Fluence Analytics

# Transforming the Polymer Manufacturing Industry With Next-Generation Realtime Monitoring Technology

Greater yields.  Increased Quality. Shorter Product Cycle Times.  Reduced Operational Costs.

# BUSINESS TRANSFORMATION & REAL-TIME ANALYTICS

One of the main things we're particularly interested in at Fluence Analytics is realtime analytics, which can truly transform business in several areas.

Some of the key priorities we see with our customers is reducing operational expenses, so customers gain market share through competitive advantage, and yield -- getting more and more out of your assets, with less effort and cost.

On the quality side, being able to consistently produce the same quality of product to customers, as well as develop new products, and then standardize that quality within a very tight specification globally, is another very big challenge.

And finally, from an operational health, safety, and environmental perspective, mitigating operator exposure, waste reduction, reduced environmental footprint, and using feedstock and materials more intelligently, make a significant impact toward a sustainable operation.

At the end of the day, we develop technology solutions that help our customers make their products BETTER.

# BUSINESS TRANSFORMATION & REAL-TIME ANALYTICS

## Cost

Reduce costs and gain market share

## Quality

Improve quality and develop new products

## Yield

Streamline processes and drive yield


## ESG

Reduce waste and environmental footprint

# TRADITIONAL PROCESS FOR MEASUREMENT & CONTROL

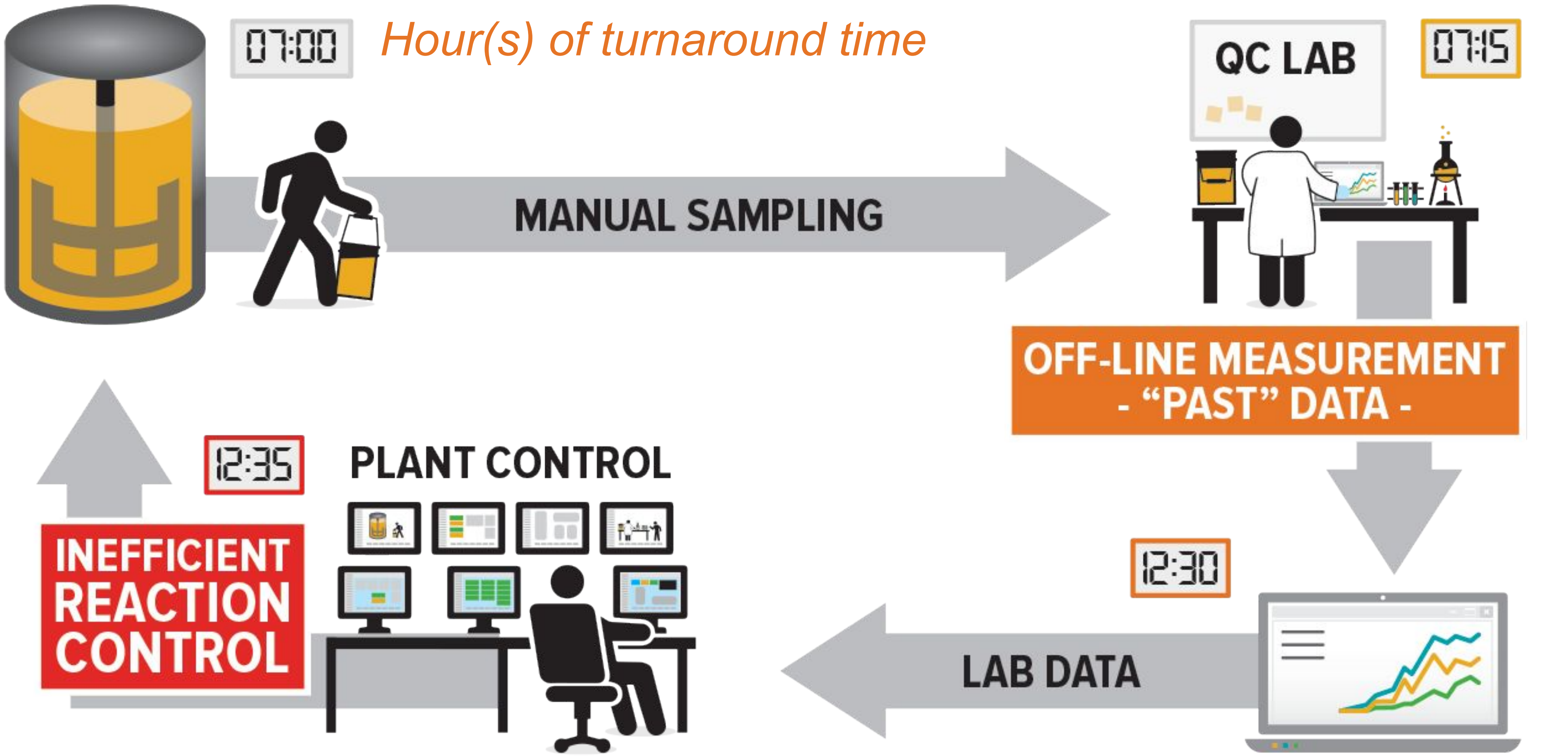
Some of the issues our experts in the field have seen in the industry over the years across the globe are centered around the challenges of the current status quo of manual sampling of product from reactors.

We've seen, in the polymer industry specifically, an extremely heavy reliance on manual sampling during the QC (quality control) phase of the manufacturing process to analyze critical performance properties of interest. What this means is that at the end of a batch or every 1-2 hours in a continuous production cycle or semi batch production cycle, there are operators performing manual sampling of the reactor contents and taking these samples to a QC lab where a technician makes sample preparation and one or many measurements to determine characteristics. At this point, you have data that is typically hours old by the time it is sent to the control room to either take a very conservative control action, or just to see what was made in the batch. This is enormously inefficient.

Manual sampling does of course work, however there are many inefficiencies when you don't have access to realtime information concerning the properties of interest, which is fundamentally what our customers in polymer manufacturing are selling to the end users, and how those polymers will perform in the final application. We have seen this as a very standard and well-known issue in the industry.

# TRADITIONAL PROCESS FOR MEASUREMENT AND CONTROL

Batch
Semi-batch
Continuous




***'Postmortem' analysis, conservative control strategies and decisions with stale data***

# BUSINESS COSTS OF INTERMITTENT OR NO DATA

Taking a look look at the business implications of intermittent or no data, there exists a scenario where end product quality is affected by off spec material generation that deviates from the steady state in batch, semi-batch, and continuous process that affect the target material outcome after a full production cycle.

This leads to material rework that has to be blended with other target quality products to get an average product to sell to a customer, thus sacrificing profits in the process.  Or you end up altering your production style and schedule to minimize some of the issues that are known in transitioning material or campaigning certain batches, which leads to excess inventory that is not needed, if more visibility and better control of the process was achieved, more dynamic optimization might not be required.

On the quality side we've actually seen that manufacturing plants that have the same reactor, the same operators, the same feedstocks, have different end product outcomes.  Now imagine this inefficiency scaled to a globally level, where you have different feedstocks, different translated SOP's, different operators skillsets, and different equipment at different stages of equipment wear in their lifecycle, so being able to replicate quality with all these dynamic variables is a key point and can be very challenging to manage.  This is where more dynamic control and/or dynamic measurement can help optimize and stabilize manufacturing quality and consistency.

On the control side, we're looking at opportunities for enhancing visibility, over the years we've heard a lot of people say their manufacturing process is somewhat of a "black box", and don't quite understand exactly what parameters affect what outputs.  And if you DO want to understand it can be quite a time consuming endeavour with a lot of R&D resources required for modelling single reactors to truly map out what is happening within the manufacturing process.

On the efficiency side, if you're looking to scale up, produce new products, change different recipes, and target very specific applications, that scale up process can be very difficult, and break in for production can be very time consuming if some of the issues aren't worked out.  In addition, there is also quite a bit of lab work needed to trace problems.  There is a better way.

# BUSINESS COSTS OF INTERMITTENT OR NO DATA

## Off-spec

- ✔ Batch rework/losses
- ✔ Higher inventory
- ✔ Periodic write-offs of dead stock

## Quality Deviations

- ✔ Inconsistent batches
- ✔ Customer returns of “shipped on-spec” material

## Poor Control

- ✔ Always “flying blind”
- ✔ Cannot see process upsets till too late
- ✔ Reliance on PhDs for modelling/intervention

## Reduced Efficiency

- ✔ Slow/ineffective scale-up of new products
- ✔ Redundant lab work
- ✔ Hard to trace problems to root cause

# THE SOLUTION: ACOMP


So, our talented team at Fluence Analytics created a much more – elegant solution called **ACOMP** (automatic continuous monitoring of polymerizations).

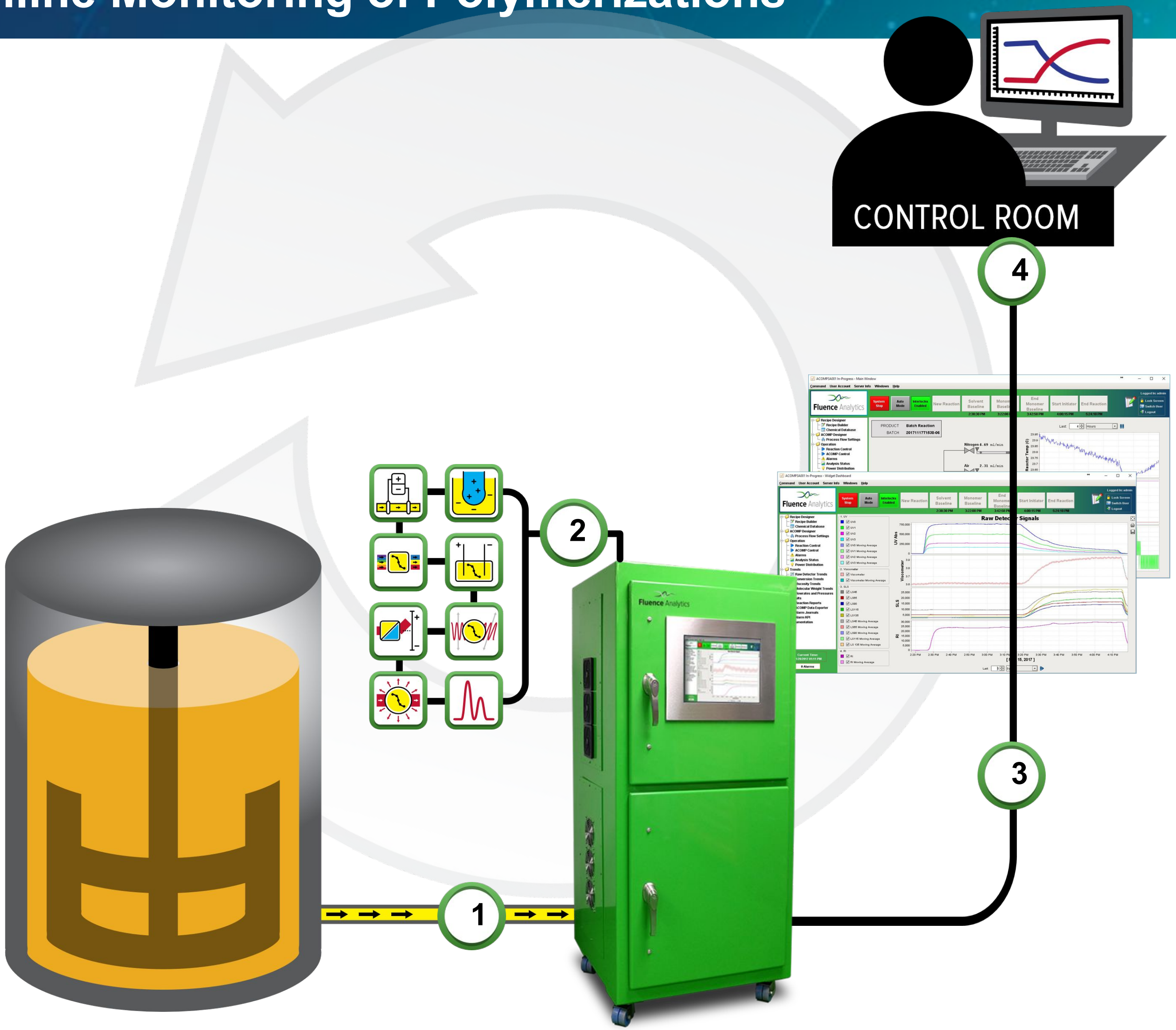
At a very high level this is how ACOMP works.

