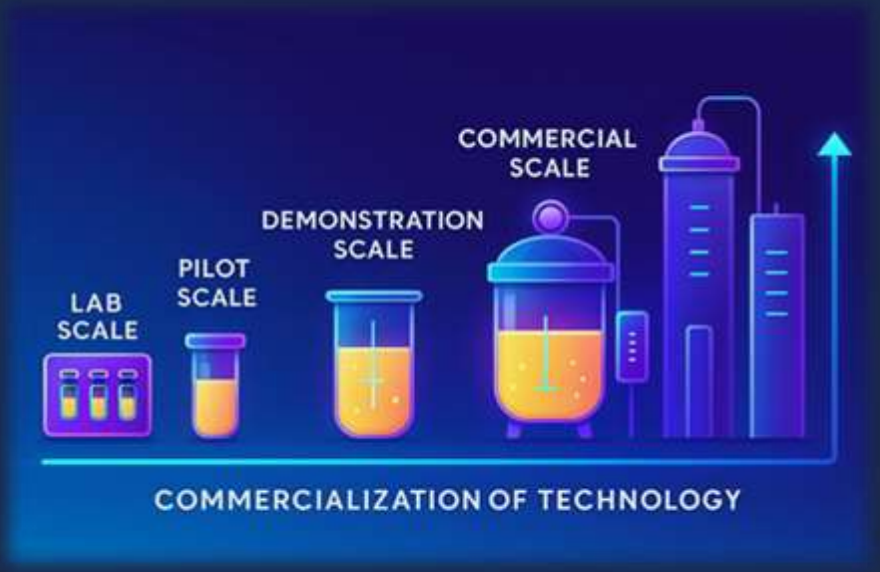
PILON'S TECHNOLOGY SCALE-UP ROADMAP

From Process Validation to Commercial Success

BATCH TO CONTINUOUS...



A Phased Scale-Up Roadmap — From Lab Studies to Commercial Production

WITNESS TRIAL

POC

PILOTING

DEMONSTRATION/ COMMERCIAL

POWERED BY PILON ENGINEERING

PILON ENGINEERING PVT. LTD.

TECHNOLOGY READINESS LEVEL, PROCESS DEVELOPMENT ROADMAP

From first on-site trials to commercial deployment — a staged, evidence-led path for scaling your process.

1

Demo Trials

Prove Feasibility, seeing is believing

2

1-5 kg/day

Prove Feasibility

3

50–500 kg/day

Scale-Up Production

4

TPD Scale Production

Commercial Plant

Each milestone builds on validated data from the previous stage — lab batch studies at the Pilon’s R&D facility are backup for 5 kg/day prototype; prototype data drives the 100–150 kg/day scale-up; scale-up data underpins the final 200–500 TPD commercial plant, built at Pilon's continuous plant design facility.

1. **Trials at client premises**
   1-2 day
2. POC
   2-3 weeks
3. Piloting
   12-16 weeks
4. Demonstration/ Commercial
   30-45 weeks

First Trials Witness at Client Site

Before committing to a formal proof-of-concept program, Pilon runs short, low-risk trials directly at client facility — on your feedstock, with your raw materials — to confirm the chemistry is worth pursuing further.

A OBJECTIVES

1. Witness complete batch reaction
2. Study catalyst type, particle size/loading and performance
3. Review raw materials, charging sequence and mixing
4. Record temperature, pressure, dosing, agitation, residence time
5. Observe sampling points, yield, selectivity and impurities

B ACTIVITIES

1. Witness plant trials
2. Record process conditions
3. Discuss technical challenges
4. Define project objectives
5. Trial observation report

Results will give an unambiguous signal to invest in a full POC program

OUTCOME: Trials will confirm that the reaction proceeds cleanly on the client's real feedstock — the project can be taken up to formal POC planning.

PHASE 02 · POC
1-5 kg/day

POC _Proof of Concepts

After successful Trials at client side, PILON performs a Proof of Concept (POC) on its systems to validate the technical feasibility of converting the client's batch process into a continuous process while optimizing critical process parameters.

