# Simulation, Turnarounds, and FCC Operational Cycles


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# Simulation of FCCUs


## Simulation goals

- Look inside FCCU
- Identify root cause of underperformance
- Learn from current and historical operations
- Virtual testing of proposed changes

## Impact of simulation

- Increase likelihood of success
- Reduced risk of negative consequences during operation
- Reduce risk of unplanned shutdown

## Simulation results in this presentation are from Barracuda Virtual Reactor®

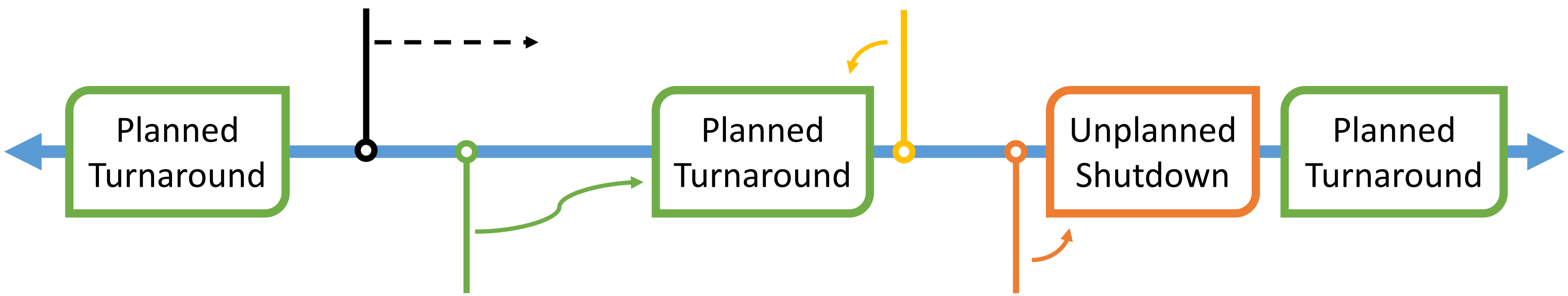
# When to Use Simulation?

**Established Baseline**

- Proactive modeling efforts
- Enables quick response for other simulation efforts

**Post-Audit**

- Used to understand unexpected performance changes
- Can lead to planning for next planned turnaround




**Turnaround Planning**

- In support of next planned turnaround
- Enough time to make more significant changes

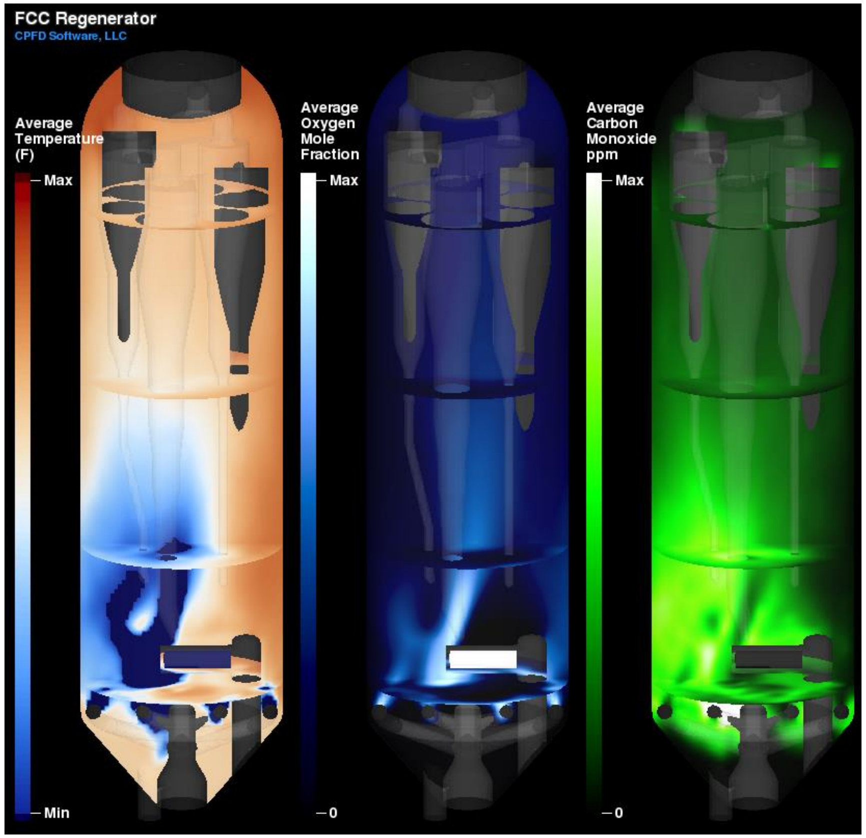
**Unplanned Shutdown**

- Used to support decisions that must be made quickly
- Not enough time to make significant changes

# Simulation During Turnaround Planning

**Example courtesy of a North American refiner**

- Afterburn, CO promoter, MAB limitations
- Thermal asymmetry, O2 bypassing, high CO