We continually extract from the reactor and have conditioning and measurements all happening in an automated system inside our enclosure, with multiple sensors. Then our proprietary software computes that raw data/parameters of interest to our customers and is then sent to the control room where control decisions can be made to control the process.

# THE SOLUTION: ACOMP*

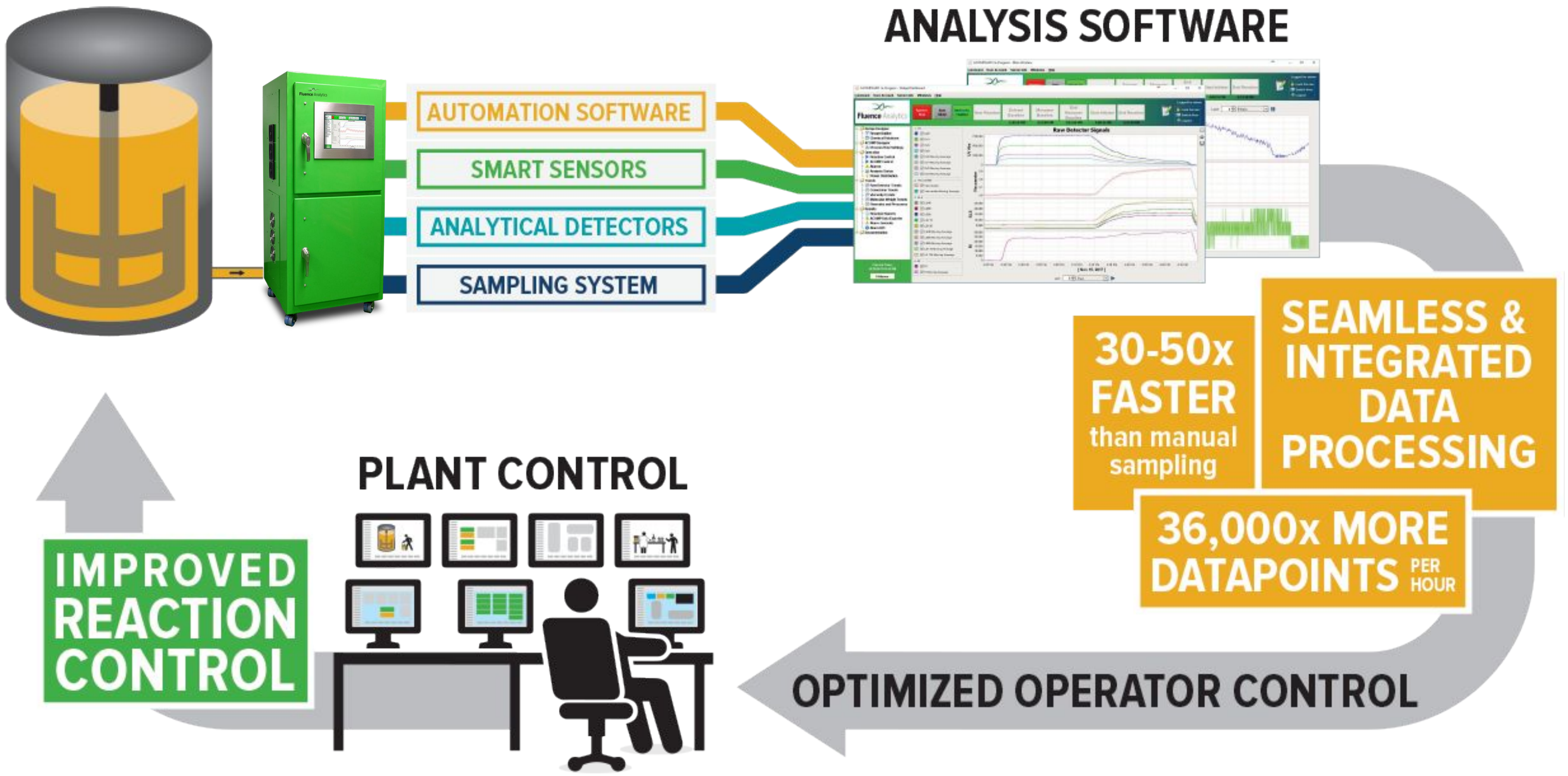
*Automatic Continuous Online Monitoring of Polymerizations

1. Polymer is **continuously extracted** from the reactor
2. Automated **real-time measurements** with multiple sensors
3. **Proprietary analysis algorithms output** key parameters for **optimization**
4. Enables **optimized process control**, plant digitization, reduced cycle times, **improved yields** and consistency



# ACOMP IN YOUR PROCESS

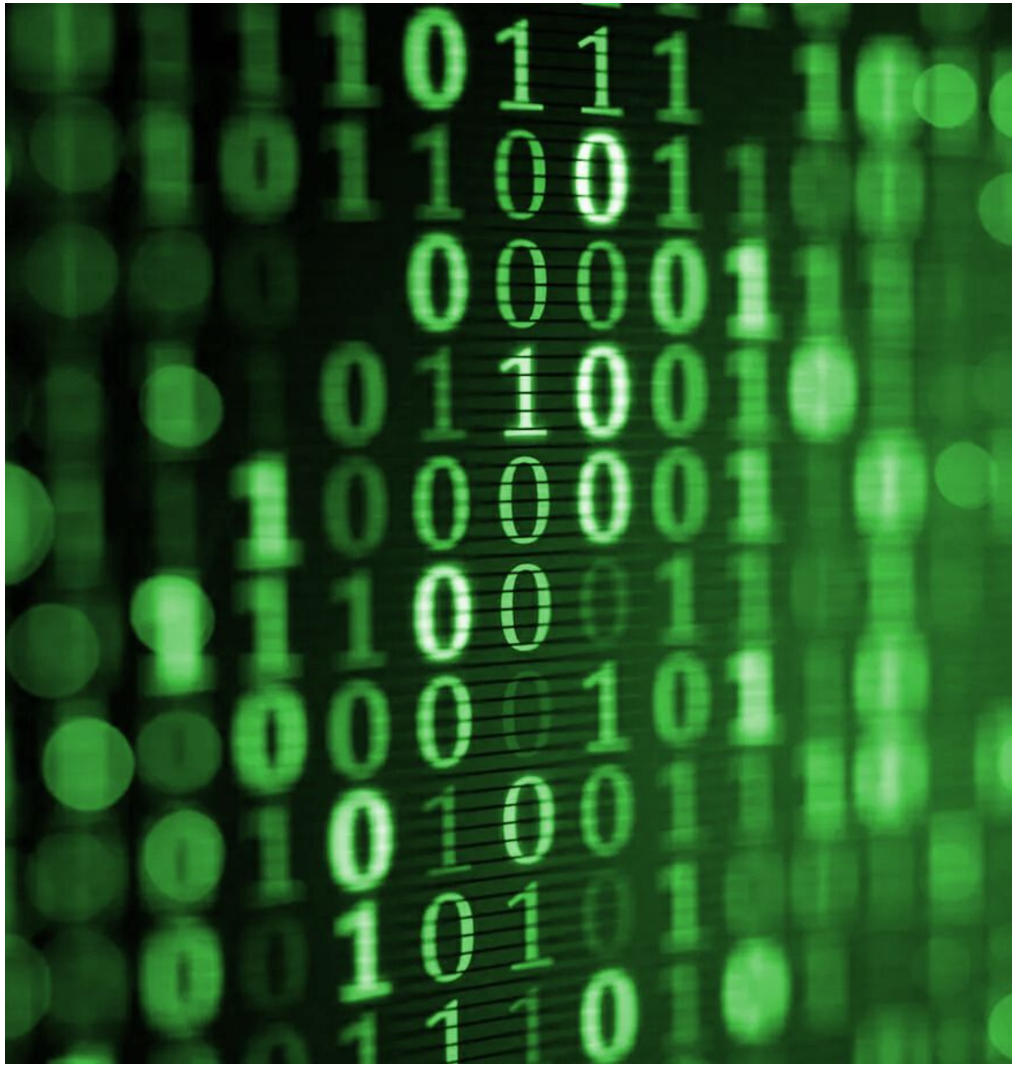
Batch
Semi-batch
Continuous



# REALTIME MONITORING PROPOSITION

If we think about the business implications, the cost, and the effects are from a lack of data, so if we really break it down - how do we translate that to value?  We're talking about cycle time reduction, and freeing up capacity, were looking at need for certain analytical testing over time, we're looking at avoiding degradation of product, and off spec production, and then we're thinking about where we can impact this waste and environmental footprint, manual sampling, and emissions.

These are unnecessary exposures and safety risks for operators and plant personnel, and anytime there's an opportunity to reduce consumption, we've seen ROI in the less than 1 year, and in one case 6 months for delivering on a few of these different areas.