A OBJECTIVES

Demonstrate feasibility of converting the batch process to continuous manufacturing process

B ACTIVITIES

1. Design experimental campaign
2. Replicate reaction on PILON lab flow reactors by developing necessary systems
3. Resolve challenges (mixing, heat transfer, clogging, catalyst, kinetics)
4. Optimize reaction parameters
5. Compare results with batch process (Yield/Conversion ±5% target)
6. Improve, yield, conversion, residence time, selectivity etc.

Results will establish a validated continuous process, providing the engineering confidence required for Pilot Plant execution. Raw materials and analytical part execution can be discussed during final stages.

OUTCOME: POC trials will confirm process feasibility, optimize critical operating parameters, mitigate technical risks, and deliver the engineering data necessary for successful pilot-scale implementation

PHASE 02 · POC
1-5 kg/day

Cost Structure & Deliverables

Cost Structure

- Chemical cost
- Resources cost
- Plant & facility cost
- Investment cost (plant modification)
- Project management & travel cost
- Analytical & RM cost in client scope. Catalyst scope to be discussed.

₹2.5 to 4.5 Lakh / week for MGFR/ SFR/ ContiHYflow reaction feasibility

Optimization of reactions is secondary which can be extended after feasibility

Minimum support cost to be paid to the Pilon team weekly, for fast execution. This is full-time equivalent cost invested for 24X7 running of plant

Milestone-01 Overall Cost can be proposed after witnessing reactions at client premises_(Nitration/ Hydrogenation, other homogeneous/ heterogeneous reactions)

Deliverables

Safety

Process safety validated during continuous run, utility optimization, Life Cycle Reduction etc.

Utility Cost

Utility consumption benchmarked at pilot scale

Batch Cycle Reduction

Limited by reaction kinetics — an inherent, chemistry-dependent property. Some molecules improve; others remain unchanged.

Pilot Plant

Upon successful completion of the POC, the Pilot Plant phase will be initiated for further process validation and continuous trials.

A OBJECTIVES

1. Pilot Scale Validation
2. Validate the process at pilot scale.
3. Optimize operating parameters.
4. Generate scale-up data.
5. Verify continuous process stability.
6. Minimize scale-up risks.

B ACTIVITIES

1. Witness plant trials
2. Continuous pilot plant trials.
3. Process optimization.
4. Catalyst performance evaluation.
5. Product quality validation.
6. Data collection for commercial scale-up.

Results will provide the confidence and engineering data required to proceed with the Demonstration Plant (500 kg/day–1 TPD).

Pilot plant trials will validate continuous operation, process stability, and product quality, enabling scale-up to the Demonstration Plant phase.

Approach & Execution Timeline

__Goal__: Scale production ahead of the larger commercial investment — steps run in parallel with Milestone 1.

1 Data Analysis from Milestone-01

This can initiate simultaneously as well if Milestone-01 gives confidence, meanwhile further Milestone-01 optimization can work parallelly.

2 BDEP (Basic & Detailed Engineering Package)

Costing, simulation, CFD, sizing, datasheet preparation_ up to 6 weeks

3 Approval & alignment between both parties to move ahead with project

7-8th Week

4 Procurement

Material gets received till 10-12th Week from BEP approval

5 Manufacturing & Integration of system

Till 14-16nd week from BEP approval

6 FAT in Pilon premises & SAT at client premises

Till 16-18th Week from BEP approval

7 Plant Testing on actual feeds

Post 18th Week till the period of 4-8 weeks

Resourcing note: Pilon provides supervisory support during testing; plant is operated by the client, with all HAZOP and site requirements in the client's scope. Pilon resources to be billed on monthly basis.

Cost & Completion

Cost Components

- Engineering Cost
- Plant and resources cost
- Cost of technology
- Installation of plant, completed before start-up

Analytical Handoff

Unlike Milestone 1, analytical work for Milestone 2 moves fully to the client's own facility.

Milestone Stages

- Stage-A: Pilon acts as EPC partner for Milestone-2 plant development
- Stage-B: Pilon acts in a Supervisory role while Operations will be carried by client.

Milestone 2 Completion

All Technology rights to be reserved with Pilon.

