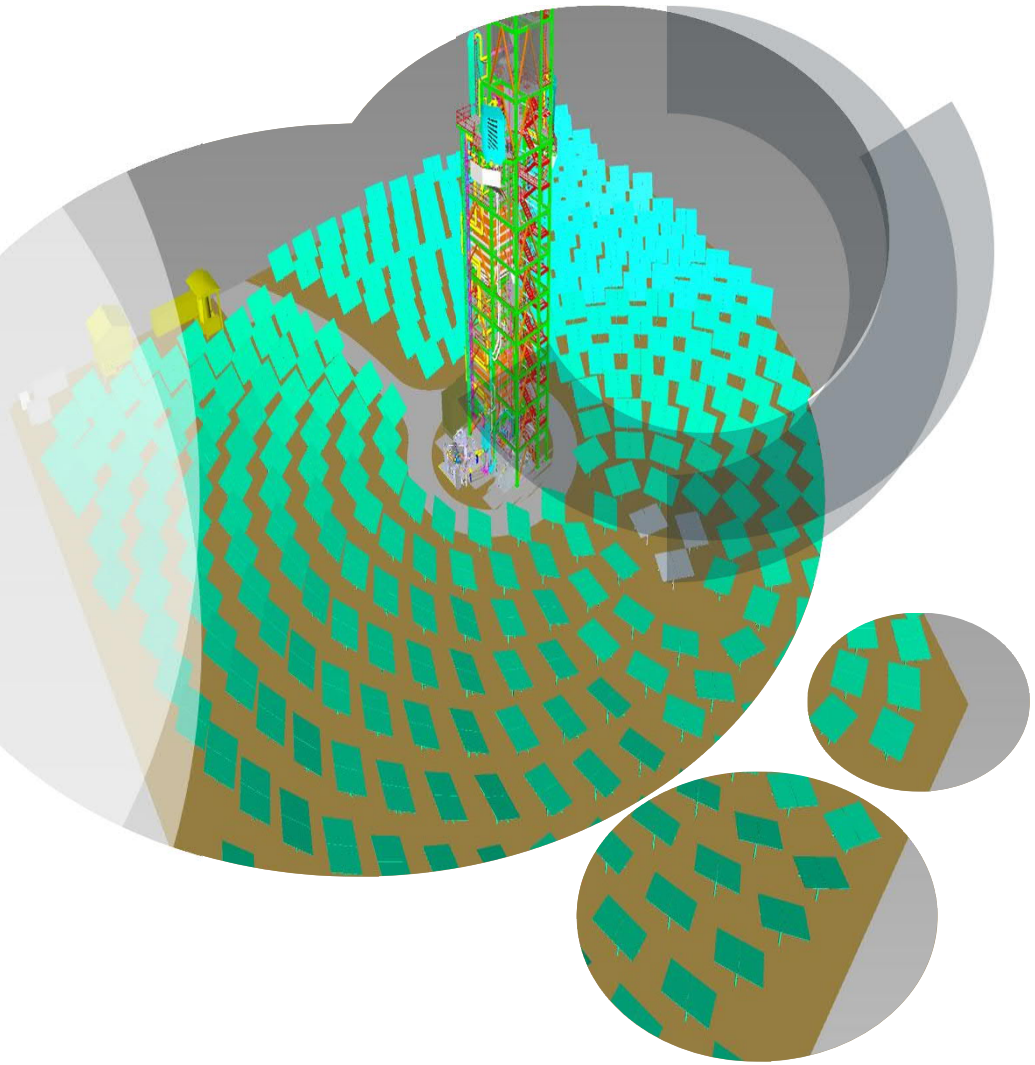

Gen3 CSP Summit 2021
Gas Panel

Solid Particle Material Handling & System Integration

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Advisian
Worley Group

US DOE SETO Award DE-EE0008368,

sub-contractor to Brayton Energy LLC

BraytonEnergy

Worley
energy | chemicals | resources

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Worley has over 48,000 employees in 49 countries.