# REALTIME MONITORING PROPOSITION

## Reduce costs and gain market share

- ✔ Batch cycle time reduction - up to $1+ million
- ✔ Additional capacity made available

## Improve quality and develop new products

- ✔ Avoid product degradation
- ✔ Faster introduction of new product recipes

## Streamline processes and drive efficiencies

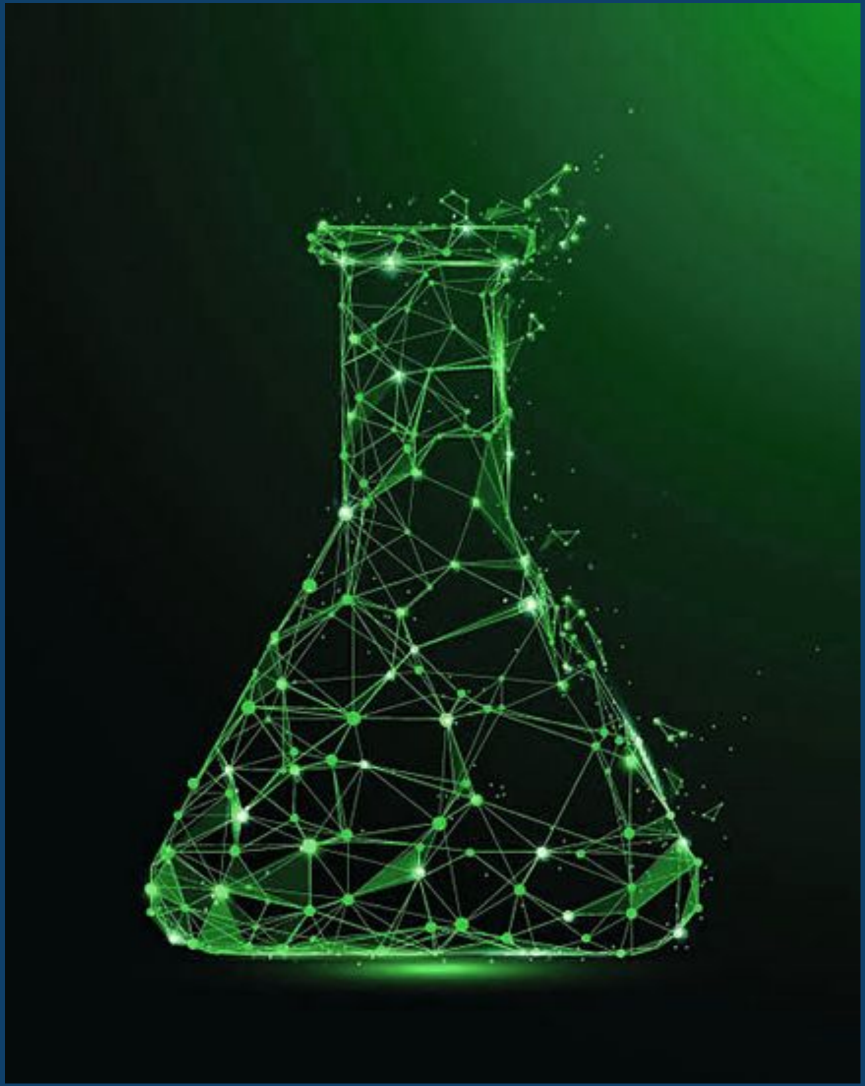
- ✔ Eliminate analytical testing
- ✔ Reduce overtime

## Reduce waste and environmental footprint

- ✔ Reduce energy consumption
- ✔ Less manual sampling
- ✔ Lower VOC emissions

**Payback 6 months at one specialty chemical customer!**

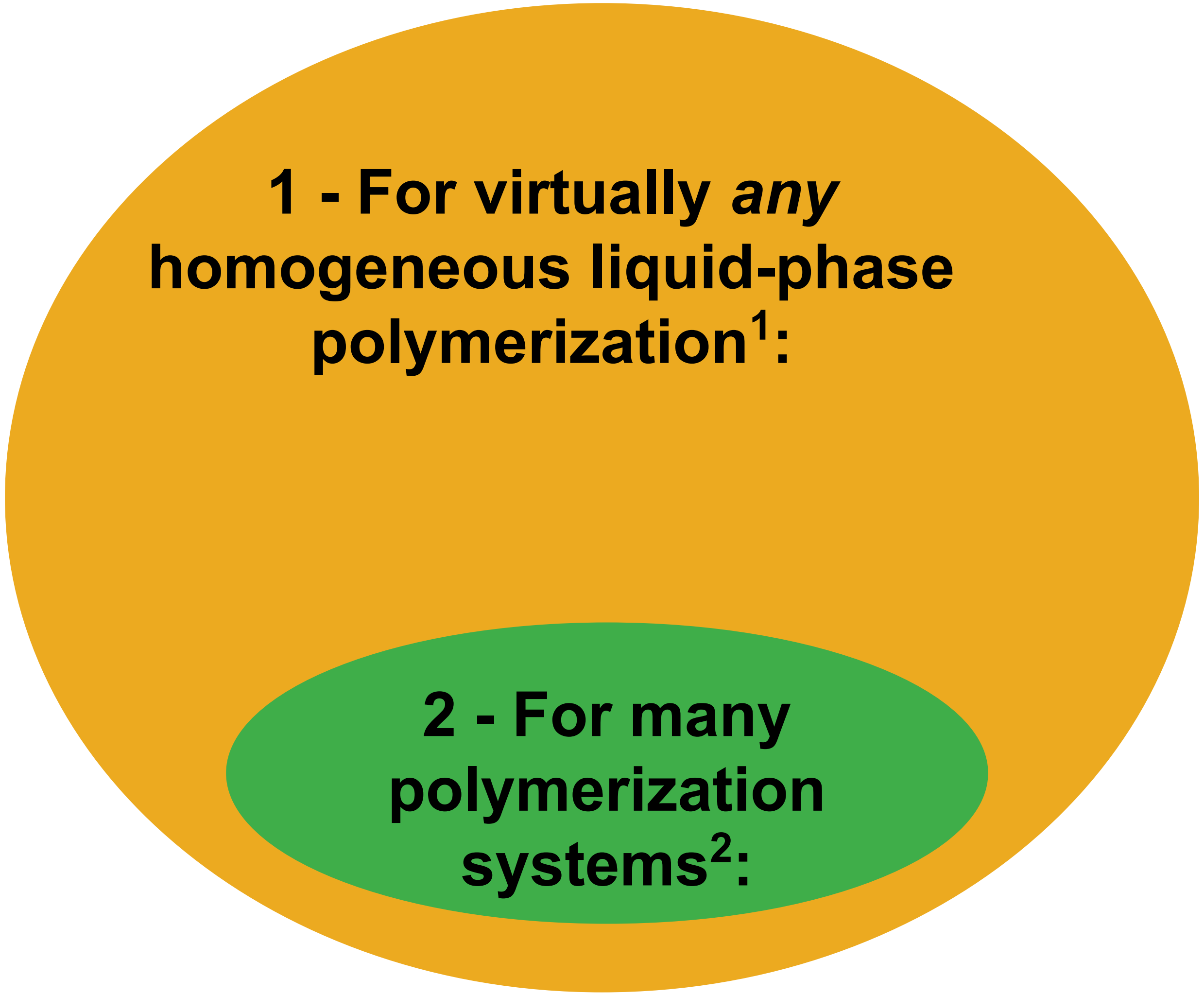
# ACOMP TECHNOLOGY CORE ABILITIES



If we look at what chemistries ACOMP technology works with, this is not a tool we can use everywhere today.  We do have a technology roadmap to cover as much of the very diverse polymer industry as we can, since it has everything from commodity to high volume plastics, all the way to low volume specialty materials, high value batches for semiconductors or electronics, certain adhesives, and paints & coatings.

Today we are particularly focused on anything that is in a liquid or melt phase, which is where we can do most of our measurements.  For some applications, maybe we can’t make all the measurements, but we can track certain other key parameters for correlation if clients decide to engage with us to evaluate our ACOMP technology platform, where we would assess your applications discuss your optimization objectives and create a path forward using our technology.

# ACOMP CORE CAPABILITIES




- Measure polymer intrinsic or reduced viscosity at desired shear rates
- Measure polymer weight-average molecular weight
- Track process deviations via above

*[1] Can measure as long as polymer can be dissolved into a solution – not chemistry-dependent*

- Measure monomer consumption (batch or semi-batch)
- Measure polymer composition
- Track process deviations via above

*[2] Depends on light absorption/refraction qualities of the polymer, therefore chemistry-dependent*

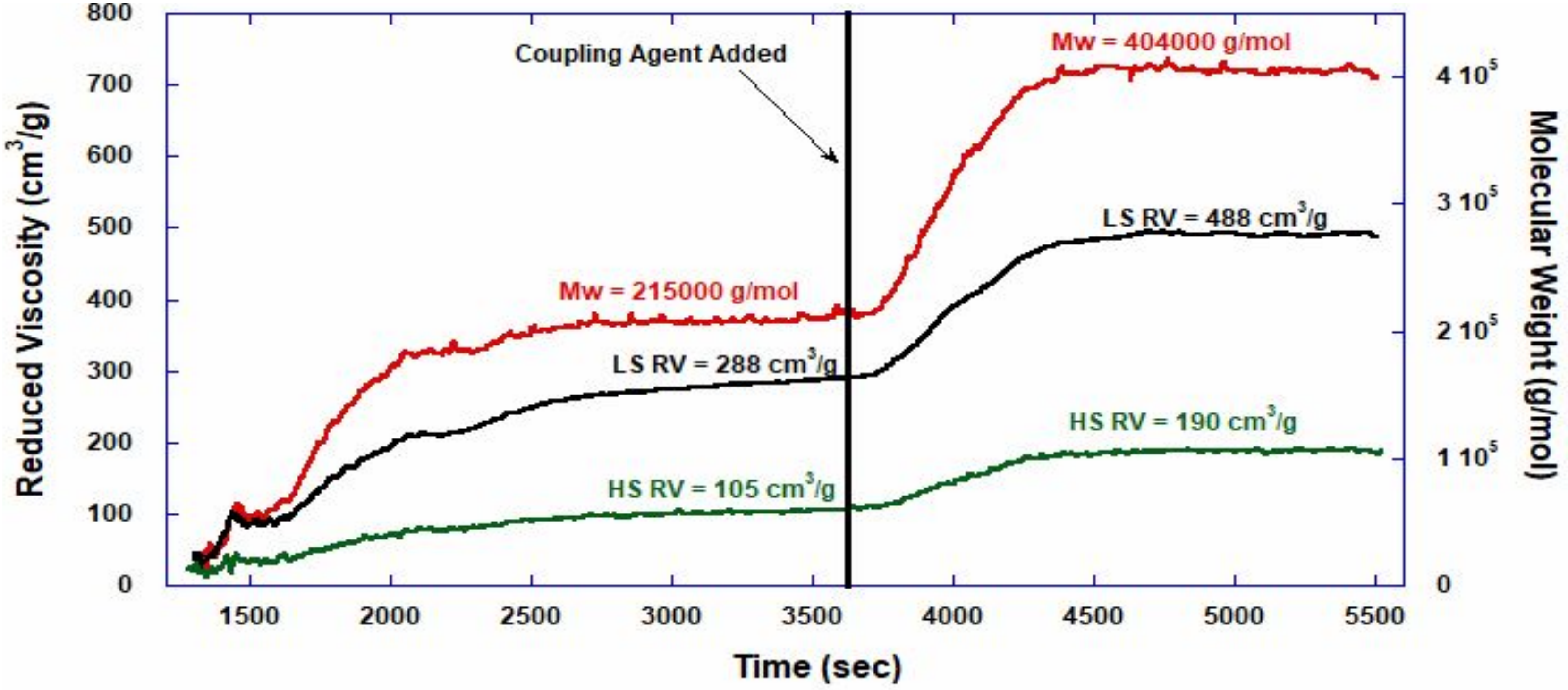
# CASE 1-1: USING ACOMP TO TRACK COUPLING

