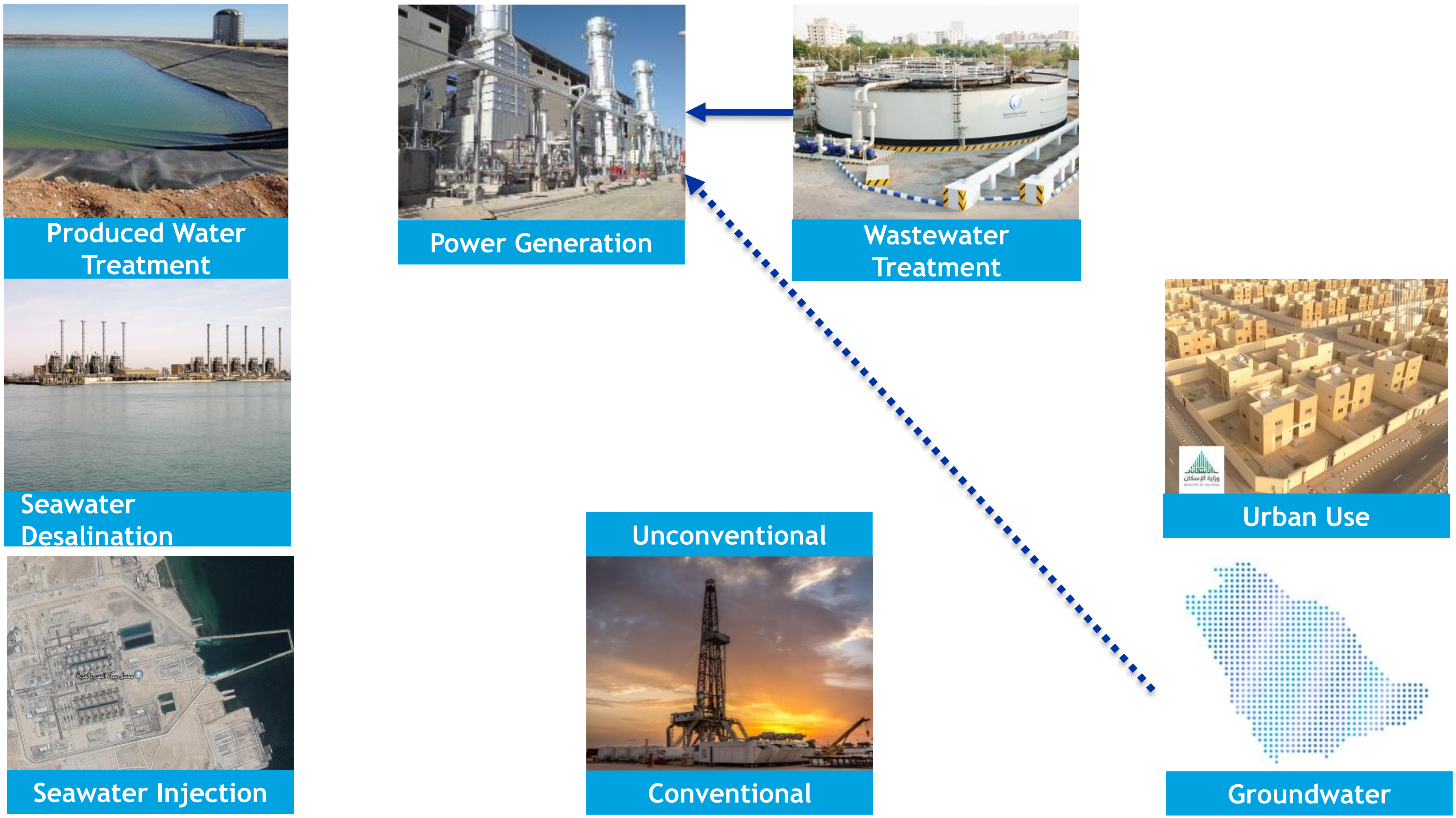
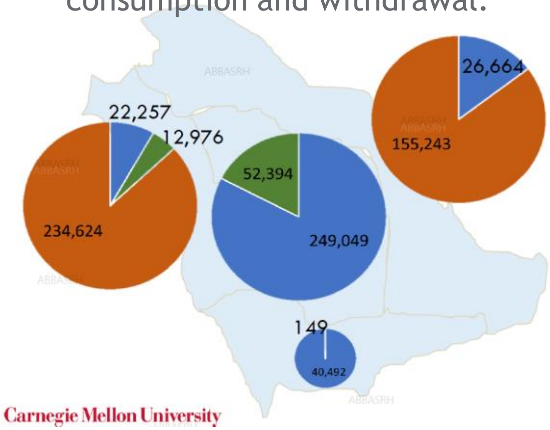
How may we reduce groundwater consumption for power generation?