Investment Milestones:

- Proposal Report for Capex investment
- Plant & Machinery Cost

Demonstration Plant to Commercial

Upon successful completion of the Pilot Plant phase, the Demonstration Plant will be established to validate long-duration continuous operation, confirm process robustness, and generate commercial-scale operating data

A Demonstration Plant (500-2000 kg/day)

1. Basic & Detailed Engineering
2. Procurement, Manufacturing
3. FAT, SAT & Trial Runs
4. Duration: 5–7 Months

B Commercial Plant

1. Detailed Engineering
2. Fabrication & Installation
3. Commissioning & Performance Guarantee
4. Duration: 8–12 Months

Results will establish a fully operational commercial process, delivering sustainable production with proven performance and reliability.

Outcome: Commercial Plant commissioning will confirm process guarantees, production capacity, product quality, and operational reliability, enabling long-term commercial manufacturing with minimized technical risk.

Approach & Ownership Model

***Goal**: Build the full commercial plant, using validated Milestone 2 data.*

1

Capex BEP Preparation & Purchase Order

Cost, resources, simulation, CFD, sizing, datasheets, automation, mechanical 3D & GA drawings.

12 weeks after M2

Ownership Model

Pilon develops BEP

Engineering of Plant to be done by Pilon

Plant Exclusivity

Exclusivity applies specifically to commercial-scale work.

If Built by Another Vendor

Pilon acts as reviewer and supervisor of the commercial plant. Pilon to earn royalty on total production or Client may pay one time technology cost against exclusivity for 5 years.

Loss of Opportunity clause will be implemented in case development doesn't proceeds beyond Milestone-02 due to unforeseen circumstances.

Build Timeline

12

weeks

Detailing

→

20-25

weeks

Build-Up

if no deviation

→

8-12

weeks

Trials & Commissioning

~30-45 weeks total, PO to commercial production

Detailing, build-up, and trial durations are largely fixed by engineering and safety requirements.

PROCESS ENGINEERING RISKS

Continuous Process Challenges

Eight variables that must be engineered and controlled together to run safely at scale.

- Transport & Hydraulics
- Reaction Control & Safety

HYDROGENATION SCALE-UP

01 **Gas–Liquid–Solid Mass Transfer**
Uneven contact limits conversion

02 **Material Solubility**
Caps reaction rate at scale

03 **Catalyst Wetting**
Uneven liquid coverage on catalyst

04 **Pressure Drop**
Rises with bed length & flow

05 **Hot Spot Formation**
Localized overheating, runaway risk

06 **Catalyst Deactivation**
Fouling, poisoning, sintering over time

07 **Residence Time**
Balances conversion against throughput

08 **Gas Distribution & Safety**
Even feed, leak prevention

PILON ENGINEERING PVT. LTD.

Why Choose Pilon Engineering?

End-to-End Scale-Up Partner — *from laboratory proof-of-concept to commercial production, complete hydrogenation scale-up solutions under one roof.*

OUR EXPERTISE

1 Process Development

- Reaction feasibility studies
- Catalyst screening & optimization
- Process intensification

2 Reactor Portfolio

- Continuous Flow & Fixed Bed
- Slurry & CSTR Cascade
- Trickle Bed Reactors & many more..

3 High-Pressure Reactions

- Design pressure up to 100+ bar
- Temperature up to 500°C
- Safe hydrogen handling

4 Process Safety

- HAZOP-oriented engineering
- H_2 leak prevention & inert purging
- Automated safety interlocks

5 Automation

- PLC-SCADA & recipe control
- Remote monitoring
- Complete data logging

6 Global Project Execution

- Design, manufacturing & FAT
- Installation, SAT & commissioning
- Operator training