Here's a case study in an SSBR, solution styrene butadiene production. The process conditions at the bottom of the slide. This is the second phase of a reaction using real-time ACOMP data, so we're looking at the molecular weight, reduced viscosity, and then we have a proprietary high shear viscosity measurement where we intentionally shear the molecules as they pass trough our viscometer getting additional information about architecture and things of that nature.

What we are particularly interested in here is the trend of the molecular weight and viscosity as you build up the first stage of the production polymer. In the second stage where there is a coupling step, seeing the efficiency of that coupling going from step 1 to 2, and looking at some of these ratios and even optimizing when to take this step, so there is quite a few advantage in knowing the properties as you approach that critical next step of the reaction and then obviously if you are thinking about it, if you don't have extra steps how you can use that data to know when batch is done if you're targeting a very specific Mw or viscosity.

# CASE 1-1: USING ACOMP TO TRACK COUPLING

Measurement of viscosity/molecular weight is possible for the vast majority of liquid-phase polymerizations. ACOMP is highly sensitive to the coupling reaction and tracks in real time.




**SSBR, case study at Bridgestone/Firestone**

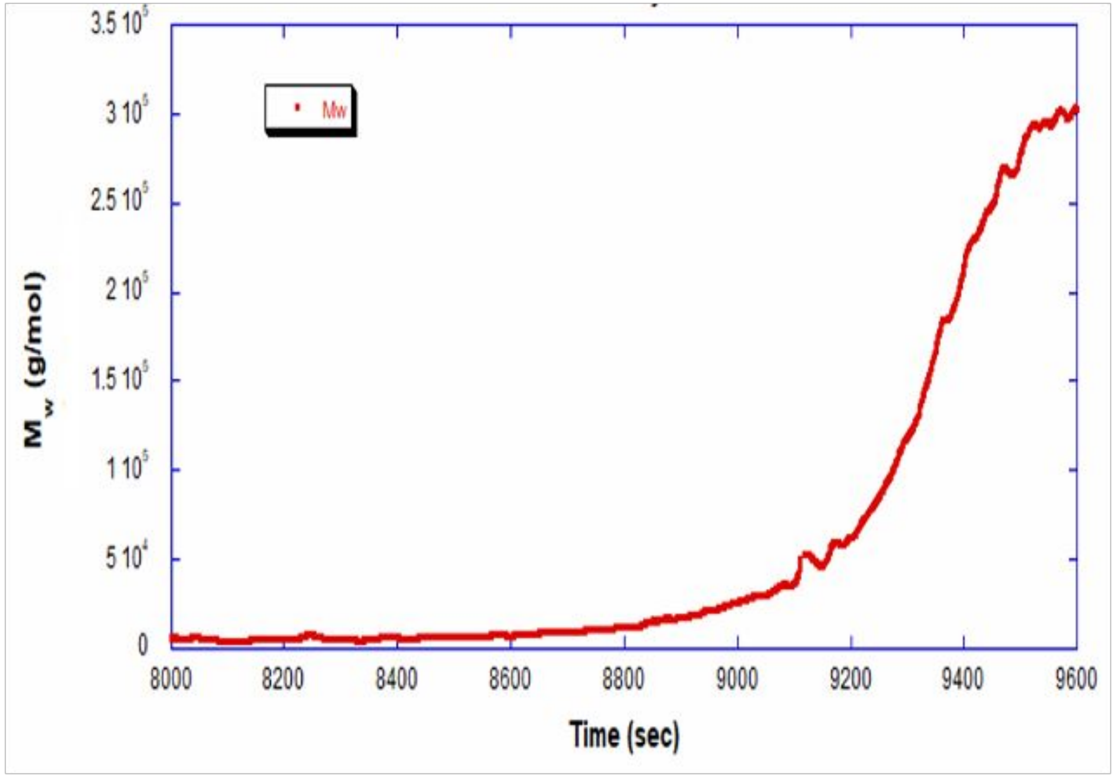
20-liter anionic polymerization: styrene (127 gr), butadiene (508 gr) in hexanes at 14 wt% monomer. Catalyst of n-BuLi (4.46 mmol) and ditetrahydrofurylpropane (2.9 mmol). Tin tetrachloride (1.1 mmol) added for coupling

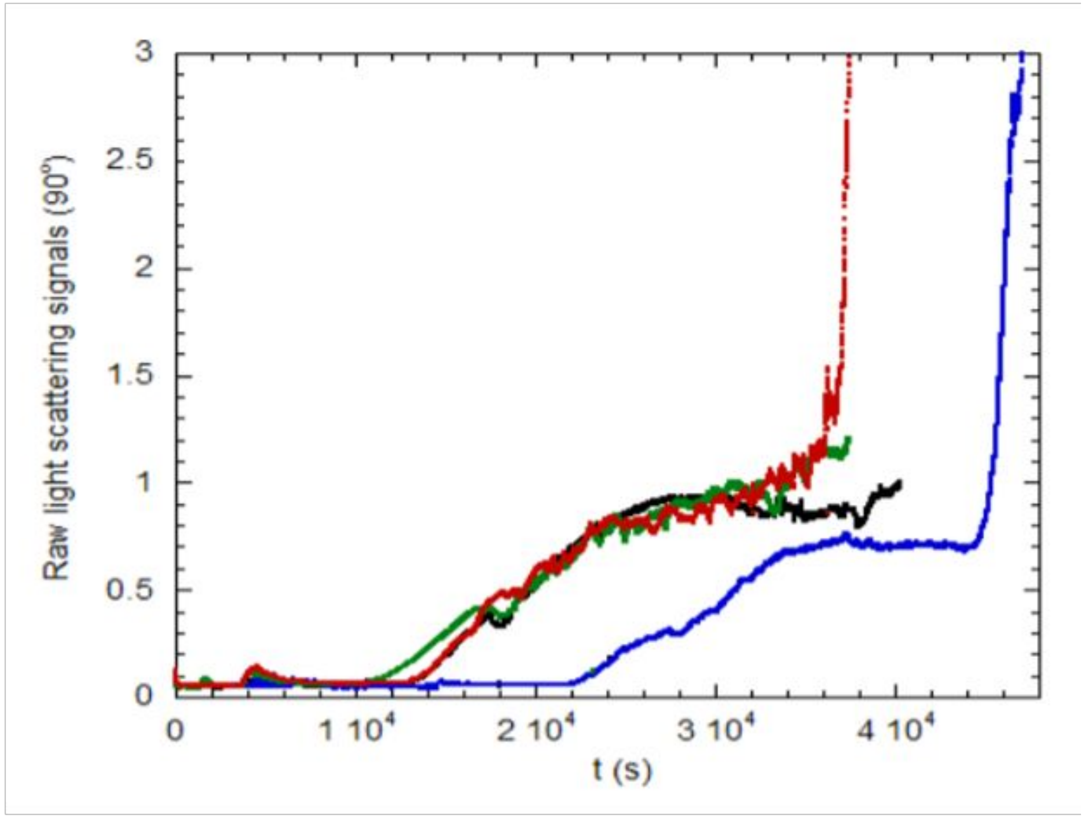
# CASE 1-2: TRACK ONSET OF GELATION

Looking at gelation, we have a way to assess at a very sensitive and at a very low concentration way the onset of gelation events.  This is a step growth of a polycondensation reaction where we can see where we are tracking Mw over time, and then looking at light scattering signatures and then suddenly, you see some spiking towards the end of the reaction.  This occurred well before visible gelation, but it did end up gelling, so an early alarm of that gelation can be seen in this process.

# CASE 1-2: TRACK ONSET OF GELATION

- Light scattering is very sensitive to formation of high molecular weight species and can be used to ***predict the onset of gelation***
- Benefit – prevent batch failure!



# CASE 1-3: CONTINUOUS PROCESS OPTIMIZATION

In continuous production you see here below that basically as mentioned before, this is an EPDM example and the objective is to make a product, in this case a Mooney viscosity measurement, which we've correlated to Mw, and the customer tried to target a very specific window of Mooney in production, which is very standard in this industry.