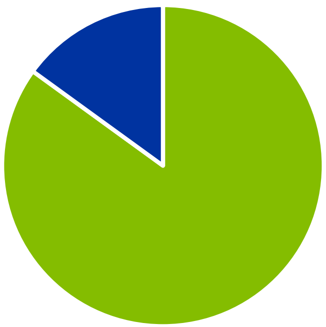
KSA's power plants, burning oil and gas, require water for thermo-electric cooling. GW is used at inland power plants.

Model calculated water consumption and withdrawal.



Abbas et al, 2017

GW for thermo-electric cooling ~15% of desal → 1 BOE/yr



Abbas et al, 2017

1. Transition to TSE for cooling at inland power plants

2. Site new power plants, including alternative energy, to use less GW

3. Retrofit and design power plants with optimal water cooling, considering energy penalty.

GW is used for cooling at inland power plants.

Water withdrawal and consumption was calculated by region and by source water, including seawater, groundwater and TSE. GW represented 24% of total consumption.

Quantity = 15% of KSA desalination capacity.

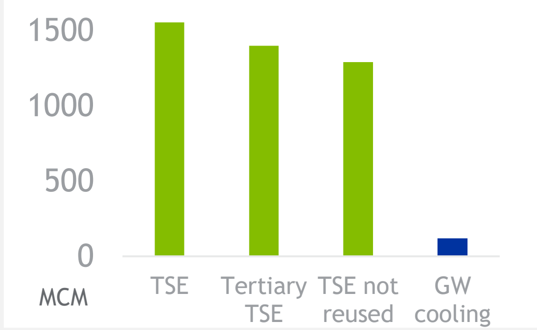
GW consumption compares to 15% of total withdrawals from groundwater for industrial purposes. If KSA were to make up for it by desalination, it would consume just under 1 million Barrels of Oil Equivalent annually.

Several alternatives may reduce GW for cooling.

Three potential alternatives described in following slides.

1- TSE is used for thermo-electric cooling on limited scale, and can be expanded on national and regional levels.