Source: R. Fletcher, AFPM AM-16-15

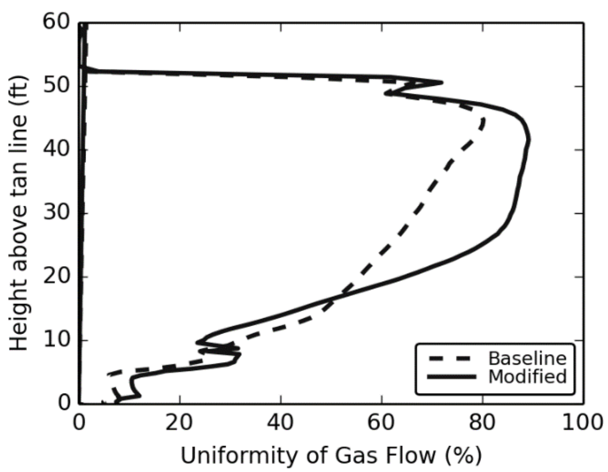
# Regenerator Maldistribution

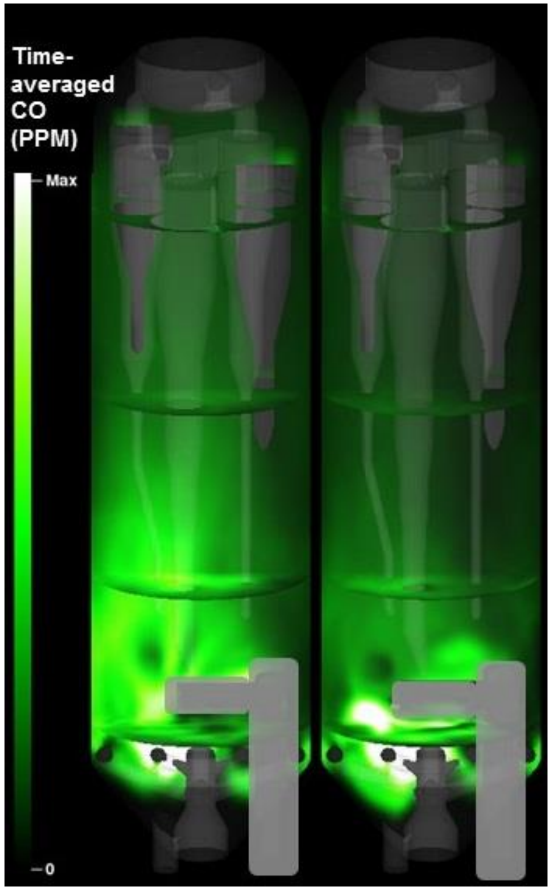
## Changes tested before turnaround

- New spent catalyst distributor design

## Outcome

- Emissions within specs
- Afterburn nearly eliminated
- Reduced air requirements
- Eliminated CO promotor use




**Baseline** **New Design**

Source: R. Fletcher, AFPM AM-16-15

# Simulation during Post-Audit

**Example Courtesy of Viva Energy Refining Pty Ltd (Geelong, Australia)**

**2011 changes**

- Increased afterburn / flue gas temp spikes
- Panel operator intervention
- Reduced throughput

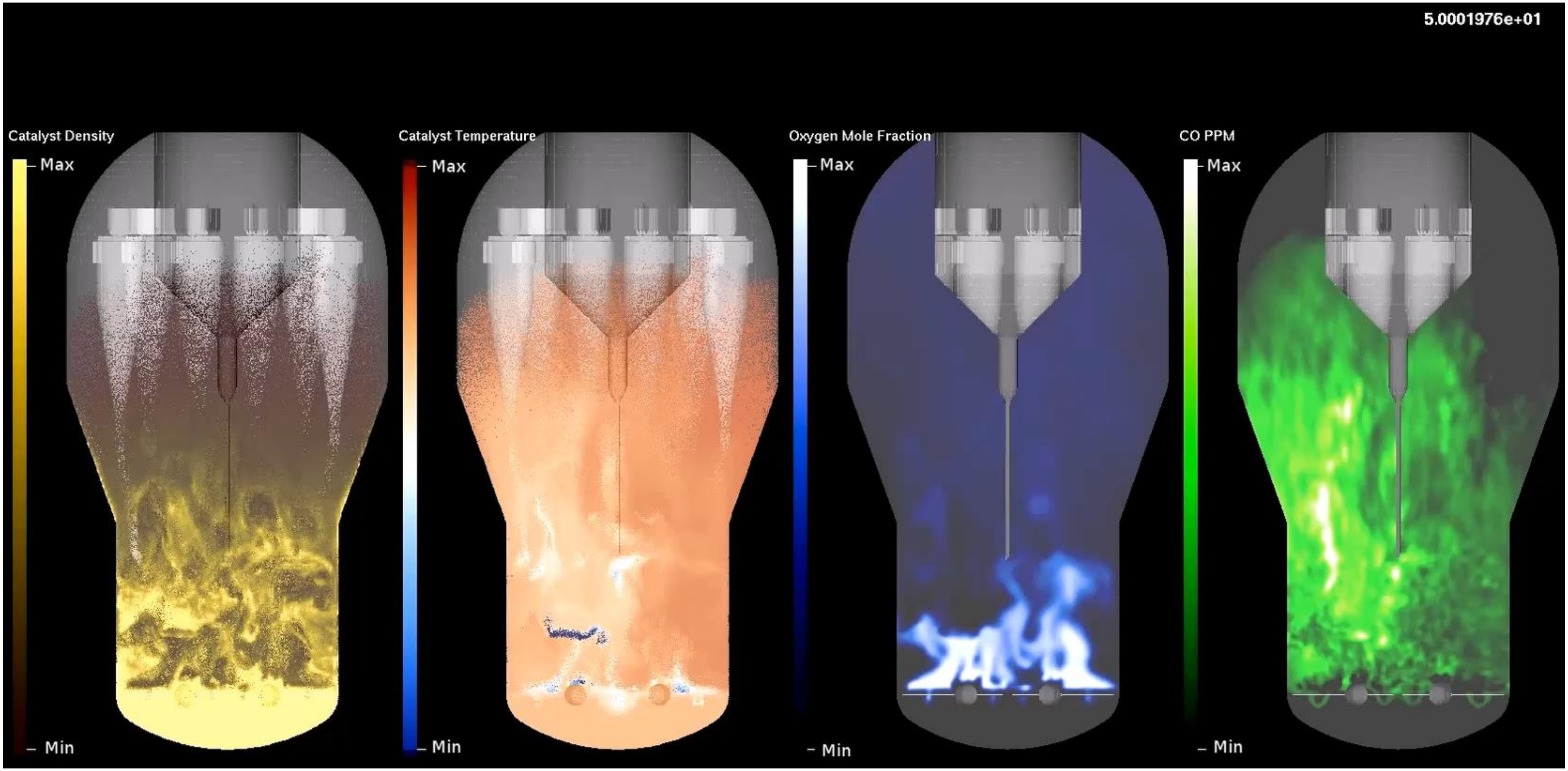
**Baseline models of historical operations created prior to 2016 turnaround**