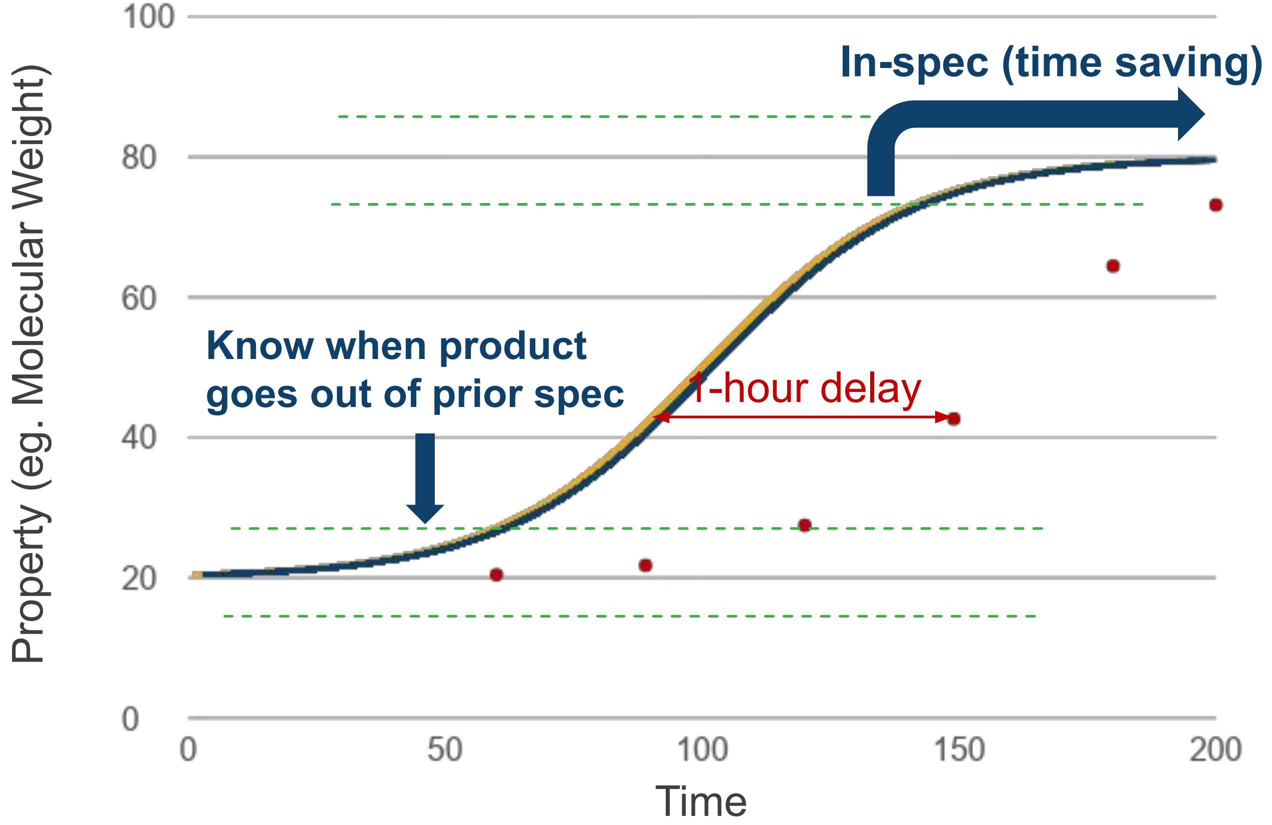
At the bottom of the graph at a Mw of 20, you can see the grey line which would be the midpoint, is the middle of the specification target to maintain.  Realistically, if you could get there as quickly as possible and stay there for the whole production run, you would be making a perfect product, which is what we're targeting.  So, the big benefit here is this grade transition.

Either you go back to a solvent and build back up, or you do a transition from one grade to another, either one that evolution from whatever the previous the condition was, up to that next target property grade, and doing that as quickly as possible minimizes off spec production.

You can see this time from one spec to the next spec, in some cases, that can be many hours of off spec production. And if a lot of times that control is driven by, or at least validated by offline data points taken every 30, 60, or 120 minutes, you can imagine that the control properties are in some cases conservative, or control algorithms used to drive those processes are conservative to account for the fact that there is a lot less live data.  The advantage here is that having realtime information allows a faster path to get to and know when you're in spec, and target to get to spec.  And then once you're at steady state, for example producing at this midpoint, anytime you saw a steady state deviation out of specification then you would know based on the real time information and take corrective action.

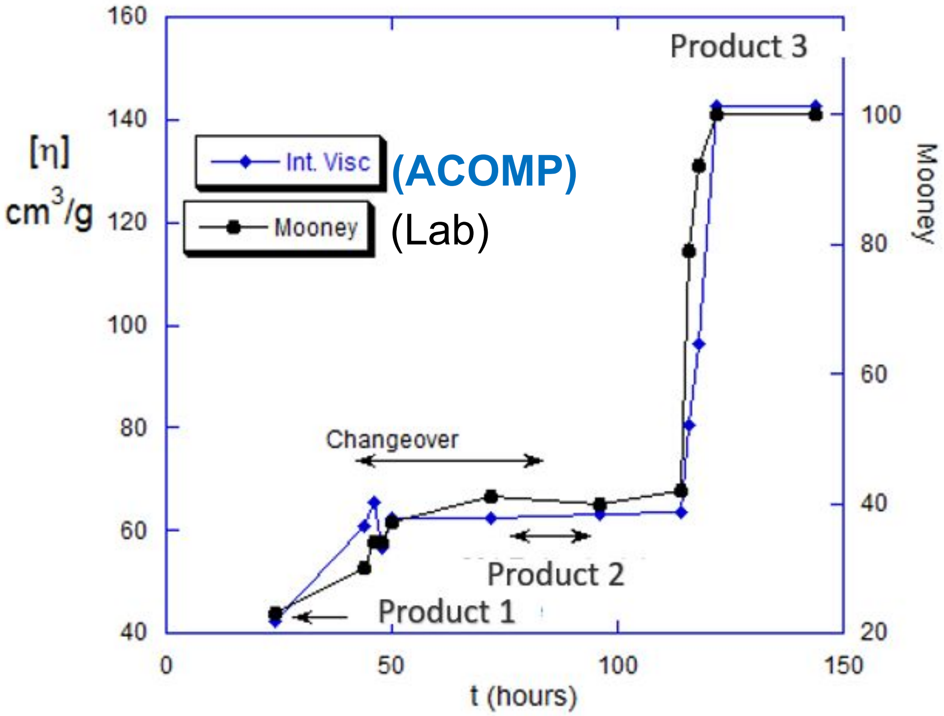
# CASE 1-3: CONTINUOUS PROCESS OPTIMIZATION

## Concept – improved grade transitions




- Real Process - ACOMP Measurement • Lab Measurement

## Proof of concept with discrete samples (EPDM)



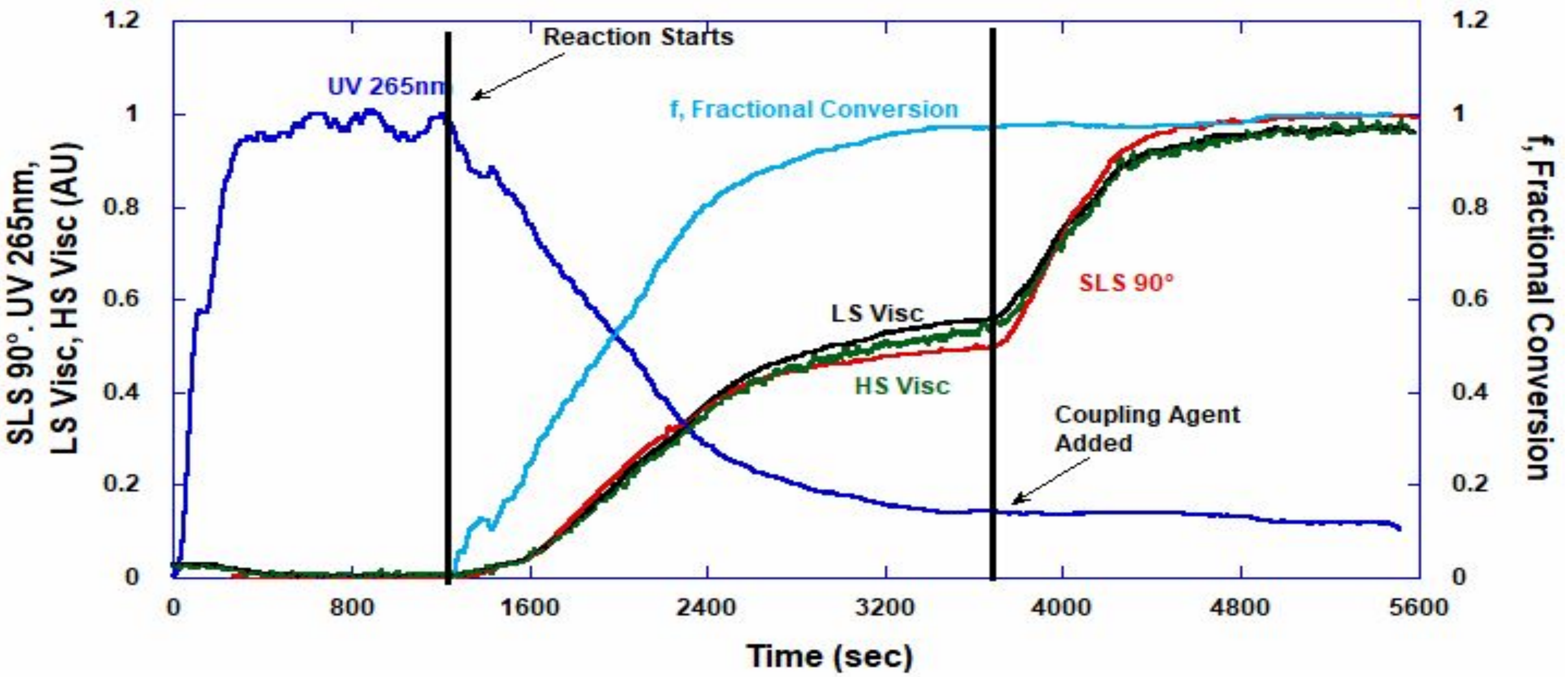
# CASE 2-1: TRACKING OF CONVERSION

Below, is the complete data set with the raw data of that SSBR run, so the first time we showed a focus on the molecular weight properties and the evolution of the reaction towards the last stages, one would see the full run. If one were to look at other types of batch or semi batch applications, this is how we we track conversion, so we're looking at the monomers converting into polymers here through the in this case the UV signature, that's the monomer being consumed over time, and then our calculated conversion value based on that raw data.

And then as expected, as the monomer is being turned into a polymer, you see your polymer mass, whether its from viscosity light scattering or even the sheer viscosity building up over time. This is a very good visual representation showing how the evolution of the reaction and have that information available for control or assessment of the completion of a batch.

# CASE 2-1: TRACKING OF CONVERSION

Tracking of conversion in real time (depending on the number of monomers and their UV traces, this may not always be feasible)




**Bridgestone/Firestone case study, SSBR**

Conditions: see Case 1-1

# CASE 2-2: TRACKING  RESIDUAL MONOMER

Here this is a case below where we were doing residual monomer chasing.  The customer was a specialty manufacturer that had a lot of different grades produced in each reactor, so what we were looking for was a way to understand dynamically the end point of the reaction.