~30,000 m³/day TSE supplied for cooling



TSE sufficient on national level

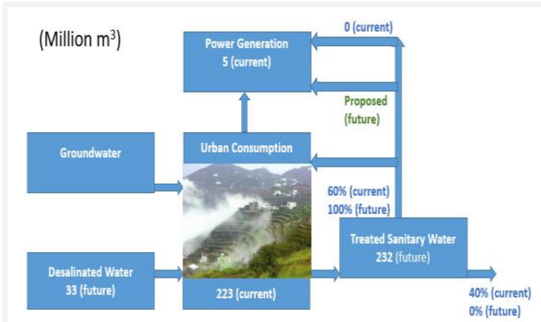
Central Region

Southwest Region

Western Region

TSE sufficiency calculated regionally

Water Balance – Central

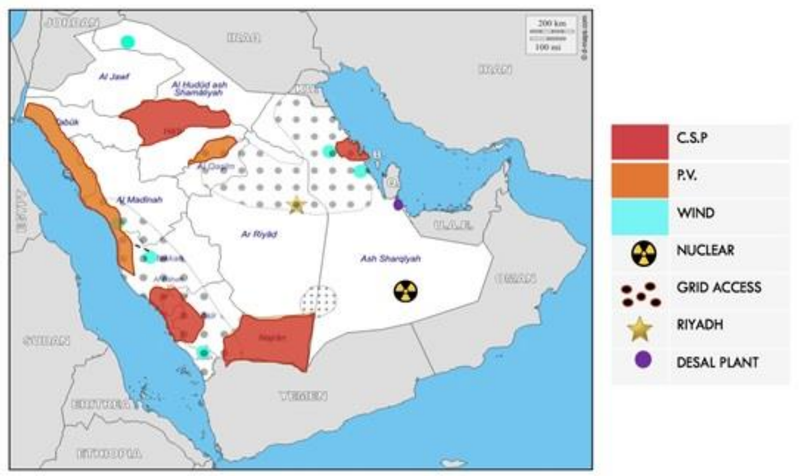


Water Balance – Southwest

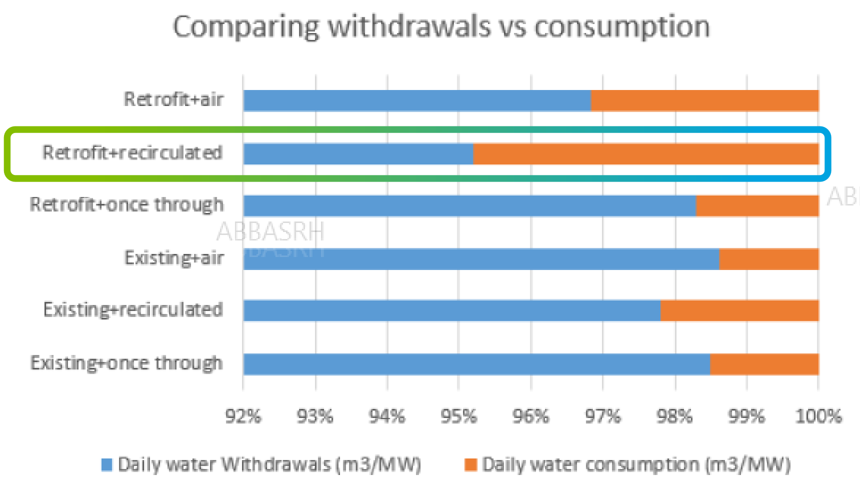
Water Balance - West

Abbas et al. 2017

2- Consider water consumption in siting new power plants.
3- Design and retrofit w/less water-intensive cooling systems.



Abbas et al, 2017



Abbas et al, 2017.

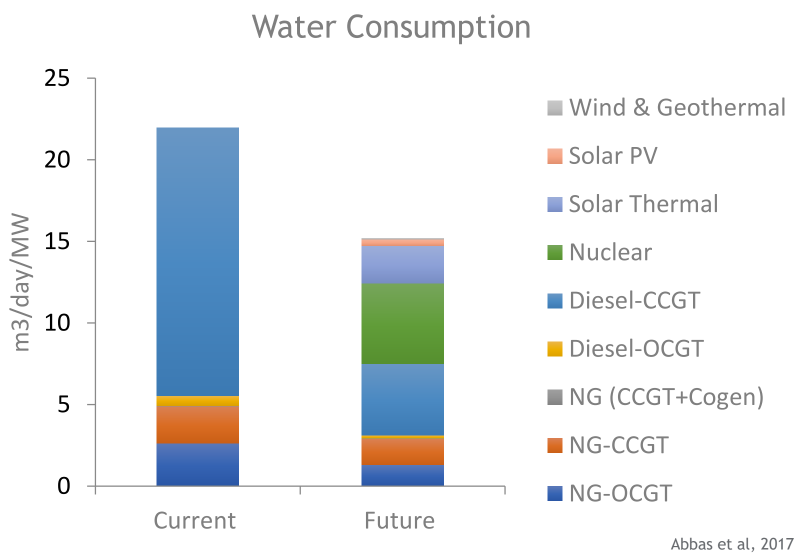
Site new power plants to avoid exacerbating local GW consumption