SCALE-UP PATHWAY

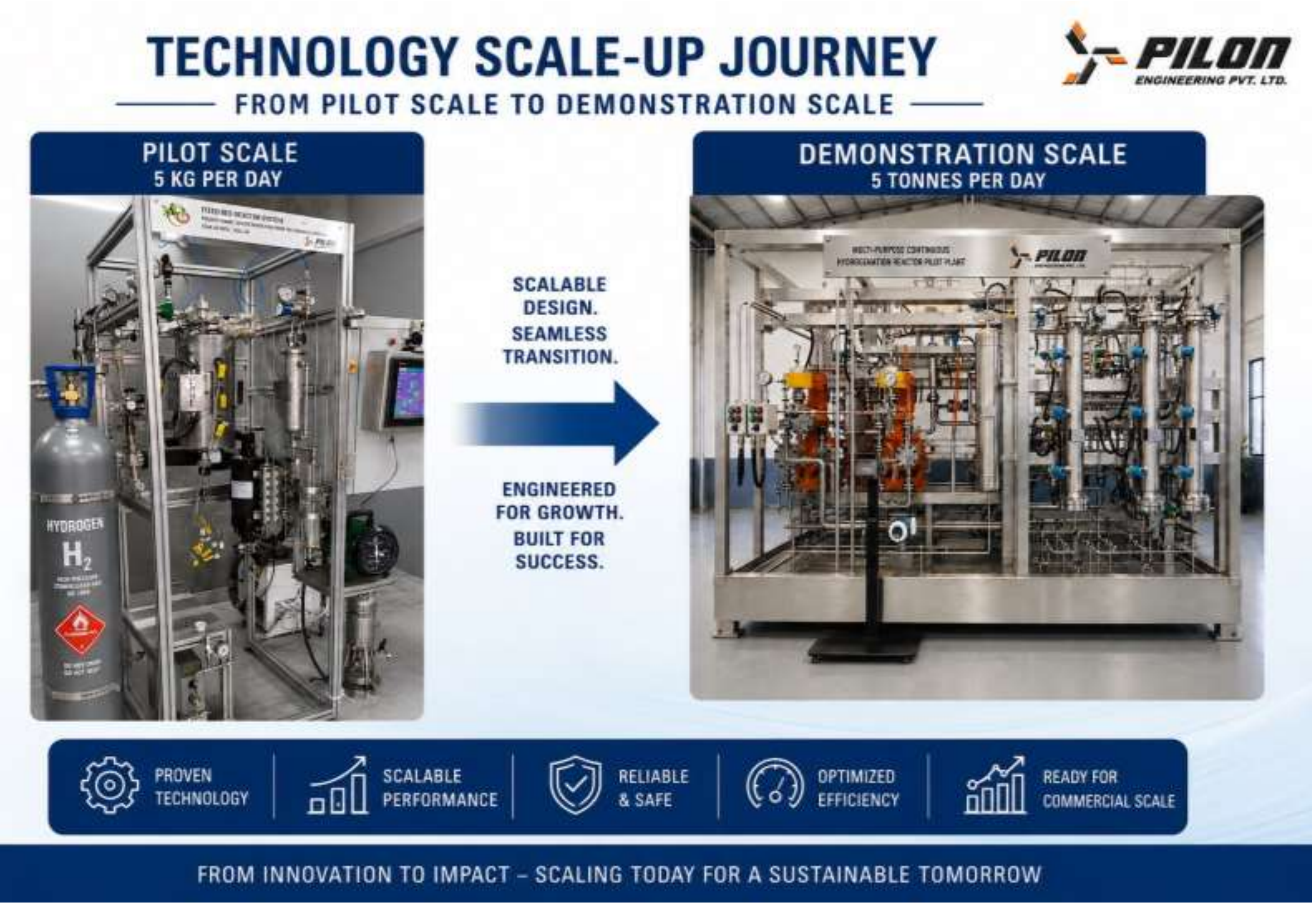
POC › Pilot Plant › Demonstration Plant › Commercial EPC

WHY CUSTOMERS CHOOSE PILON

- ✓ End-to-End Engineering Partner
- ✓ Reduced Scale-Up Risk
- ✓ Faster Time-to-Commercialization
- ✓ Proven Continuous Hydrogenation Expertise
- ✓ Customized Pilot & Demonstration Plants
- ✓ Complete EPC Solution

PILON'S CONTIHYFLOW

CONTINUOUS HYDROGENATION CAPABILITIES



PROCESS PARAMETER RANGE

Parameter	Typical Range
Pressure	1–350 barg
Temperature	Ambient to 950°C
Hydrogen Flow	1 mL/min to several thousand Nm^3/h
Reactor Volume	mL scale to commercial plants
Residence Time	Seconds to several hours
Catalyst	Pd, Pt, Ru, Rh, Ni, Cu, Co, Raney Ni, Raney Co, noble metals, custom catalysts