| | 2011 Changes* |
|---|---|
| **Design** | |
| SCID | New design |
| Cat cooler | Hoppers removed |
| **Operational** | |
| Catalyst circulation | + 4.4% |
| Air rate | +14.7% |
| SCID aeration | Major changes |
| Cat cooler | Minor changes |

* Changes relative to pre-2011 baseline configuration and operating conditions

Source: P. Blaser, ARTC 2018

# Simulation of Historical Operations




Source: P. Blaser, ARTC 2018

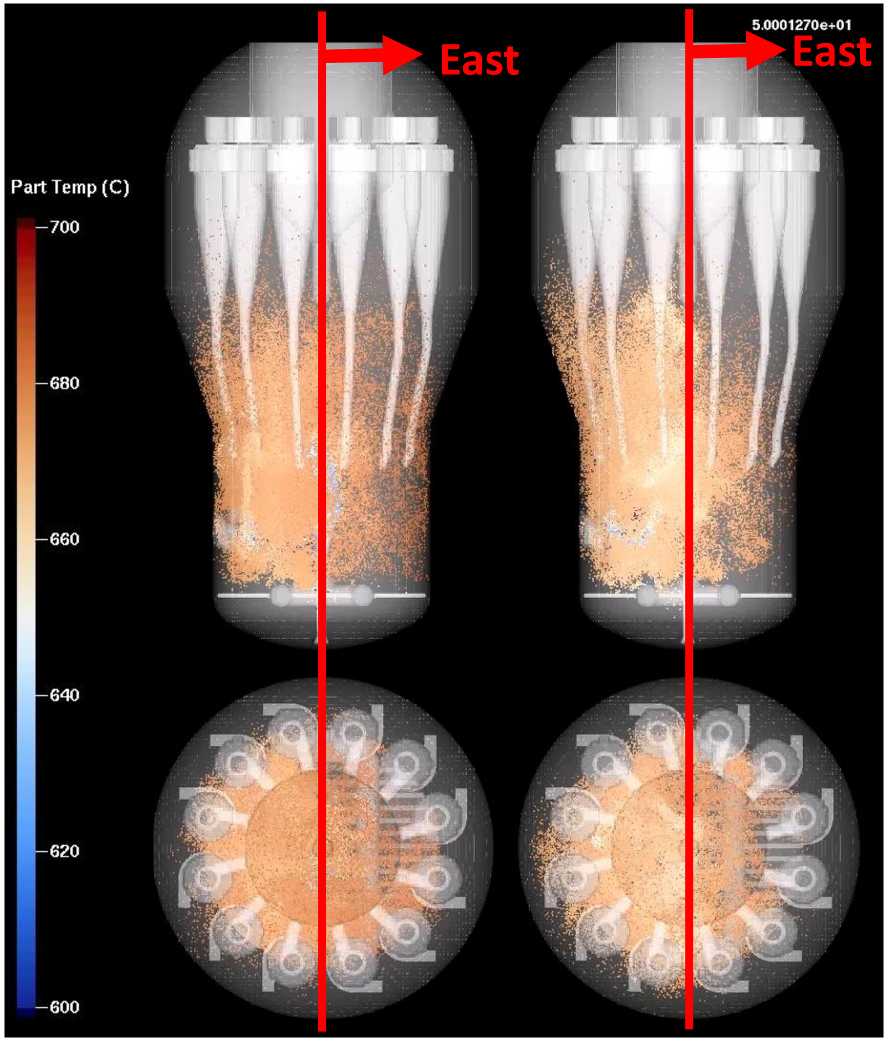
# Increased Maldistribution

**Spent cat < 10 seconds residence time shown**

**Percent reaching east side < 10 seconds**

- Pre-2011: 21.3%
- 2011-2016: 10.7%

**Maldistribution of air and catalyst increased significantly following the 2011 turnaround**




**Pre-2011** **2011-2016**

Source: P. Blaser, ARTC 2018

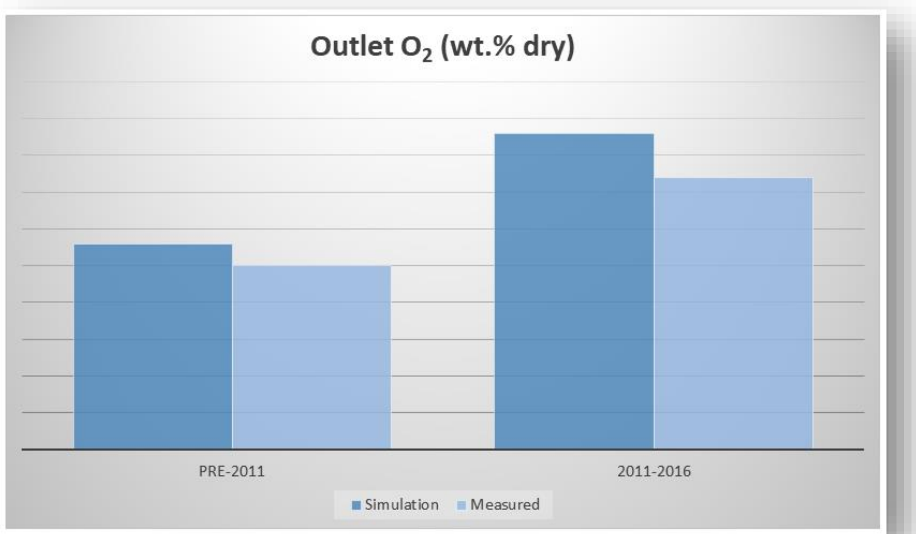
# Effects of Maldistribution

## Maldistribution of gas entering cyclones

- The increased maldistribution of spent catalyst results in non-uniformity of gas composition at the cyclone inlet elevation