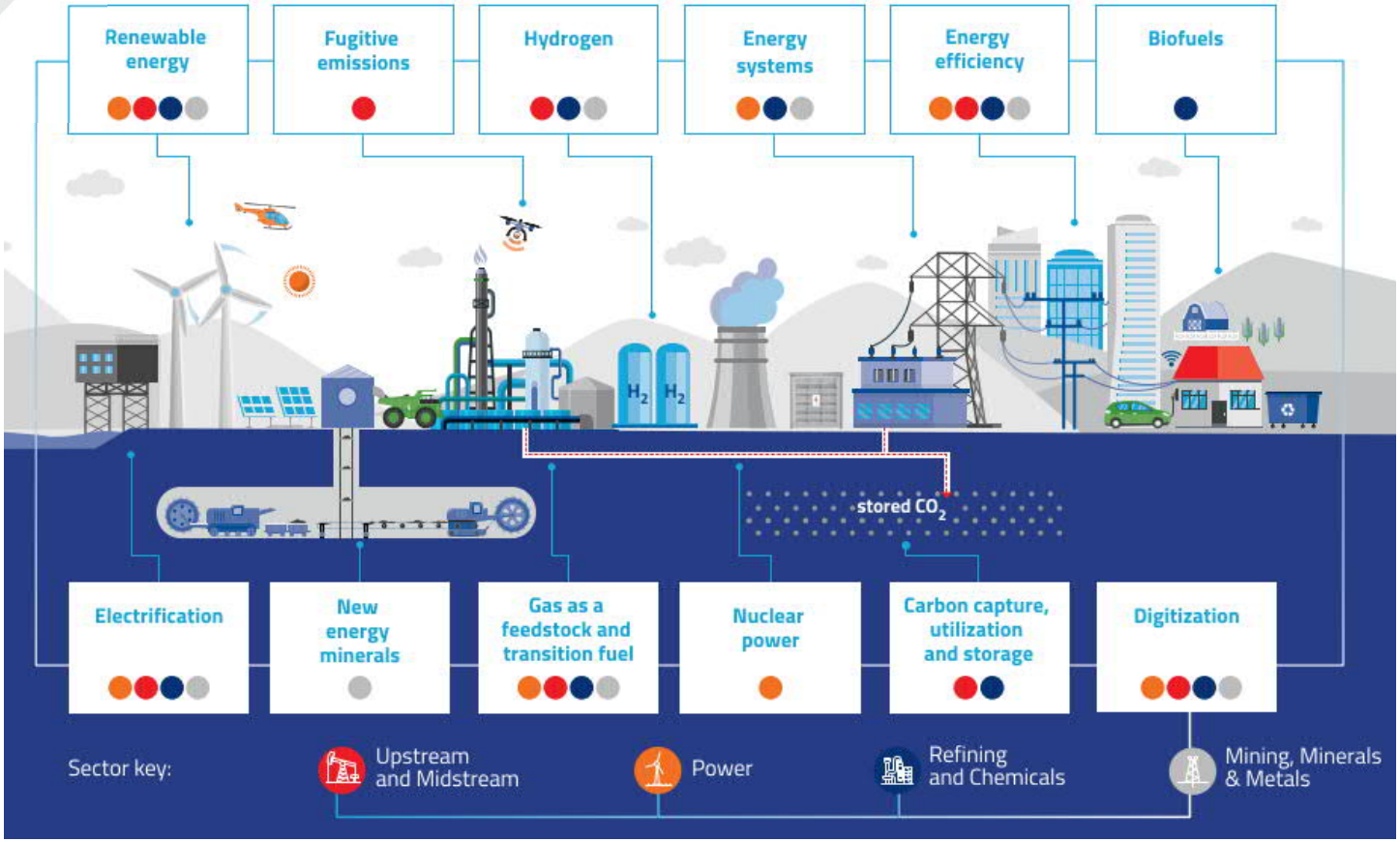
We contribute our project delivery and technical expertise to enable our customers to meet the world's changing energy needs in a safe, responsible and sustainable manner, in line with the ambitions of the Paris Agreement and the UN Sustainable Development Goals.

We are committed to achieving net zero Scope 1 and Scope 2 GHG emissions by 2030, and to pro-actively supporting our customers to reduce emissions on their projects and assets.

"*From ambition to reality - weaving the threads of net-zero delivery*"

In this ground-breaking paper, Worley and Princeton University's Andlinger Center for Energy and the Environment explore the practical shifts required to develop and deliver the energy infrastructure needed to achieve our net-zero ambitions.