PROCESS COMPARISON

Why go for Continuous Process

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PARAMETER	BATCH HYDROGENATION	CONTINUOUS HYDROGENATION
Operation	One batch at a time	Continuous feed and product withdrawal
Impurities	Higher	Lower
Production	Intermittent	Steady, uninterrupted
Product Quality	Can vary batch to batch	Highly consistent
Hydrogen Utilization	Lower efficiency	Higher efficiency, better contact
Heat Transfer	Difficult, highly exothermic	Excellent removal & control
Safety	Larger reactant inventory	Smaller volume, reduced risk
Pressure & Temp Control	Can fluctuate	Maintained at setpoints
Catalyst Use	Slurry, needs separation	Fixed-bed / continuous system
Scale-up	Increase reactor size	Number-up or run longer
Automation	Limited	High level of automation
Downtime	Charge/heat/cool/clean cycle	Minimal downtime
Operating Cost	Higher labor & utility cost	Lower cost over time
Capital Cost	Lower initial investment	Higher initial investment
Best For	Small volumes, R&D	Large-volume, consistent production

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REACTIONS IN CONTIHYFLOW

01 NITRO GROUP HYDROGENATION

- Nitrobenzene → Aniline
- Dinitro compounds → Diamines
- Nitro pyridines
- Nitro heterocycles
- Nitro aromatics

02 OLEFIN HYDROGENATION

$$R-CH=CH-R' \xrightarrow{H_2} R-CH_2-CH_2-R'$$

- Alkene → Alkane
- Styrene → Ethylbenzene
- Vinyl toluene hydrogenation
- Diene saturation
- Polyunsaturated compounds

03 ALKYNE HYDROGENATION

$$R-C\equiv C-R' \xrightarrow{H_2\ \text{(partial)}} R-CH=CH-R' \xrightarrow{H_2\ \text{(complete)}} R-CH_2-CH_2-R'$$

- Alkyne → Alkene (partial)
- Alkyne → Alkane (complete)
- Acetylene removal
- Selective semi-hydrogenation

04 AROMATIC RING HYDROGENATION

- Benzene → Cyclohexane
- Toluene → Methylcyclohexane
- Naphthalene → Tetralin/Decalin
- Phenol → Cyclohexanone/ Cyclohexanol

05 CARBONYL HYDROGENATION

$$R-\overset{O}{\overset{\|}{C}}-R' \xrightarrow{H_2} R-\overset{OH}{\overset{|}{C}H}-R'$$

- Aldehydes → Alcohols
- Ketones → Secondary alcohols
- Aromatic ketones
- α,β-Unsaturated ketones

06 ESTER HYDROGENATION

$$R-\overset{O}{\overset{\|}{C}}-OR' \xrightarrow{H_2} R-\overset{OH}{\overset{|}{C}H_2}-R'$$

- Fatty esters
- Methyl esters
- Biodiesel intermediates
- Specialty esters

07 CARBOXYLIC ACID HYDROGENATION

$$R-\overset{O}{\overset{\|}{C}}-OH \xrightarrow{H_2} R-CH_2-OH$$

- Organic acids
- Aromatic acids
- Fatty acids

08 AMIDE HYDROGENATION

$$R-\overset{O}{\overset{\|}{C}}-NH_2 \xrightarrow{H_2} R-CH_2-NH_2$$

- Primary amides
- Secondary amides
- Specialty intermediates

09 NITRILE HYDROGENATION

$$R-C\equiv N \rightarrow R-CH_2-NH_2$$

- Benzonitrile → Benzylamine
- Aliphatic nitriles
- Dinitriles

10 IMINE HYDROGENATION

$$R-CH=N-R' \xrightarrow{H_2} R-CH_2-NH-R'$$

- Schiff bases
- Pharmaceutical intermediates

11 OXIME HYDROGENATION

$$R-CH=NOH \rightarrow R-CH_2-NH_2$$

- Oximes → Amines

12 AZIDE HYDROGENATION

$$R-N_3 \rightarrow R-NH_2$$

- Organic azides → Amines

13 REDUCTIVE AMINATION

$$R-\overset{O}{\overset{\|}{C}}-R' + R'''NH_2 \rightarrow R-CH-R'-NHR''$$

- Carbonyl + Amine + H_2
- One-pot reductive amination
- Pharmaceutical APIs
- Fine chemicals