## O2 breakthrough

- Both simulation and operational data show the increase in O2 breakthrough
- Transient CO and O2 levels result in the observed afterburn and flue gas temperature spikes




Source: P. Blaser, ARTC 2018

# 2016 Turnaround and Outcome

## 2016 Turnaround

- Simulation indicated the planned changes would be beneficial
- The changes were implemented during the 2016 turnaround

## Outcome

- 12 months of operational data were compared for the operational periods immediately before and after the 2016 turnaround
- Average afterburn 5°C lower
- Number of panel interventions reduced 75%
- Max daily average throughput 4% higher


Source: P. Blaser, ARTC 2018

# Simulation During Unplanned Shutdowns

## Example courtesy of a North American Refiner

- Changes made in late 2015 had unexpected problems

## FCC exceeded emissions constraints:

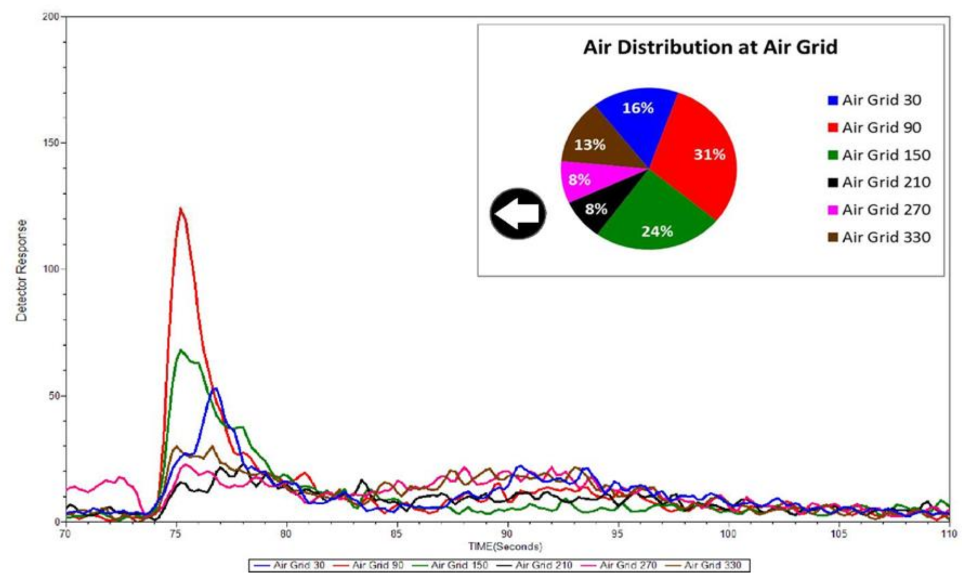
- NOx: 10% over 365 day rolling average
- CO: 43% over 365 day rolling average
- Particulate emissions: frequent high loss episodes
- Significant afterburn