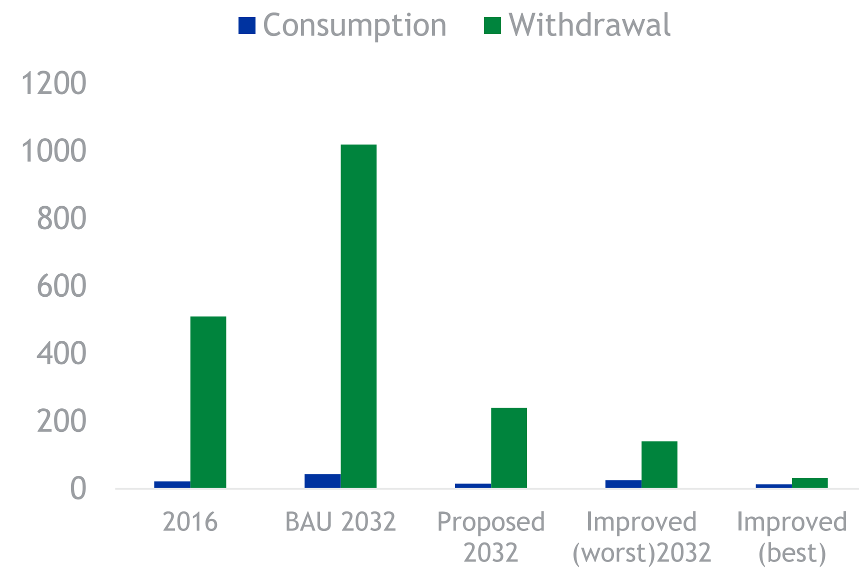
For example, siting CSP, which has a higher demand for water than PV, can be located in the Southwest of the Kingdom, where renewable groundwater and dams are more available. This siting exercise would also meet generation location diversification to help integrate renewable energy to the grid.

Design new and retrofit old PPs with less water intensive cooling systems

- 50% of open-cycle natural gas power plants would be retrofitted to recirculating-cooling systems and design new gas power plants with the same system.
- Air cooling would entail energy penalty of 3.3-5 GW.
- Cost is also a consideration.

KSA's 2032 energy mix for power generation reduces water consumption per MW, recommendations will reduce even more.





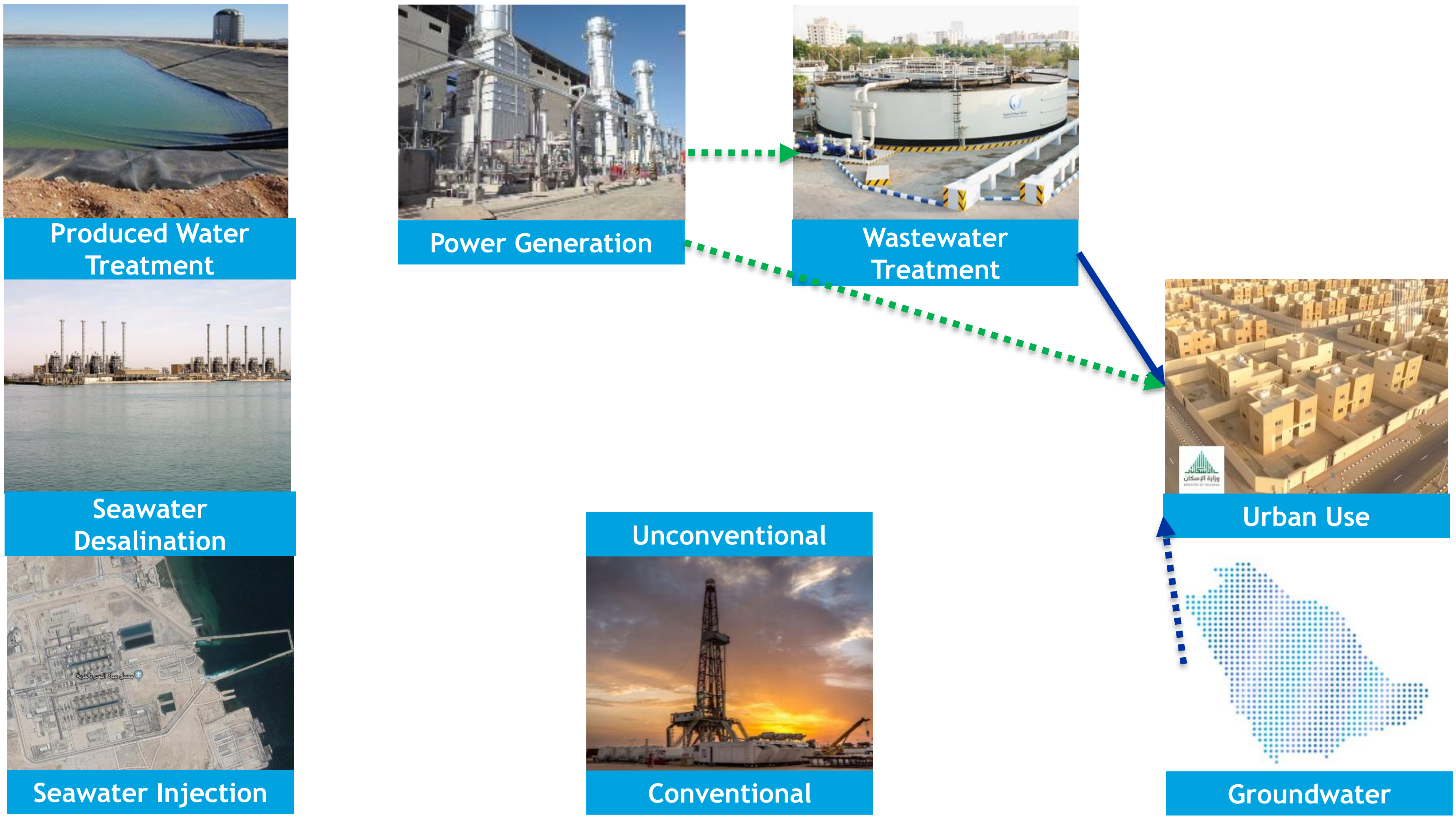
KSA's proposed 2032 energy mix improves water consumption