14 HYRODEHALOGENATION

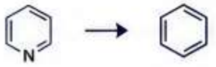
$$R-X \rightarrow R-H$$

- Chlorinated compounds
- Brominated compounds
- Iodinated compounds

15 HYDRODESULFURIZATION (HDS)

- Benzothiophene
- Dibenzothiophene
- Thiophenes
- Benzol sulfur removal
- Fuel purification

16 HYDRODENITROGENATION (HDN)



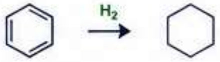
- Heteroaromatic N removal
- Fuel upgrading
- Specialty chemicals

17 HYDRODEOXYGENATION (HDO)

$$R-O-R' \rightarrow R-H + R'-H$$

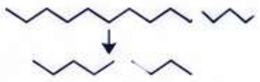
- Bio-oils
- Phenolics
- Renewable feedstocks

18 HYDRODEAROMATIZATION (HDA)



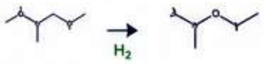
- Aromatic saturation
- Lube base oil production
- Specialty chemicals

19 HYDROCRACKING (LAB & PILOT SCALE)



- Heavy molecules → lighter fractions
- Pilot scale hydrocracking

20 HYDROISOMERIZATION



- Straight chain → Iso-paraffins
- Improve fuel & lube properties

21 SELECTIVE HYDROGENATION

$$R-CH=CH-R' \rightarrow R-CH_2-CH_2-R'$$

- Trace impurity removal
- Color body removal
- Unsaturated impurity removal

22 HYDROGENOLYSIS

$$R-CH_2-X \rightarrow R-CH_3$$

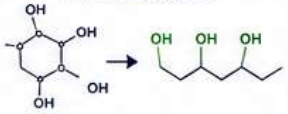
- C–O bond cleavage
- C–N bond cleavage
- Protecting group removal

23 DEPROTECTION REACTIONS

$$R-O-CH_2Ph \xrightarrow{H_2} R-OH$$

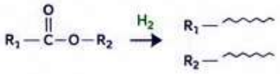
- Cbz removal
- Benzyl removal
- N–O bond reduction

24 SUGAR HYDROGENATION



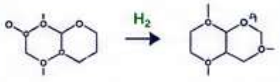
- Glucose → Sorbitol
- Xylose → Xylitol

25 FAT & OIL HYDROGENATION



- Vegetable oils
- Fatty acid derivatives
- Waxes

26 RESIN HYDROGENATION

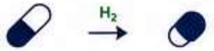


- Hydrocarbon resins
- Petroleum resins
- C5/C9 resins

27 FRAGRANCE & FLAVOUR HYDROGENATION

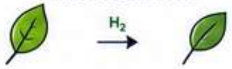
- Citral, Ionones, Terpenes
- Menthone derivatives
- Aroma & flavour compounds

28 PHARMACEUTICAL INTERMEDIATE HYDROGENATION



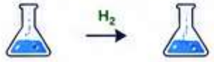
- API intermediates
- Chiral hydrogenation
- Heterocyclic reductions
- Final API hydrogenation

29 AGROCHEMICAL INTERMEDIATE HYDROGENATION



- Herbicide intermediates
- Insecticide intermediates
- Fungicide intermediates

30 SPECIALTY CHEMICAL HYDROGENATION

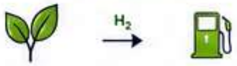


- Electronic chemicals
- Dye intermediates
- Pigment intermediates
- UV absorber intermediates

31 MINERAL OIL HYDROGENATION

- White oil production
- Cosmetic oils
- Pharmaceutical oils
- Transformer oils
- Heavy mineral oil upgrading

32 BIOMASS UPGRADING (HYDROGENATION)



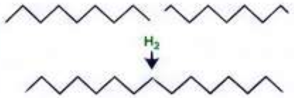
- Platform molecules
- Levulinic acid derivatives
- Furfural → Furfuryl alcohol
- HMF hydrogenation

33 POLYMER INTERMEDIATE HYDROGENATION

$$(-CH=CH-)_n \xrightarrow{H_2} (-CH_2-CH_2-)_n$$

- Latex intermediates
- Functional monomers

34 FISCHER-TROPSCH WAX HYDROGENATION



- FT wax upgrading

35 OTHER APPLICATIONS

- Ketimine reduction
- Sulfoxide → Sulfide
- N–O bond reduction
- And many more...