## Radioactive tracer study performed

- Significant maldistribution
- Potential damage

Source: R. Fletcher, AFPM CCS 2016

Example courtesy of: Tracerco



# Formation of Team and Initial Finding

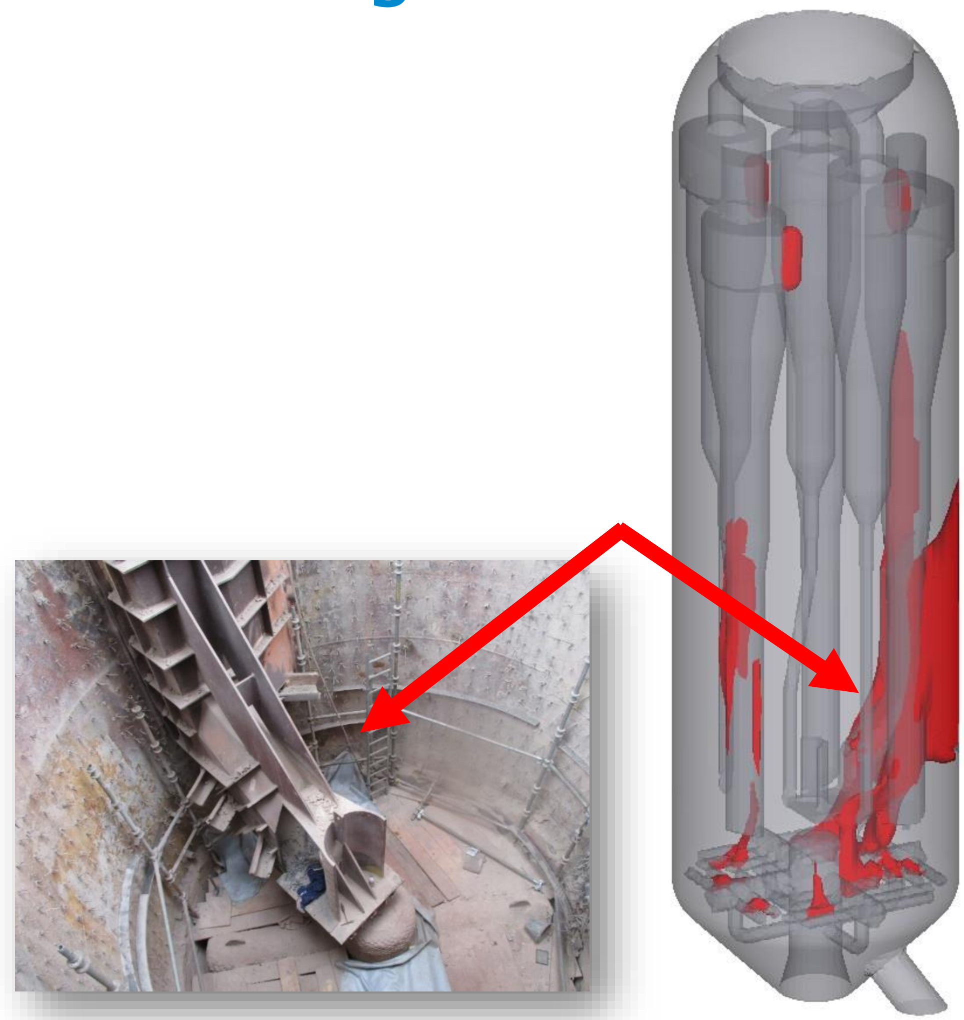
**Shutdown scheduled to repair expected damage**

**The simulation predicted significant gas channeling (without air grid damage)**

- The spent catalyst distributor exacerbates the maldistribution

**6 weeks before shutdown: Team formed to propose options if no damage was found**

- Refinery engineers, corporate staff, cyclone vendor, two independent consultants, simulation expertise

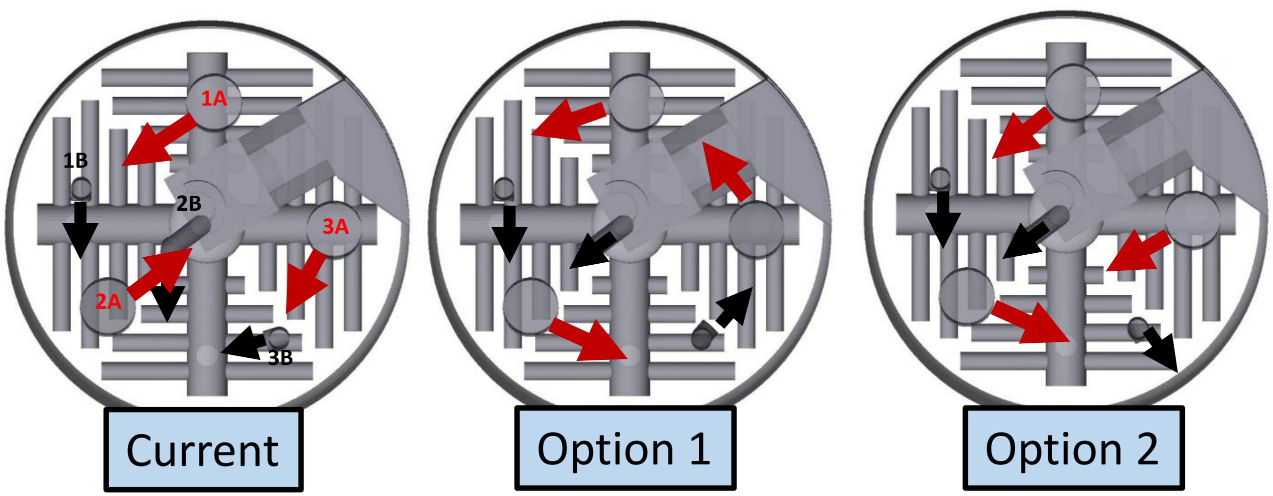


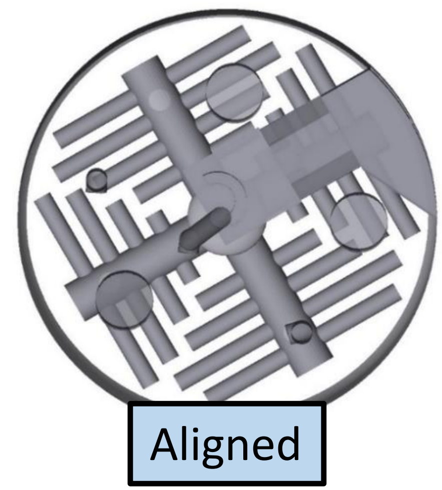
Source: R. Fletcher, AFPM CCS 2016

# What Could be Modified if No Damage Found?

**During shutdown could alter:**

- Air grid orientation
- Dipleg discharge direction
- Shortening secondary dipleg lengths