Incorporating alternative energy sources to the energy mix for power generation, and transitioning from oil power plants, improves water consumption from 22 to 15 m^3/day/MW.

Proposed changes to cooling further improves withdrawal and consumption

Transitioning from groundwater to TSE and incorporating less water-intensive cooling systems further improves both withdrawals and consumption. The higher priority is to reduce withdrawals, since it is not returned to the watershed. Withdrawals will reduce from 1020 m^3/day/MW in Business As Usual to 32-140 m^3/day/MW.

How may we reduce groundwater consumption for **Urban Use**? What is the impact on power consumption?



How can world’s 3rd largest water per capita consumption be reduced at a household level? How much reduction?

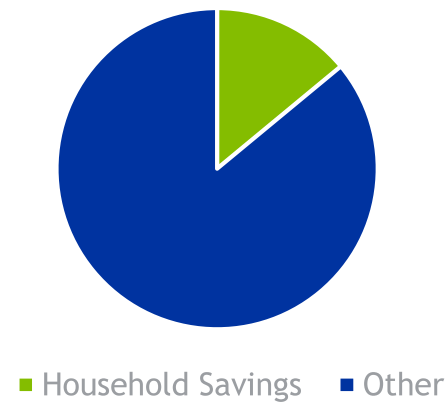
Water Efficient Devices

https://images.app.goo.gl/LKHMoqtdZ2dsEWb77

EPIPHANY WATER SOLUTIONS

Epiphany

Household GW savings reach 14% of total domestic consumption.



Abbas et al, 2018b.

Phase I: install and retrofit efficient devices

Each Saudi household would reduce water consumption up to 40% by retrofitting with water-efficient devices, e.g., toilets, washing machines, faucets, and shower heads.

Phase II: greywater treatment and reuse

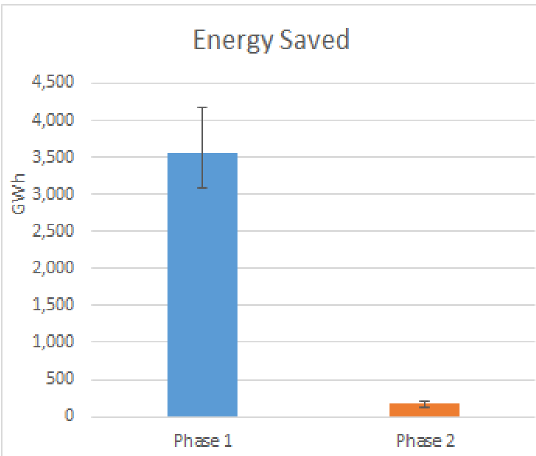
Fit new residence with greywater reuse, obtained from showers, baths, sinks and washing machines. Assume solar thermal distillation, inspired by Epiphany device. Assume no energy from the grid.