PILON'S MICRO CHANNEL REACTORS

PILON'S MICROGRID REACTORS				
Reactor Model	Volume (mL)	Pressure	Temperature	MOC
PFRx-Alpha (α)	5	FV to 200 Barg	(-) 100 Deg C to 1000 Deg C	Silicon Carbide, Titanium, Inconel-600, Incolloy, Monel, Duplex, Glass, SS316, SS304, Hastelloy, Tantalum etc.
PFRx-Beta (β)	10			
PFRx-Gamma (γ)	40			
PFRx-Delta (Δ)	100			
PFRx-Epsilon (E)	200			

ALPHA | BETA | GAMMA | DELTA | EPSILON

CUSTOM MICRO CHANNELS AVAILBALE

PILON ENGINEERING PVT. LTD.

REACTIONS IN MICRO CHANNEL FLOW REACTORS

FIT GUIDE FOR MICRO GRID FLOW REACTOR

★★★★★ **EXCELLENT FIT**
Ideal for fast, exothermic, multi-step, high-mixing reactions with precise residence time control.

★★★★☆ **GOOD FIT (WITH SPECIALIZED DESIGN)**
Feasible with gas–liquid handling, catalyst integration or specialized configurations.

★☆☆☆☆ **NOT SUITABLE**
Require large catalyst inventory, long residence time, solids handling or high pressure/temperature typical of packed bed, slurry or trickle bed reactors.

NOTE: Reaction suitability depends on chemistry, conditions, solvent, concentration, scale and safety considerations.

PILON ENGINEERING PVT. LTD.

MGFR (Micro Grid Flow Reactor) & **ContiHYflow** (Continuous Hydrogenation Flow)
Units that every Lab must have