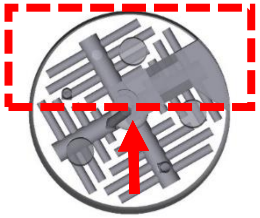
Source: R. Fletcher, AFPM CCS 2016

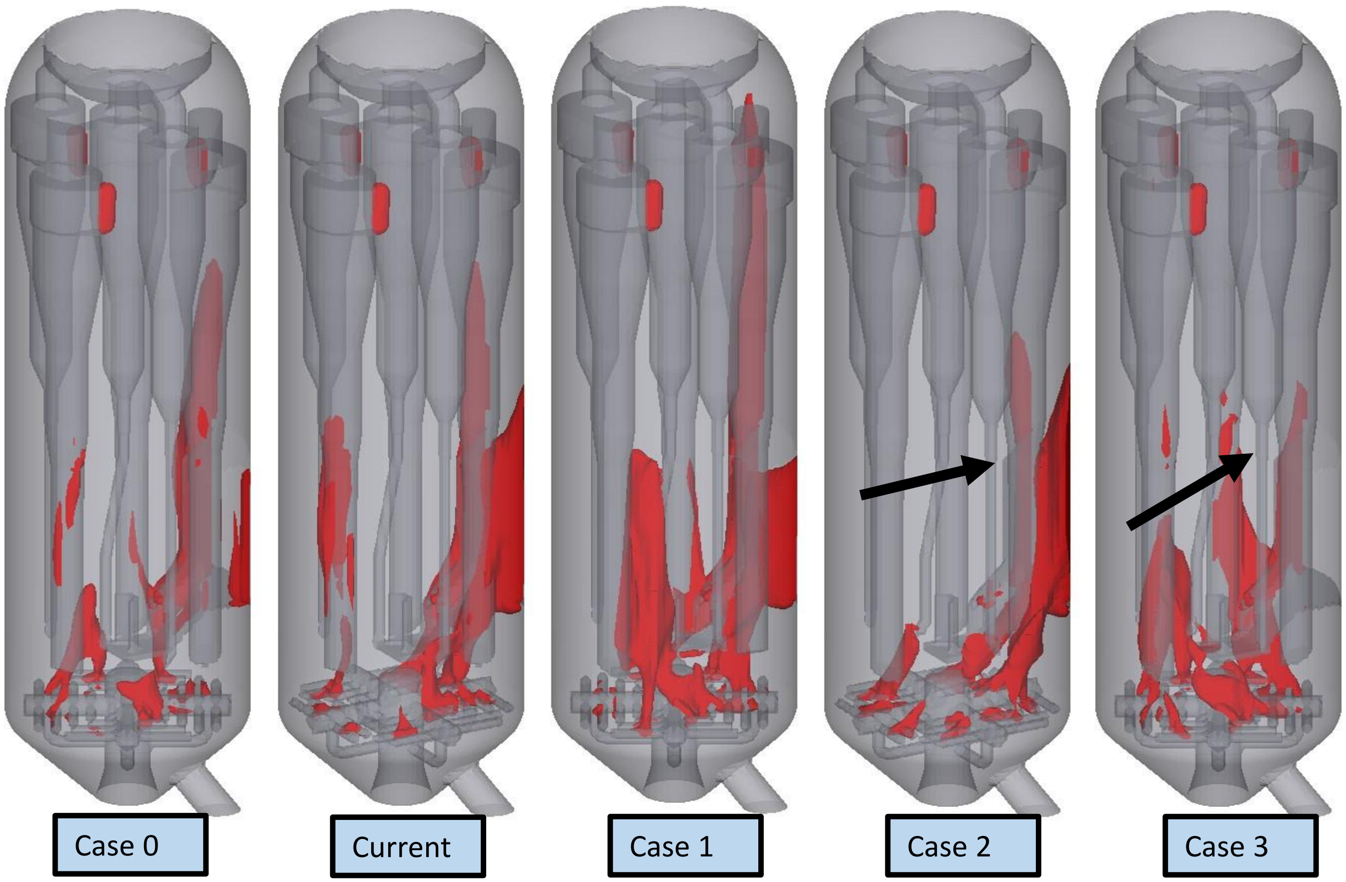
# Mixing and Channeling

**No case addresses root cause**

**Can incremental improvements be obtained?**

- Regions with highest time-averaged gas bypass shown
- Cases 2 and 3 dissipate gas jets at a lower elevation