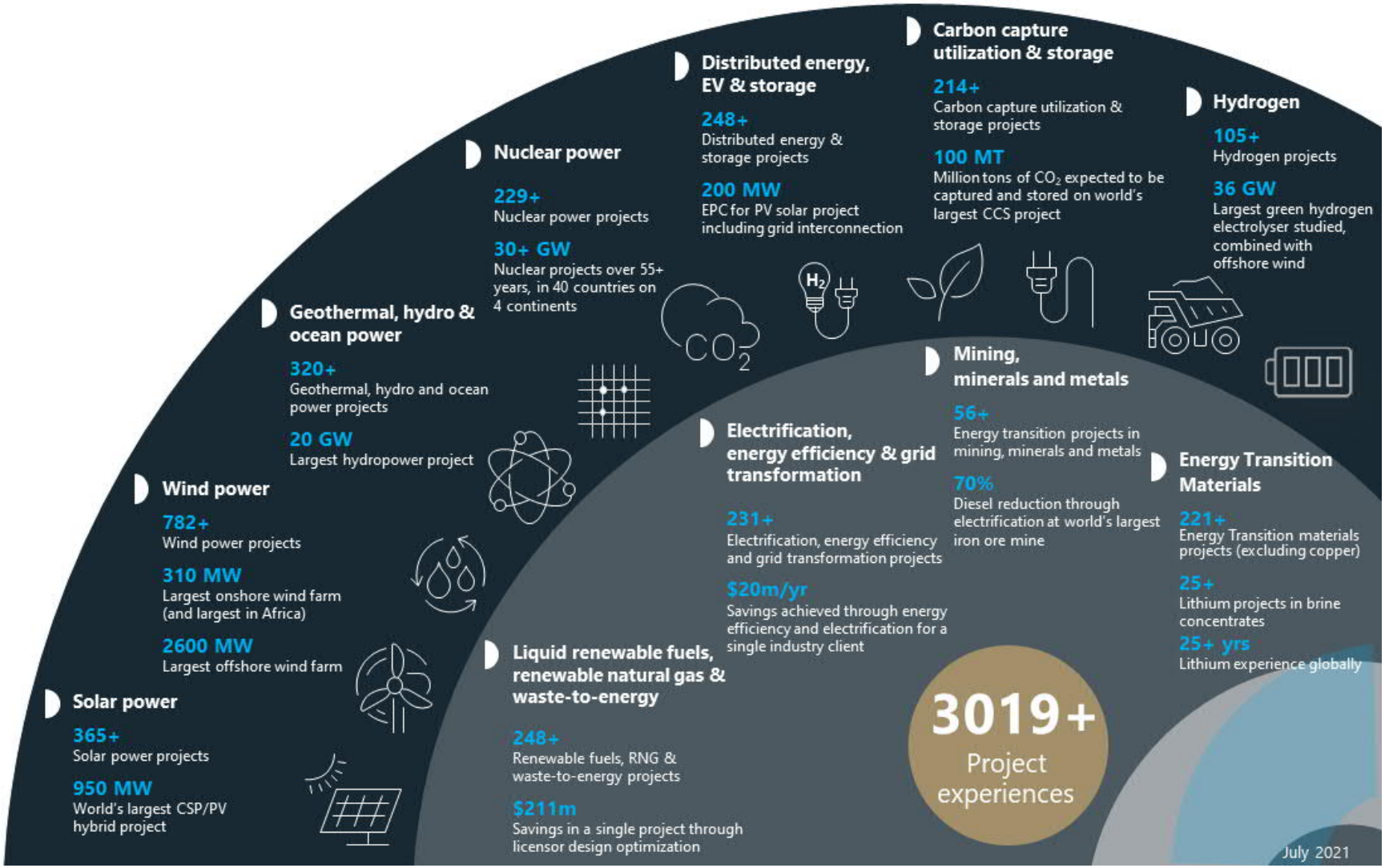
The focus of this paper is on supply-side energy infrastructure, outlining the five key shifts in thinking needed to deliver a net-zero transition. It will help you understand the scale of the task. And demonstrate how a combination of all five shifts is how we make net zero a reality.