14% reduction domestic GW consumption

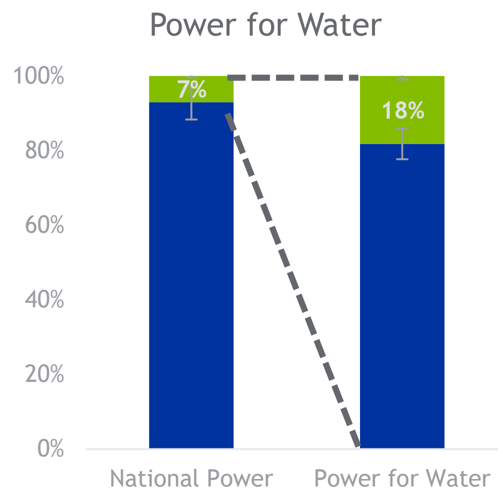
On a household level, 45-72% reductions of present consumption.

On a national level, 420 MCM of water would be saved by rolling-out Phase-I, and another 20 MCM by Phase-II.

Reduction in household water consumption saves groundwater and energy, which in turn saves groundwater.



Abbas et al, 2018b



Abbas et al, 2018b

Theoretical device, requires R&D to develop and reduce capacity to fit one household with greywater.

National energy conservation higher incentive than consumer's water bill.

Amend building code and affect incentives to install water-efficient appliances.

Household GW savings entail energy savings.

Can reduce national power consumption specifically for water provision and treatment by a calculated 18-19%, which in turn is approximated as 1.3% - 2.3% of the Kingdom's total power consumption.

Energy savings lead to GW savings in PP cooling.

The groundwater consumption avoided by avoiding power consumption for household water provision is calculated to ~ 0.83 MCM.

Households GW savings → KSA energy agenda.

GW savings not just for household water bill, but for national energy.

Greywater treatment is worth implementing at mega housing projects, such as Aramco's "Ajyal."

Summary: analysis of groundwater use and alternatives leads to recommendations aligned with KSA's Vision 2030.

Groundwater for Conventional and Unconventional

- Integrate produced water treatment and reuse with supply from seawater for unconventional.
- Seek optimal transition from minimal remaining groundwater considering high spatial resolution data on groundwater TDS, social choice economics, and continuous technological advancements.

Groundwater for Power

- Transition from groundwater to treated sanitary effluent for thermoelectric cooling.
- Site additional capacity power plants with criteria to avoid exacerbating groundwater withdrawals.
- Retrofit existing power plants and fit new ones with water-efficient cooling systems.

Groundwater for households

- Encourage retrofitting existing buildings and mandating the new with water-efficient appliances.
- Implement graywater treatment and reuse at mega-housing projects.
- Invest to innovate household-scale graywater treatment devices with low-grid power consumption.
- Update the building code to separate black water from graywater to enable treatment and reuse.

Alignment of recommendations with Vision 2030

- Take decisions in view of the water-energy-carbon equation.
  - Vision 2030 Objective 2.4.1 → NIDLP; Objective 5.4.2 → NTP & PP.
- Perform analysis with high spatial resolution.
  - National Comprehensive Water Act.
- Factor groundwater consumption in the power generation energy mix.
  - NIDLP E-13a-01-738; PP Utility Objectives; NTP Fuel Efficiency in Power Generation.
- Update the building code and invest in research on greywater reuse.
  - NTP Research, Development & Innovation in Building and Construction Sector.

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Power

- Water for Power –
  A Water-Energy Nexus Study in Saudi Arabia.
- Unpublished class project Carnegie Mellon University, 2017.
- Team
  - **Abbas, Ridha H.**
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Households

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- Unpublished class project at Carnegie Mellon University, 2018.
- Team
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Unconventional

- Water Balance – Environmental Impacts of Produced Water Management Options in the Hydraulic Fracturing Industry.
- Unpublished class project at Carnegie Mellon University, 2018.
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Thank You!