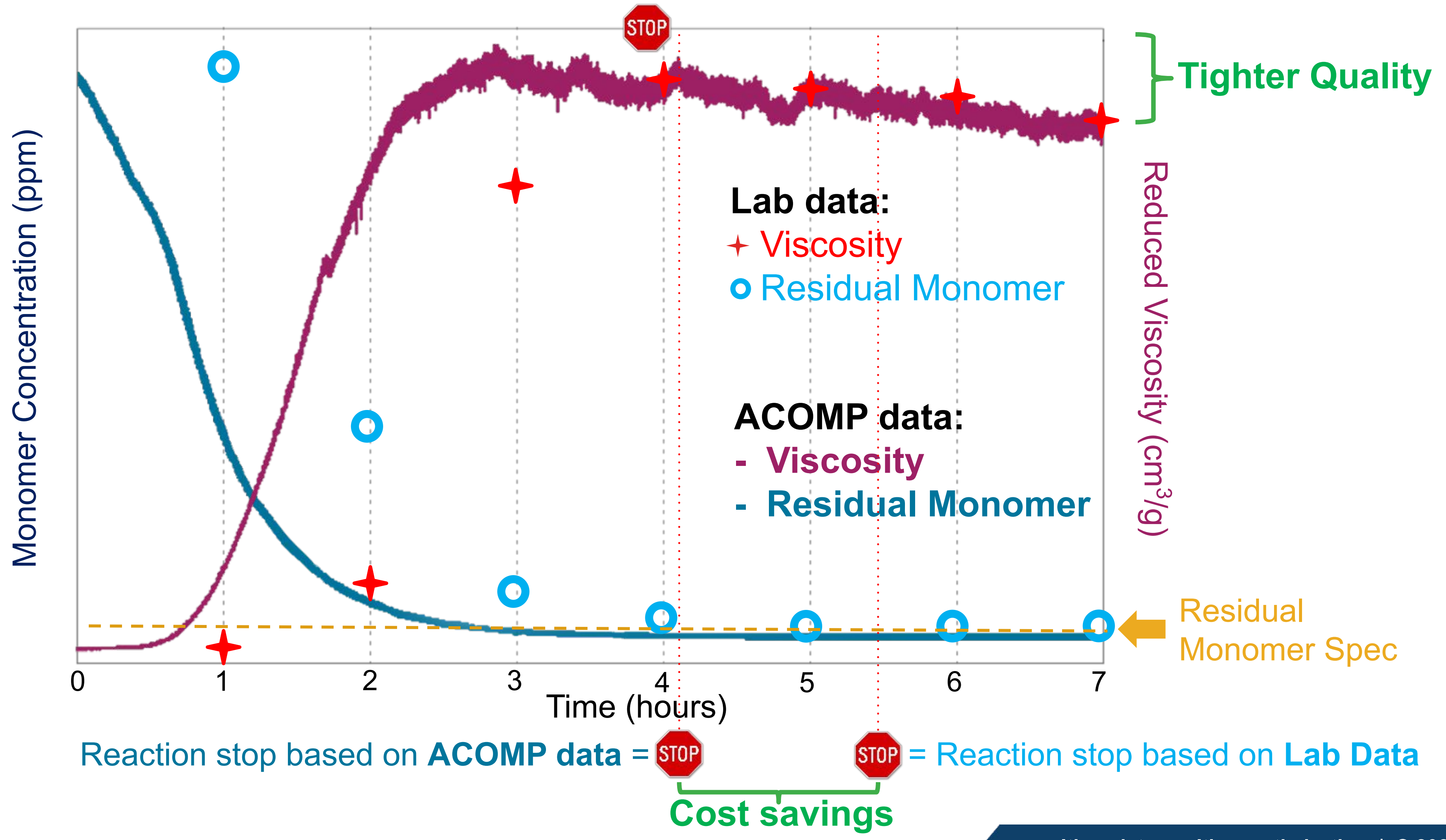
Typically, in a high mix production environments, customers will have very standardized SOP's and, in some cases, standardized to the least common denominator based on the equipment in the entire global plant network or in that specific plant.  A client might have a very specific set of conditions that need to run for example, 2 hours to complete each batch no matter what happens.  In this case what we were able to observe is that given a lot of the variability which was highlighted earlier, you see in batch production, the feedstocks, the operators, the equipment, and all those different elements can change, and the reality is that its going to hit what ever the target specification or specifications are at different points.  The kinetics will vary from reaction to reaction.

What was seen was, that on average if you use the dynamic end-points the process is complete several hours sooner than the standard SOP.  In some instances, some were close to the SOP, but on average if executed across many batches the savings was, in this case, 15-20%.

That is what is represented here in the normal recipe, and this is the stop point based on a dynamic endpoint average over all the batches.  The other thing that was noticed was that one of the key properties the client was selling to the end user was the molecular weight determined by the viscosity.  What was seen in some batches when it was completed sooner, was that the kinetics were faster than expected, and that residual PPM property was achieved, which would represent the offline PPM versus the continuous.  That molecule in that reactor with temperature and shear from the impeller, degraded over time.  It was discovered that large chain molecules under those conditions would degrade slightly.  In order to follow the recipe, there was an impact to the quality, which was unexpected, since the goal was targeting the residual monomer, so we would increase cycle time and saw a quality benefit as well.

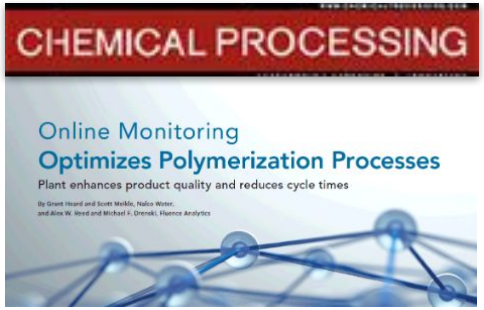
# CASE 2-2: TRACKING RESIDUAL MONOMER

Industrial Polyacrylamide



*“We are excited about the **cycle time savings*** we are seeing with ACOMP, but particularly excited about how it can help us **improve the quality of our polymers**. We pride ourselves in distinguishing our offerings in the marketplace with unmatched service and quality. **ACOMP has helped us advance that cause.**”*

**- GLOBAL DIRECTOR MANUFACTURING PROCESS DEVELOPMENT & QUALITY**
**MULTI-NATIONAL CHEMICAL MANUFACTURER**




September 2018 issue

* **Average 17%** batch cycle time savings, potential of > 500 hours of capacity addition for entire year, **45+** additional batches

# HOW ACOMP WORKS

A little bit more detail on how the technology works, we are continuously extracting a very small stream from the reactor.  We'll go anywhere from 0.05 to multiple milliliters per minute.  The stream comes into our ACOMP front end, where we developed a fully automated set of sample preparation and sample conditioning equipment.  Then we use whatever process solvent or a different solvent to get that polymer stream continuously through our process into a very low concentration which we then flow continuously through our detector train.  This is typically the intrinsic viscosity, shear viscosity, UV and light scattering, and in some of the lab cases, we have the refractive index measurement.  We get this continuous raw data which analyze the properties, which output molecular weight, intrinsic viscosity, composition, total monomer conversion, total residual monomer, PPM, and obviously evolution of the process for any detection of process anomalies we would see as well.

# HOW ACOMP WORKS

Continuously extract, dilute and condition a viscous reactor liquid stream and pass through the detectors at a concentration at which the output signals are dominated by the properties of single polymers, ***not** their interactions.*

- Typical reactor extraction rate 0.05 to 1ml/min
- Typical delay time between extraction and measurement of 30 sec to 5 min (not elution!)
- ACOMP does not employ chromatographic columns, but these can be added for discrete SEC measurements

**REACTOR** →

**SOLVENT** →

**FRONT END**

- Quenching
- Dilution
- Conditioning

→

**BACK END**
**Detector Train**

Intrinsic Viscosity

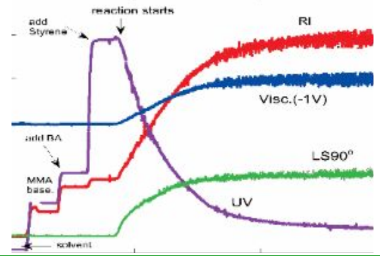
Static Light Scattering

UV Absorption

Differential Refractive Index

→

**ANALYSIS**

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**MONITORED CHARACTERISTICS**

- Molecular Weight
- Intrinsic Viscosity
- Composition
- Monomer Conversion
- Residual Monomer PPM
- Detection of Process Anomalies

# TARGET RETURNS BY DEPLOYING ACOMP

Looking at the ROI, we are driving most of our initial value to customers at the bottom of the pyramid -- the capacity, reducing or eliminating lab analysis, improving yield, and mitigating process upsets.

Quality we see in some cases, is developed over time, and in some cases its immediate, since it's the biggest pain point. We really see a lot of value being created as we help our customers launch new products and deploy those into production.

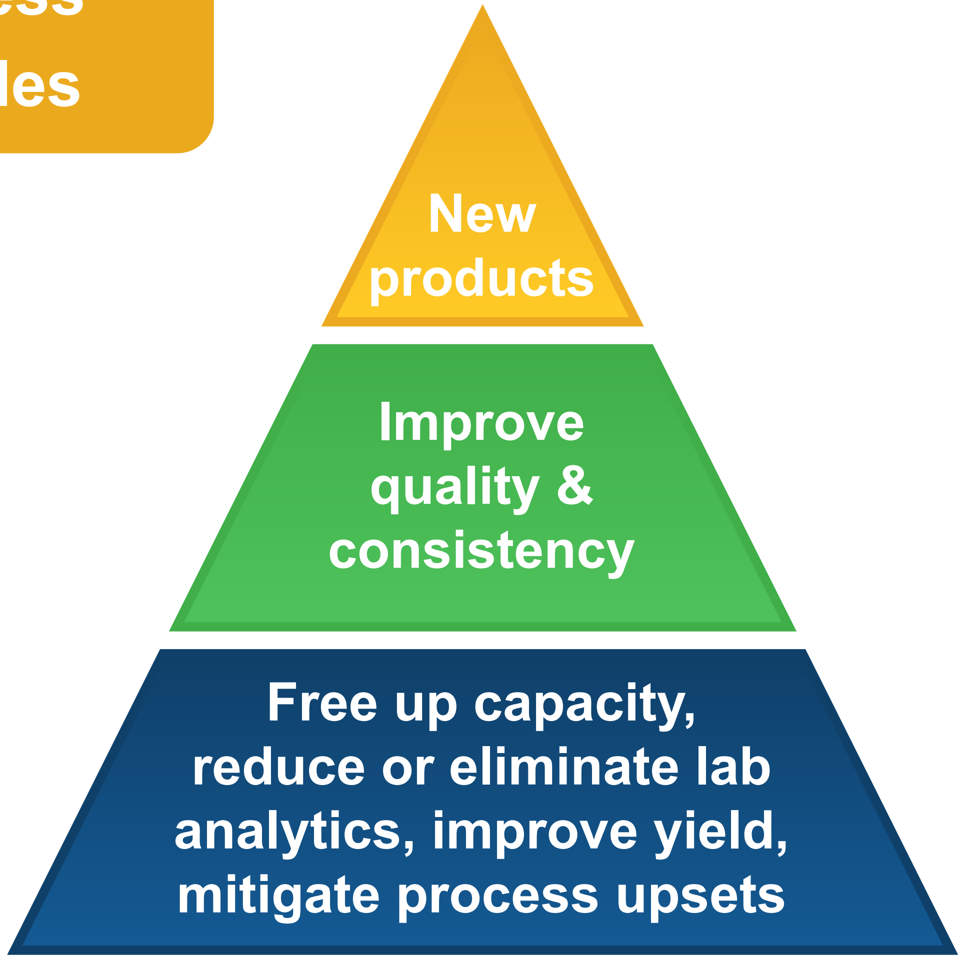
A couple examples would be the batch and semi batch process, which is a fairly large-scale batch production. The key point here is that a small impact to that cycle time based on the residual monomer key molecular weight specification would be significant. The resultant 5-10% impact would be noticeable and would certainly deliver an ROI in less than 1 year.