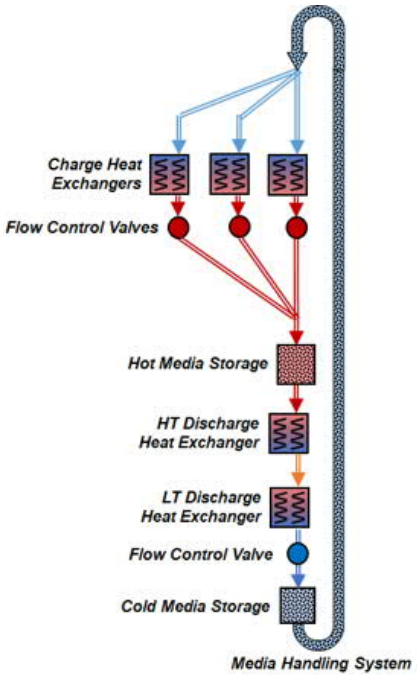


https://www.worley.com/our-thinking/from-ambition-to-reality?utm_source=gsm_email&utm_medium=direct&utm_campaign=princeton_report_gsm

We are a global leader in energy transition solutions

ENERGY TRANSITION EXPERIENCE





Phase 3 Demonstration (1 MW_t)
Project Sizing Info

- 64 mt/h (43 m^3/h)
- 44 m lift
- 7.7 kW theoretical lift power
- 570°C

Commercial Scale (33-100 MW)
Indicative Sizing Info

- 4,500 – 13,000 mt/h (3,000 – 8,700 m^3/h)
- 155 – 250 m lift
- 1.9 – 8.8 MW theoretical lift power
- 570°C

Particle Handling Design Criteria & Considerations

1) Sand is abrasive – wear must be mitigated
2) Sand is potentially friable – gentle conveying is required
3) Sand produces silica dust (inc. respirable): minimize dust emissions + technology to handle dusty environment
4) Sand is totally dry and free flowing
5) Heat loss to be minimized throughout
6) Parasitic load to be minimized (high lift efficiency)
7) Minimum practical mechanical components exposed to sand/temperature
8) CAPEX to be minimized
9) High reliability/availability
10) Simple maintenance where practical
11) Design must allow for thermal expansion (~1% for SS)
12) Multiple streams for commercial application can give redundant capacity, too many becomes O&M problem: ideally handle lift in one stage

Ideal technology is already commercially proven for capacity, lift height, and temperature (or can be easily modified to meet the criteria)

Particle Handling Technology Screening Investigation

Pneumatic (pressure)
[Ph3: Yes, Commercial: No]

Pros:
- Contained system
- Versatile arrangement
- Dense phase can limit wear
- High temp experience
- Simple pipe insulation concept

Cons:
- Need to heat feed air (recuperator w/ return air)
- Poor lift efficiency
- Capacity & lift limitations
- Need separators (cyclone)
-

"Small Skip" / Case Conveyor & Vertical Spiral Conveyor
[Ph3: Yes, Commercial: No]

Pros:
- Mech parts external to sand
- Sealed & insulated skips (low Qloss)
- No thermal expansion issues
- High lift efficiency

Cons:
- Skips/cases need multiple handling & batch feed
- Complex loading & unloading
- Capacity & lift limitations
- High power fluctuations

Olds Elevator™ (fixed screw, rotating tube)
[Ph3: Possible, Commercial: No]

Pros:
- Good dust containment
- High temp experience (Sandia)
- Drive components external to sand
- Low wear

Cons:
- Capacity & lift limitations
- Poor lift efficiency
- Particle attrition
- One supplier

Bucket Chain Elevator
[Ph3: Yes, Commercial: Possible]

Pros:
- Mature technology, versatile
- Temp contained in box casing
- Low speed can limit wear, attrition, dust
- Good lift efficiency

Cons:
- Mech parts in sand/temp contact
- Bulky (SS^{+} materials req'd)
- Chain replacement= high O&M $
- Capacity & lift limitations
- Need to remove dust from casing

"Big Skip" Mine Hoist
[Ph3: Yes, Commercial: Yes]

Pros:
- Mech parts external to sand
- Sealed & insulated skips (low Qloss)
- No thermal expansion issues
- High lift efficiency
- Best-in-class for commercial mt/h + lift

Cons:
- Batch feed
- Complex loading
- High power fluctuations
- Raises tower height

Redler / En-Masse / Chain Conveyor
[Ph3: Possible, Commercial: No]