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A Sankey diagram of water and energy resources and consumption in Saudi Arabia

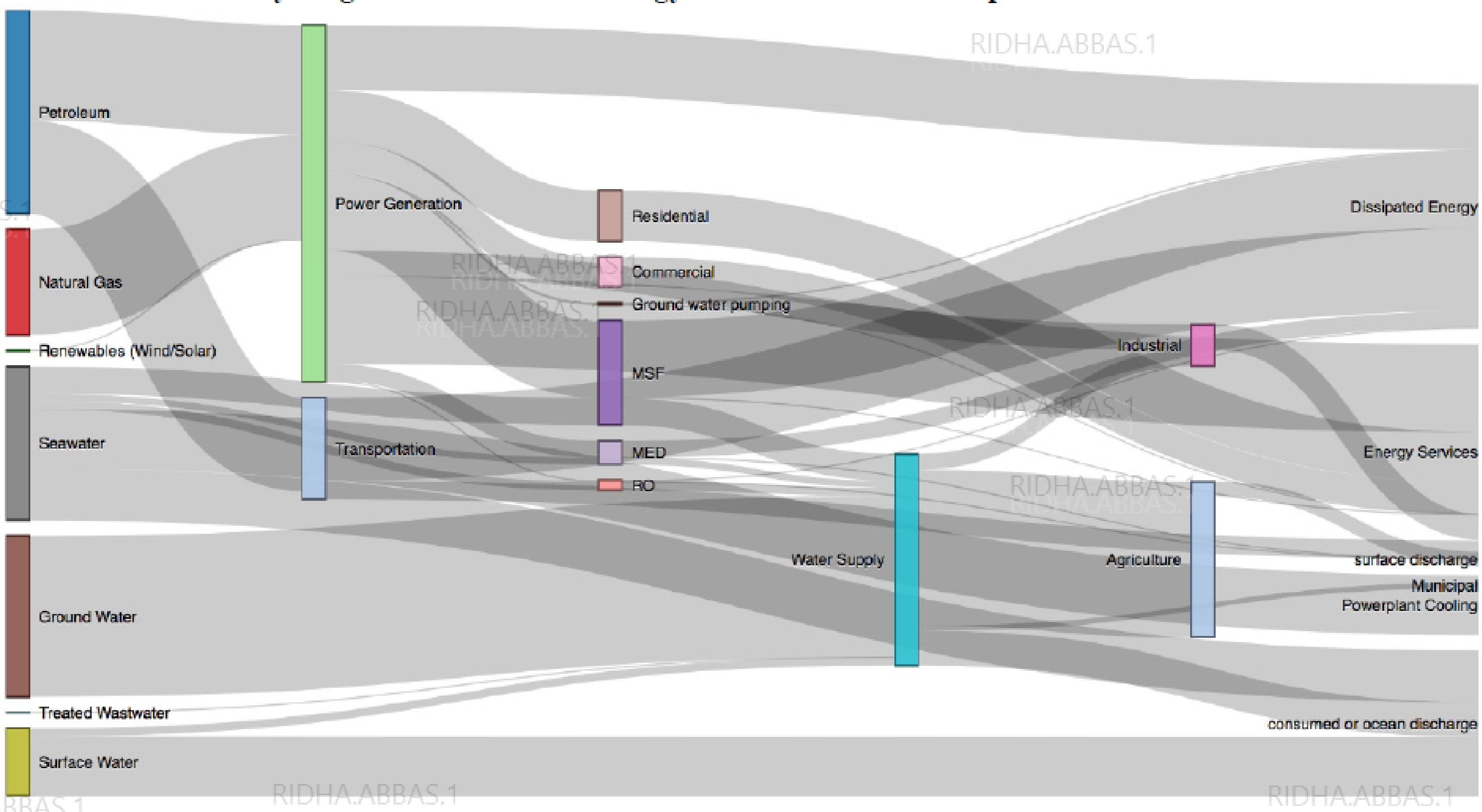
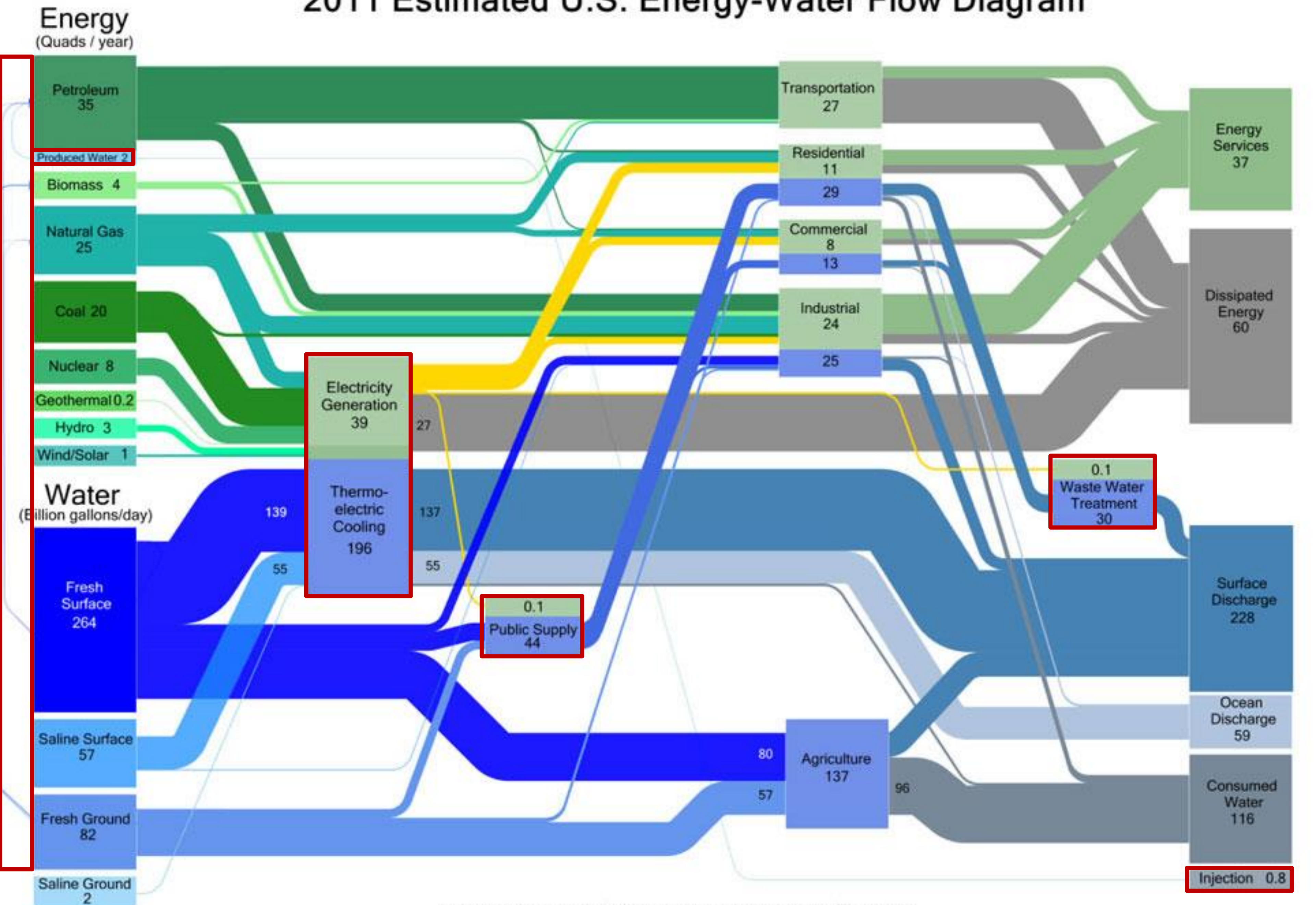


Figure 3: A Sankey diagram of water and energy resources, production, and consumption in Saudi Arabia. Created by combining multiple data sources for water and energy use and production, and making calculations with available data on system efficiencies[16][17] [18][19][20].

2011 Estimated U.S. Energy-Water Flow Diagram



Energy reported in Quads/year. Water reported in Billion Gallons/Day.

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saudi aramco