On the continuous side, the off-spec production and steady state deviation and enhanced changeover control is mitigated.

# TARGET RETURNS BY DEPLOYING ACOMP

**Batch/semi-batch process**
**Ex: 15kt plant, $40m sales**

- **Cycle time reduction – up to $1M+**
- Better product consistency
- Energy savings
- Less manual sampling




**Continuous process**
**Ex: 50kt plant, $120m sales**

- **Off-spec reduction – up to $1M+**
- Improved process control = tighter specs
- Reduce lab analytics
- Less manual sampling

# FUTURE ENHANCEMENTS

Now, as more ACOMP systems are deployed, and more realtime date is generated, there exists a tremendous opportunity for leveraging that information to do feedback control.

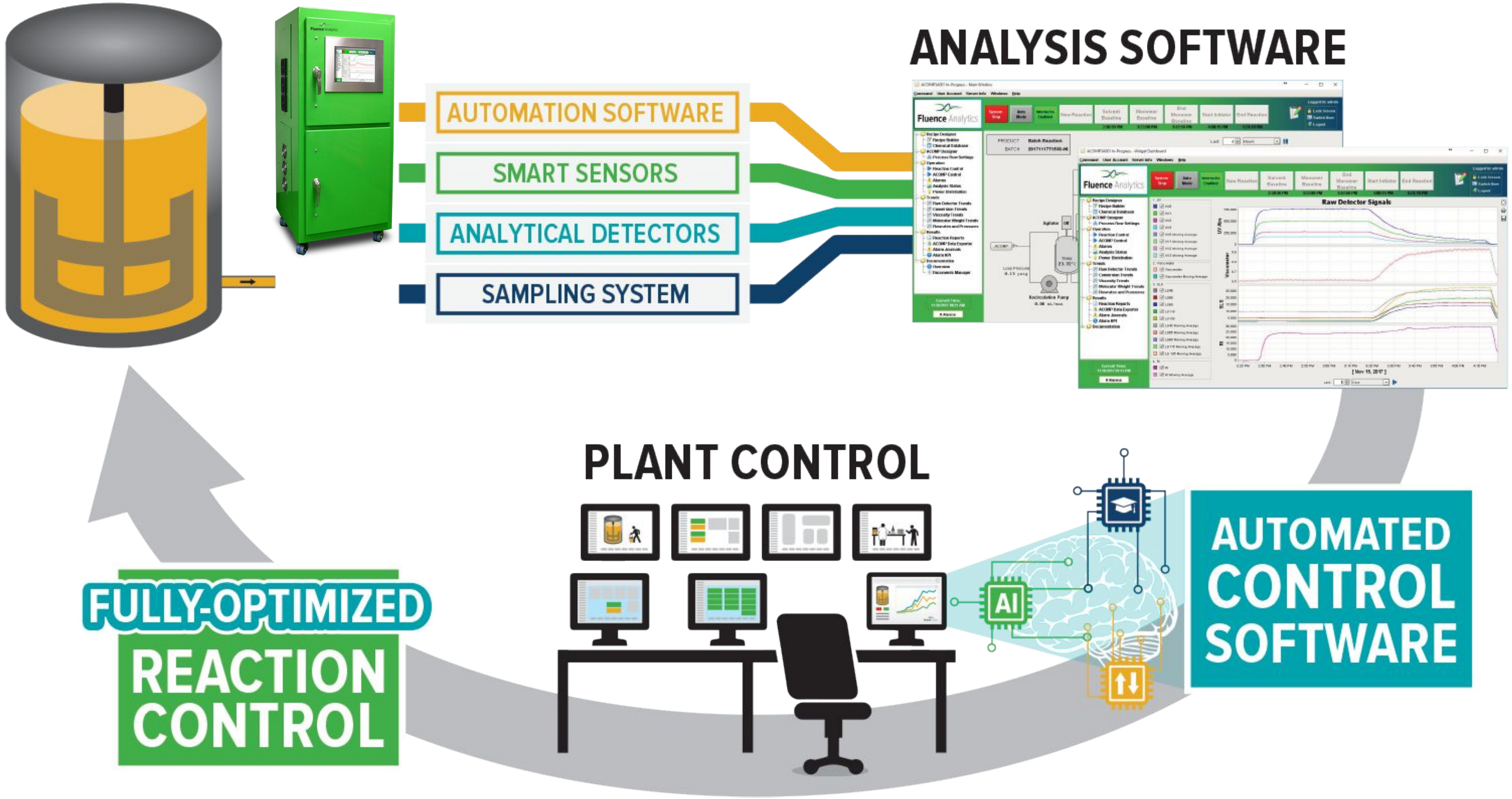
Fluence Analytics has developed some technology in this space and what we're looking at is taking that realtime data on the properties of interest that are being manufactured and sold to end users for performance applications.

We're looking at that realtime property data and designing control algorithms and partner with control systems vendors which would offer functionality to perform feedback Control action  to drive towards specific performance properties, in the end application and making each production run as close to specification as possible in a very tight window.

# FUTURE ENHANCEMENTS

***ACOMP TOMORROW -** Decisions made automatically with dynamic information*

Batch
Semi-batch
Continuous




***Feedback control driven by properties and plant parameters maximizes production efficiency***

# ACOMP-ENABLED ACTIVE CONTROL

Fluence Analytics executed a pilot scale implementation with the controller shown below on the right for a traditional polyacrylamide reaction with the batch process shown as the blue line.  This would be the natural trajectory as your polymer's molecular weight evolves over time during the polymerization process.

On the right of the diagram below is the typical ACOMP system, with the extraction, recycle, and all the mixing and analysis parameters which were available for ACOMP to control the reactor including impeller speed, heating/cooling, adding chain transfer agent, initiator monomer, oxygen, and nitrogen.

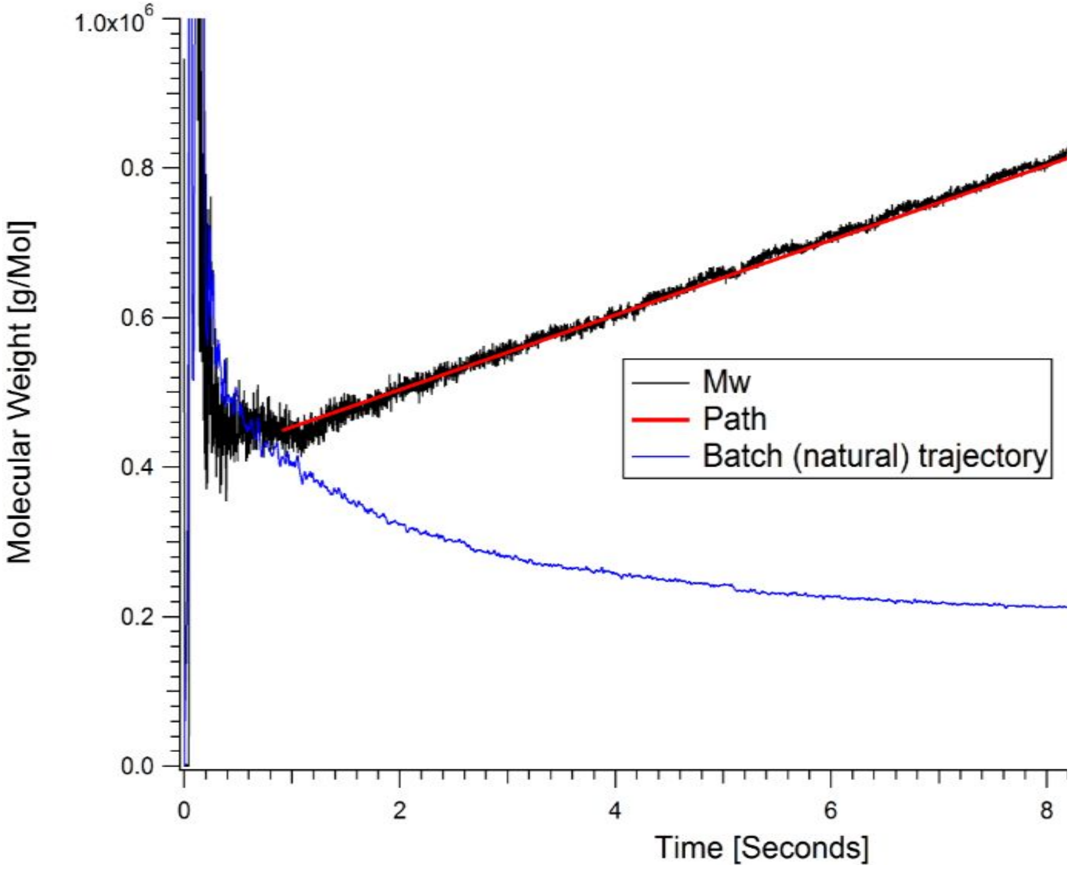
With access to all the aforementioned parameters for control, the goal was targeting Mw by dynamically adjusting control of the reaction using monomer and initiator feeds.