Pros:
- Mature technology, versatile
- Dust/temp contained in box
- High temp capable
- Low attrition
- Good lift efficiency

Cons:
- Mech parts in sand/temp contact
- Bulky, costly (SS^{+} materials req'd)
- Chain replacement= high O&M $

Pneumatic-vacuum, screw conveyors, capsule pipeline, tube conveyor (chain), vibrating screw, Magaldi EcoBelt, Rail-Veyor, Light Rail, RopeCon, troughing belt, apron feeder, chain grate conveyors, spiral tube, Flexicon helical conveyor discounted

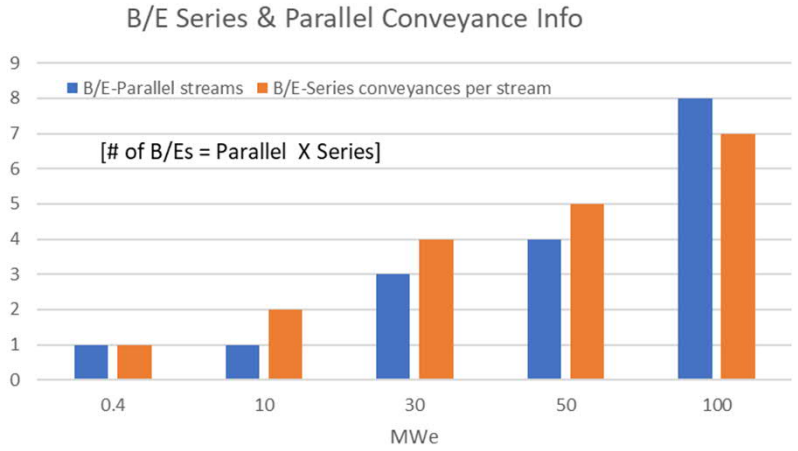
Technology Selection for Phase 3 & Commercial

Phase 3 Demonstration

- Desire to use same technology in Phase 3 as commercial for de-risking purposes
- Single drum hoist, ground mounted, w/ 1 overturning (Kimberly) insulated skip
- ~50% lifting efficiency
- Add'l cost and complexity of balanced double drum hoist w/ 2 skips not justify increased lift efficiency for demonstration project

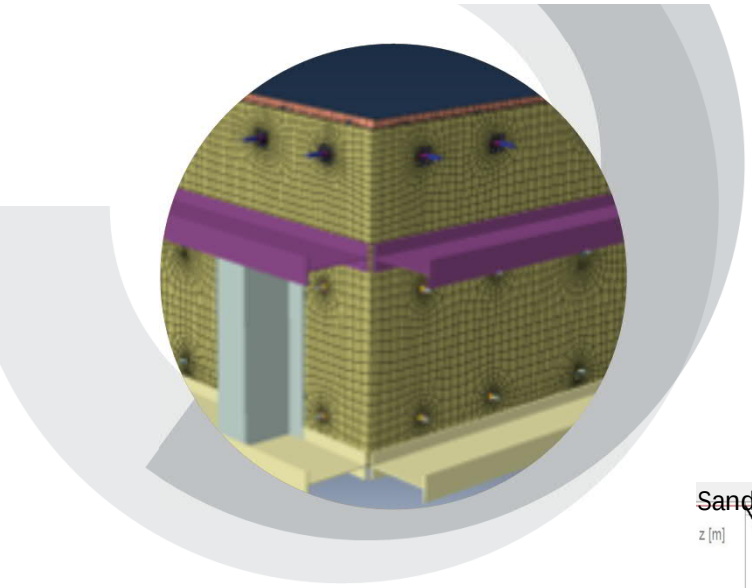
Commercial System

- Mine skip hoist needs fewer lifts vs bucket elevator (B/E). B/E needs multiple lifts in series & parallel, resulting in reliability/availability/O&M risks:



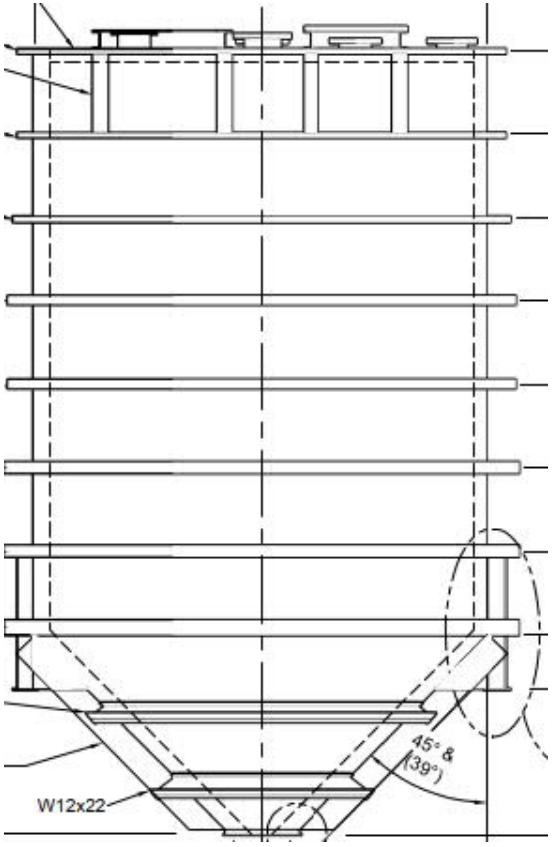
  - Multiple (parallel) double drum hoist, ground mounted, w/ 2 overturning (Kimberly) insulated skips.
  - ~80%$^{+}$ lifting efficiency

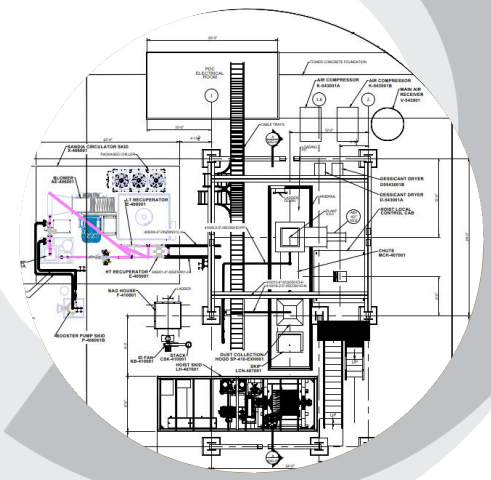
SIEMAG TECBERG & ABB engaged to provide input on preliminary design and cost estimates for Phase 3 and Commercial



Phase 3 Demonstration Project 10 MW_t-h TES Design

- 212 MT net storage, ea.
- Hot & cold silo substantially similar
- Funnel flow
- Square steel silo, pyramidal hopper w/ stiffener rings
- Thermo-mechanical FEA using Advisian's proprietary FLEXAS® accelerated solver
- Internal insulation
- Internal SS wear liner w/novel design to accommodate thermal expansion
- Maximize shop fabrication