PILON'S SLURRY FLOW REACTORS

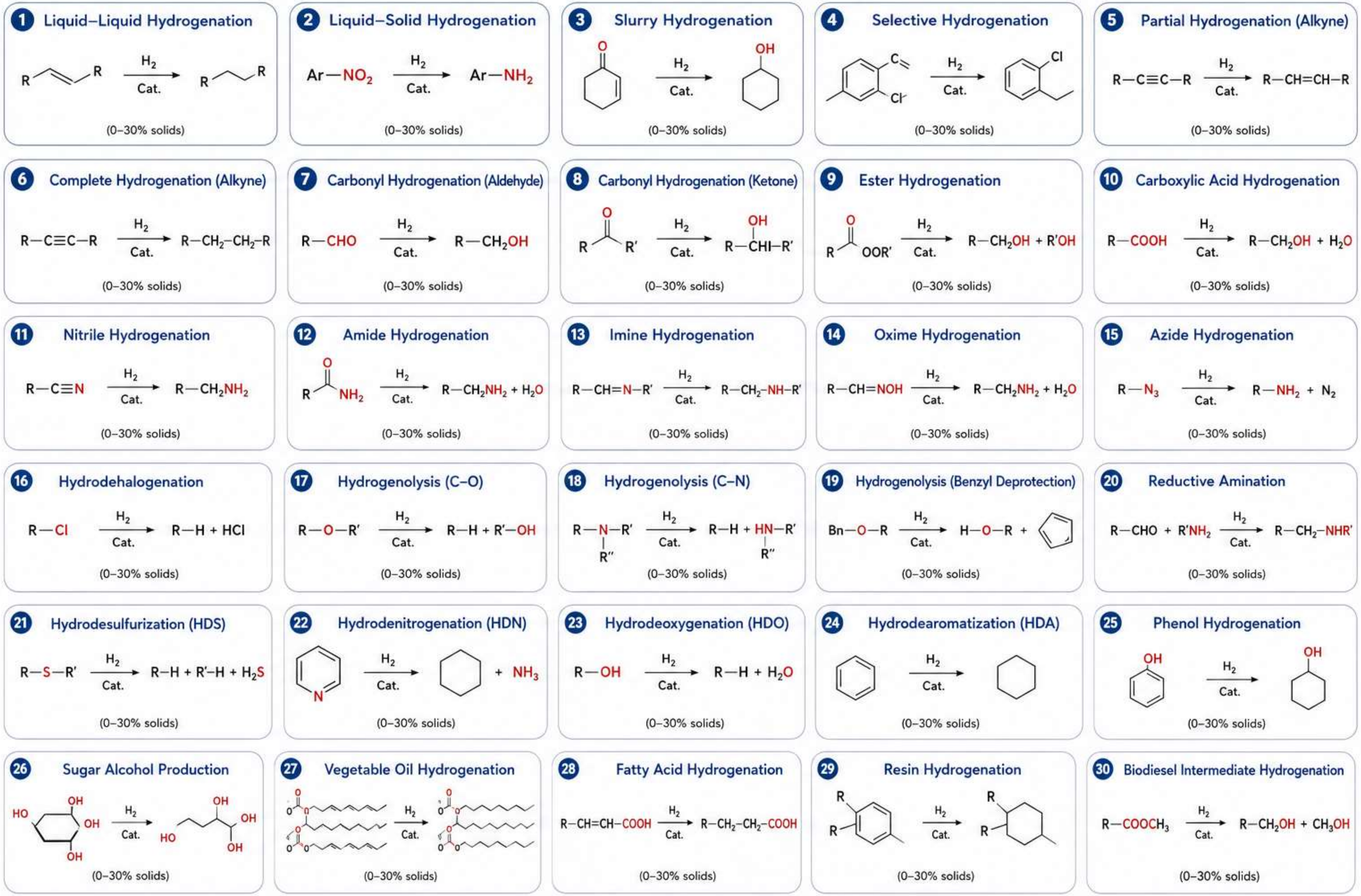
PILON ENGINEERING PVT. LTD.

PILON'S MICROGRID REACTORS				
Reactor Model	Volume (mL)	Pressure	Temperature	MOC
PILON Core™	**300mL to m3 production scale**	FV to Custom High Pressures	(-) 100 Deg C to Custom High Temperatures	Silicon Carbide, Titanium, Inconel-600, Incolloy, Monel, Duplex, Glass, SS316, SS304, Hastelloy, Tantalum etc.
PILON Vector™				
PILON Nexus™				
PILON Vertex™				
PILON Apex™				

CORE | VECTOR | NEXUS | VERTEX | APEX

CUSTOM CELLS AVAILBALE

REACTIONS IN SLURRY FLOW REACTORS




MICROGRID REACTOR SYSTEM
The Future of Safe, Smart and Sustainable Chemistry
ENHANCED SAFETY
SUPERIOR CONTROL
SUSTAINABLE
SCALABLE
PFRx Series – One Architecture, Five Volumes.
HYDROGENATION PLATFORM
SAFE
FLEXIBLE
EFFICIENT
SCALABLE
FIXED BED REACTOR SYSTEM
PILON
ENGINEERING PVT. LTD.
SMART CHEMISTRY. INTELLIGENT FLOW. SUSTAINABLE FUTURE.
OUR TECHNOLOGY, YOUR ADVANTAGE
APPLICATIONS
PATENTED MICROGRID REACTOR ARCHITECTURE
SUSTAINABILITY BY DESIGN
PFRx SERIES
FIVE MODELS. LIMITLESS POSSIBILITIES.
PFRx-Alpha 5 mL
PFRx-Beta 10 mL
PFRx-Gamma 40 mL
PFRx-Delta 100 mL
PFRx-Epsilon 200 mL
MICROGRID REACTOR SYSTEM
MICROGRID REACTOR SYSTEM
ONLINE ANALYTICS
HYDROGENATION PILOT PLANT
HYDROGENATION PILOT PLANT
HYDROGENATION PILOT PLANT
PILON
ContiHyFlow™
PILON
ENGINEERING PVT. LTD.

THANK YOU..!