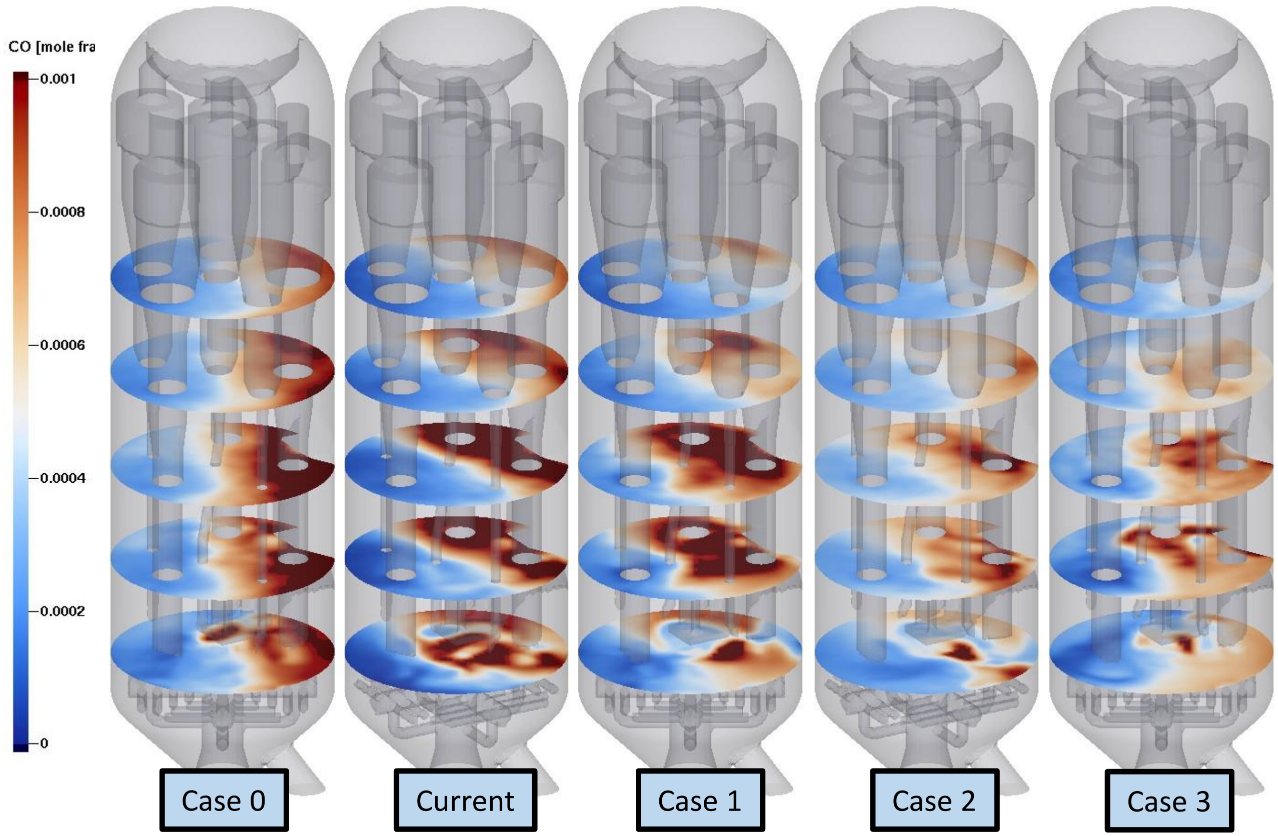




Source: R. Fletcher, AFPM CCS 2016

# Thermal and Gas Composition Profiles

**Simulations showed**

- Regenerator temperature profiles dominated by maldistribution
- High O2 reaching dilute phase
- Afterburn due to O2 and CO mixing in the dilute phase
- Cases 2 and 3 show better mixing and less maldistribution




Source: R. Fletcher, AFPM CCS 2016

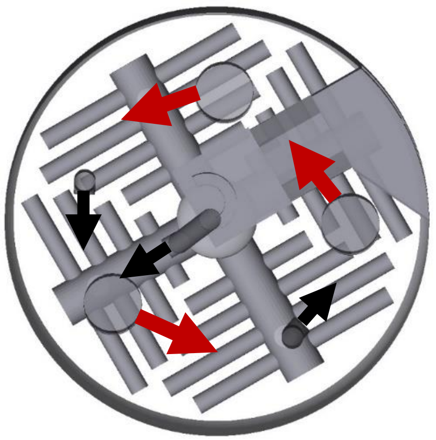
# Outcome

## During shutdown

- The  air grid wasn't broken
- Simulation gave the refiner confidence to implement the change
- The refiner opted for Case 2 with the secondary dipleg heights shortened by 1.5 ft

## Post-shutdown:

- NOx & CO maintained below 365 day rolling average
  - Dropped significantly after start-up
  - Air rate optimization performed and NOx additive used
- Catalyst losses: complete elimination of the catalyst loss events