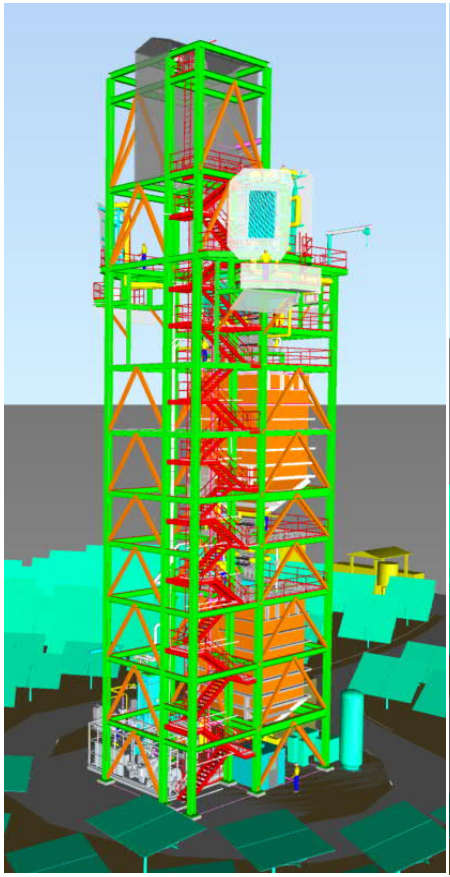




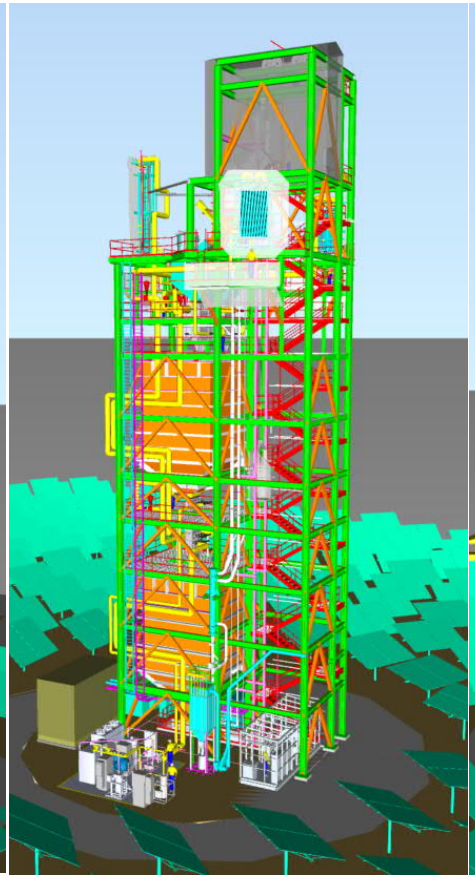
Phase 3 Demonstration System Integration - 3D Model

- 3 receivers (N, SW, SE)
- skip hoist on South
- skip unloading penthouse=grey
- hot & cold TES silos=orange
- hoist house= white steel box @ grade
- sCO_2 piping=yellow
- BOP=light blue (e.g. air comp + receiver, baghouse for silica dust removal)