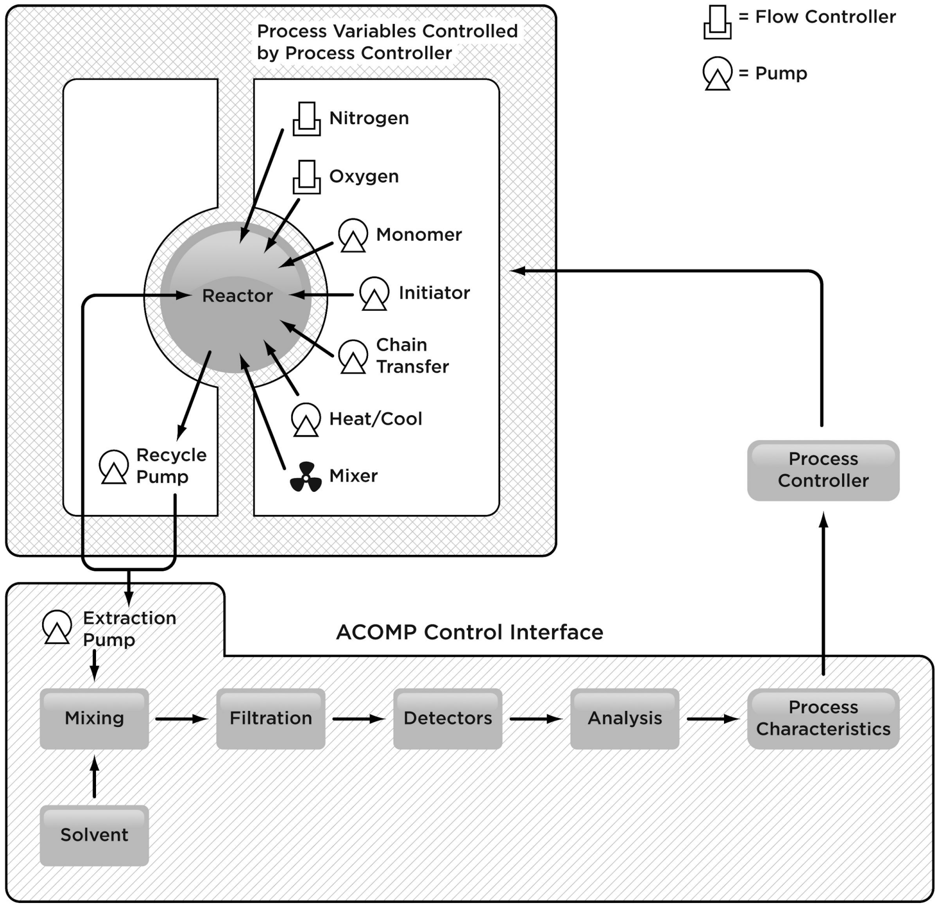
In order to show a very very different trajectory than what would be the natural path, we had a set point to increase average molecular weight throughout the rapid cycle reaction, so we had a target set point and as we were running and feeding real-time data into our controller, we could very quickly assess any kind of deviation and adjust monomer or initiator feeds to be lock-step with the set point which factored in flow rate delays.

# ACOMP-ENABLED ACTIVE CONTROL

## Aqueous Free Radical Polymerization of Acrylamide

**Note $M_w$ evolution is against the normal batch trend!**



# DATA CONTEXTUALIZATION AND PROCESS MODELING

Another area we see opportunity is in data contextualization.

In a typical plant, there's a control system with a lot of realtime process information, LIMS (laboratory information and management system), as well as a process historian such as OSI Pi which has Terabytes of historical information that they could access that has been collected over many many years.

So, combining these data sets with the context of the realtime properties generated by ACOMP is huge, since we can look at the process conditions in realtime and look at historical data to identify which of the process conditions affected and created certain results for properties with feedback to correlate with other lab data and build advanced correlations over time to a number of parameters. If one has access to realtime properties, realtime regular sensor data, temperature, pressure, and combined with the lab, then suddenly you're looking at a very interesting mix of data sets to optimize your processes over time.

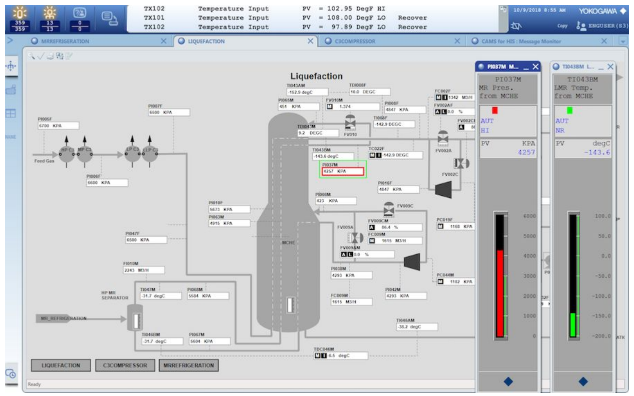
Then for troubleshooting and any kind of quality issue as indicated by the measurement technology, tracing that back to whatever it was in your feedstock, or anything in ERP for example, you could then identify the reason for that to get to the issue faster.

# DATA CONTEXTUALIZATION AND PROCESS MODELING

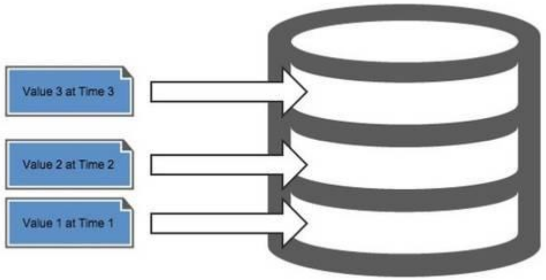
Control System:
Real-time Process Information

Optimization
Troubleshooting
Decision making
Modeling
Control strategies

Inventory, Raw Materials, Etc.

Time Series Data – Process Historian




Lab Data

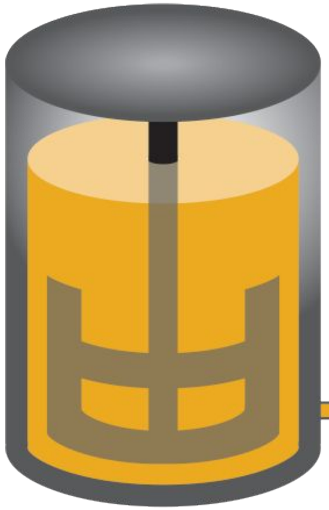

# ACOMP APPLICATIONS

A lot of the end use applications for ACOMP exist in elastomers, water soluble polymers, engineering plastics, adhesives, paint, and coating applications, which are of particular interest today. There are also different ongoing development projects working with certain customers to expand into applications that we are slated for future versions of the technology.

And for batch, semi batch and continuous processes we are working with all types of conditions and processes including solution emulsion, bulk, and evaluating whatever other conditions of interest our for customers to continually evolve the ACOMP platform to help optimize their processes.

# ACOMP APPLICATIONS

Solution
Emulsion
Bulk



AUTOMATION SOFTWARE

SMART SENSORS

ANALYTICAL DETECTORS

SAMPLING SYSTEM

## ANALYSIS SOFTWARE


### Processes

- Batch
- Semi-batch
- Continuous

### Polymer Applications

- Elastomers
- Water Soluble Polymers
- Engineering Plastics
- Adhesives
- Paints & Coatings

Continuously
Expanding
Applications

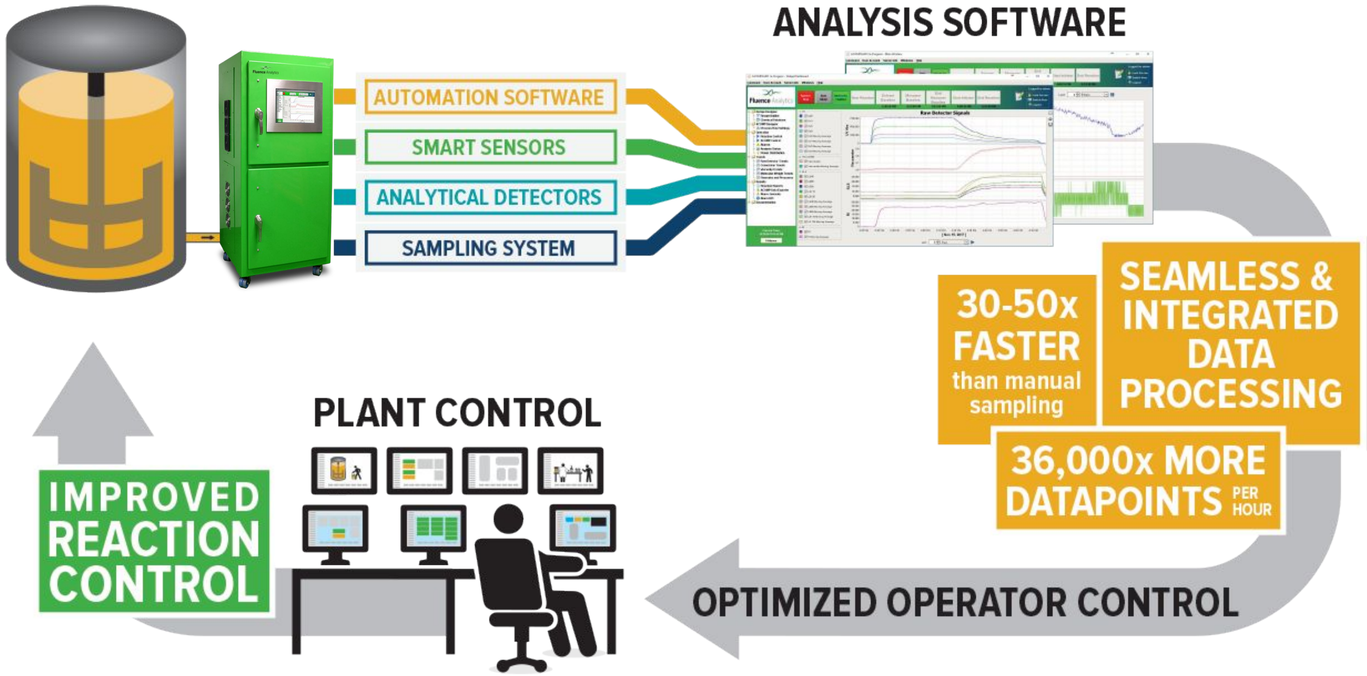
# RECAP: ACOMP MONITORING IN REALTIME

Today what we are offering a realtime dataset that has never been generated before and based on our customer feedback and data we see in the field we believe it adds tremendous value in optimization production.

Some of the key benefits are production yield, quality aspects, reducing off spec, increasing capacity, launching new products faster, reducing worker exposure, safety. All of our targets are to minimize raw material consumption and material waste.

Therefore, customers need a reliable and trusted technology partner who can help them optimize manufacturing processes and help make our customers products better.

*Decisions made **in real-time** with ACOMP hardware and software*




***We digitize the process, collect better data and optimize reaction control in a fraction of the time***

# THANK YOU

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