Case 2

Source: R. Fletcher, AFPM CCS 2016

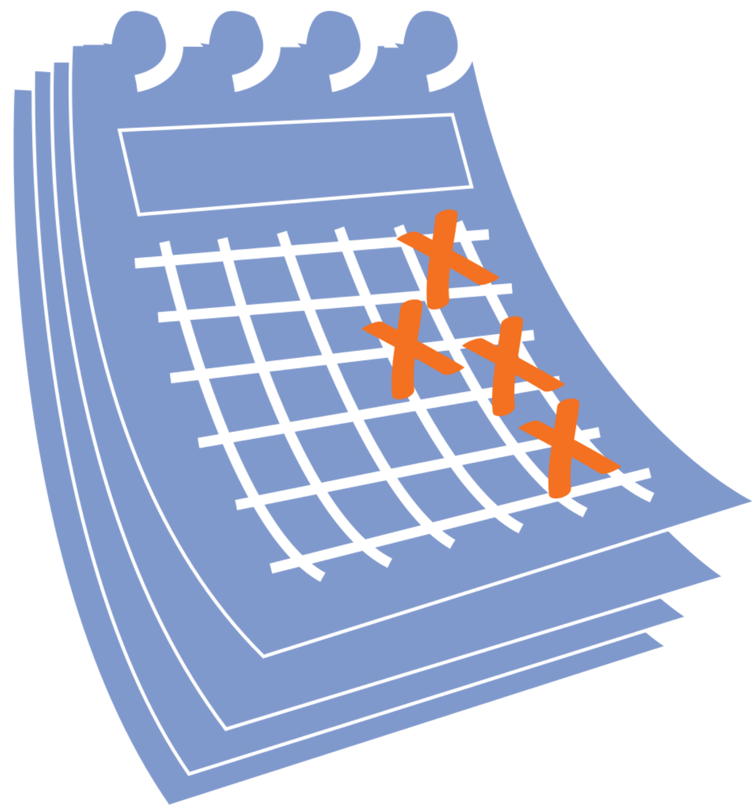
# Simulation as a Proactive Tool: Established Baseline Model

**Enables fast response for any situation**

- Unplanned shutdown
- Post-audit
- Turnaround planning

**Usually step 1 for all other use cases**

- "How was it running before?"
- "Why did this change occur?"
- "What if we change this hardware?"



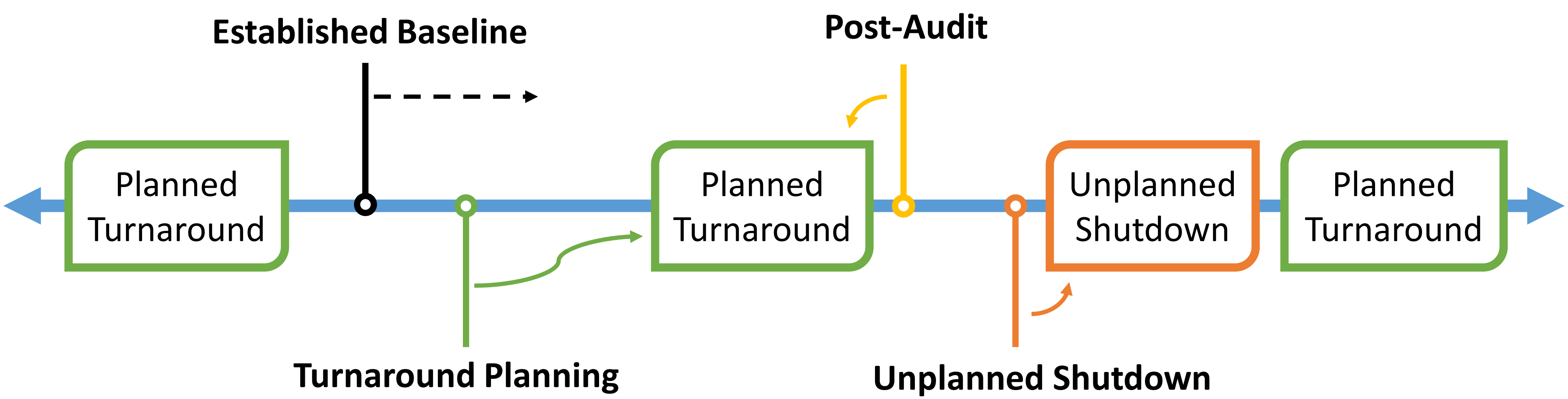
# Conclusions

**Simulations can be used in all stages of the FCC turnaround cycle**

- Different time constraints depending on situation
- Different limitations on possible solutions

**Having an established baseline model is critical**

- Enables fastest possible response time in all situations



# Acknowledgements and References

## Turnaround Planning Example


- Ray Fletcher, Sam Clark, and Peter Blaser, AM-16-15: "Identifying the Root Cause of Afterburn in Fluidized Catalytic Crackers".

  https://www2.afpm.org/forms/store/ProductFormPublic/am-16-15-identifying-the-root-cause-of-afterburn-in-fluidized-catalytic-crackers

  http://cpfd-software.com/resources/webinars/identifying-the-root-cause-of-afterburn-in-fcc-regenerators


## Post-Audit Example


- Peter Blaser, John Pendergrass, John Gabites, Angus Brooke, and Timothy Brown, "Application of CPFD Modeling to Support RCCU Hardware Changes at the Viva Energy Geelong Refinery", presented at ARTC, April 23-35, 2018.

  http://artc.wraconferences.com/


## Unplanned Shutdown Example


- Ray Fletcher, Peter Blaser, John Pendergrass, and Ken Peccatiello, CAT-16-17: "The Experience of a Team of Experts to Resolve Severe FCC Regenerator Maldistribution".

  https://www2.afpm.org/forms/store/ProductFormPublic/cat-16-17-the-experience-of-a-team-of-experts-to-resolve-severe-fcc-regenerator-maldistribution

  http://cpfd-software.com/resources/webinars/2017-ertc-presentation-resolving-severe-regenerator-maldistribution