Looking NW



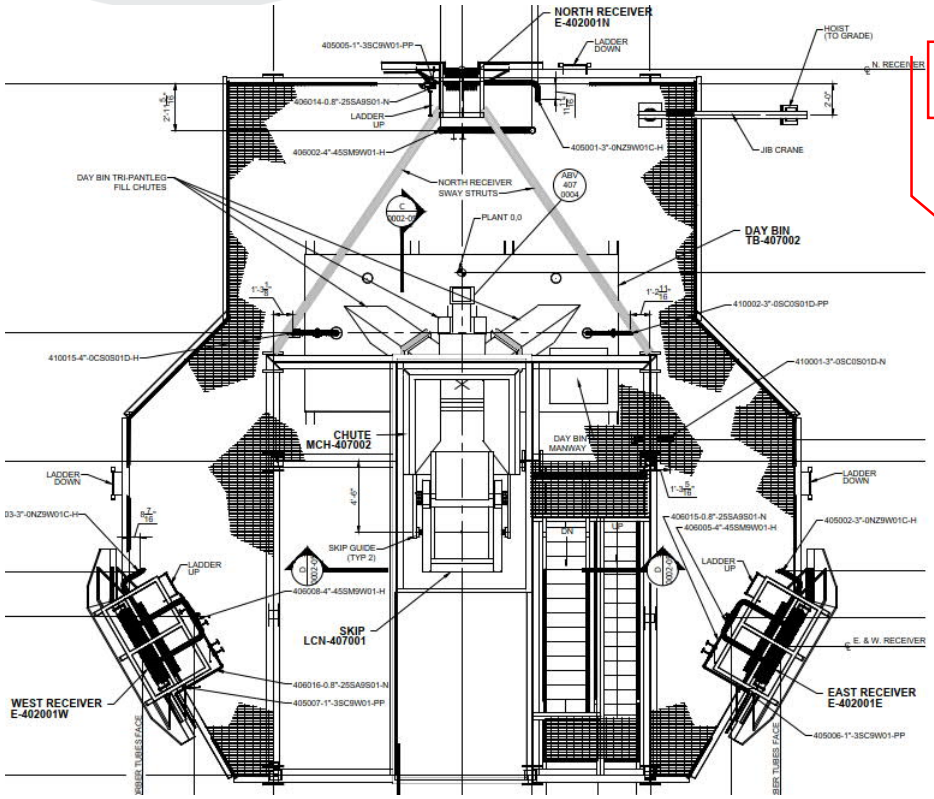
Looking ~East

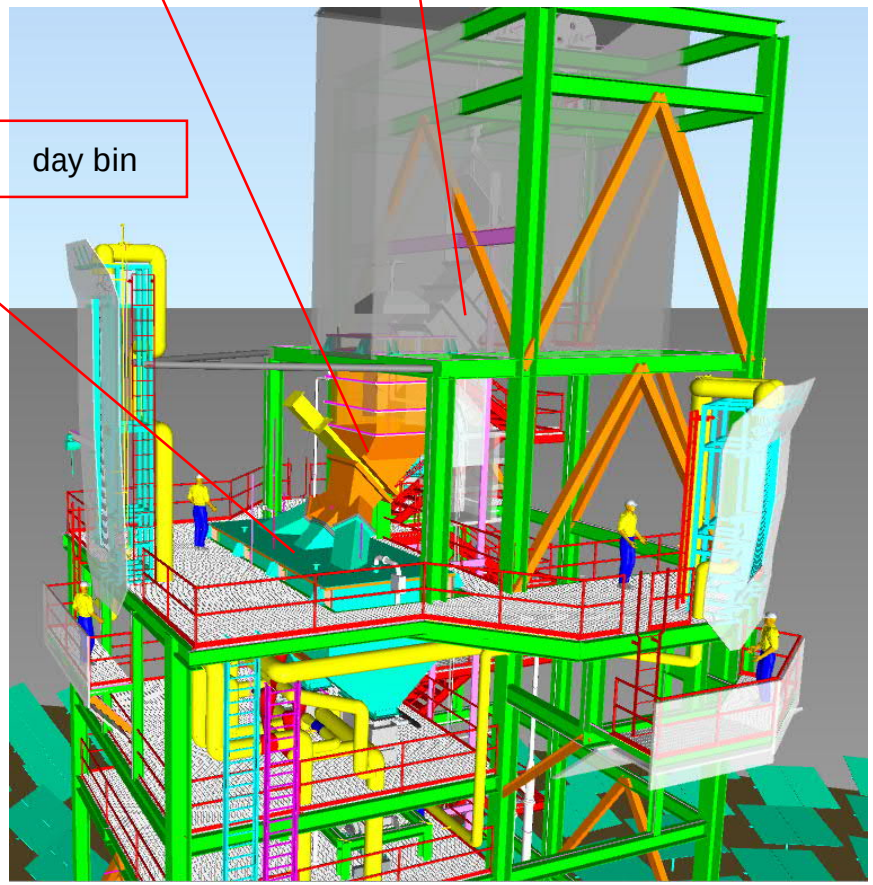


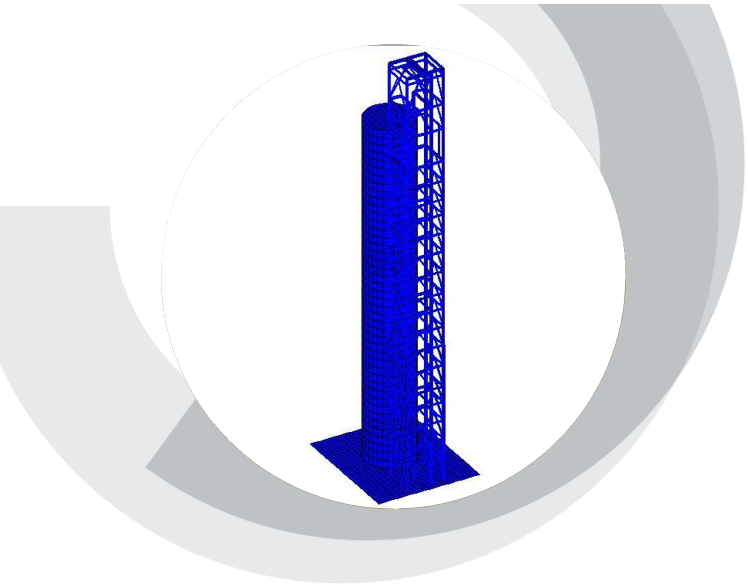
Looking North

Phase 3 Demonstration System Integration - 3D Model

Receiver Deck @ 33m (108')







Commercial System Input

Majority of Advisian scope based on Phase 3 Demonstration project design and cost estimate

LCOE Optimization Support:

- Developed cost functions for mine skip hoist and bucket elevator for 10MW - 100MW towers
- Performed conceptual design and associated cost estimates for 10MW – 100MW towers, foundations, and integral TES silos

100MWe Receiver Modular Consulting:

- Receiver assembly layout for modularization
- Module fabrication estimate (overseas) with input from Worley fab shops
- Module shipping and site installation estimate

THANK YOU

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