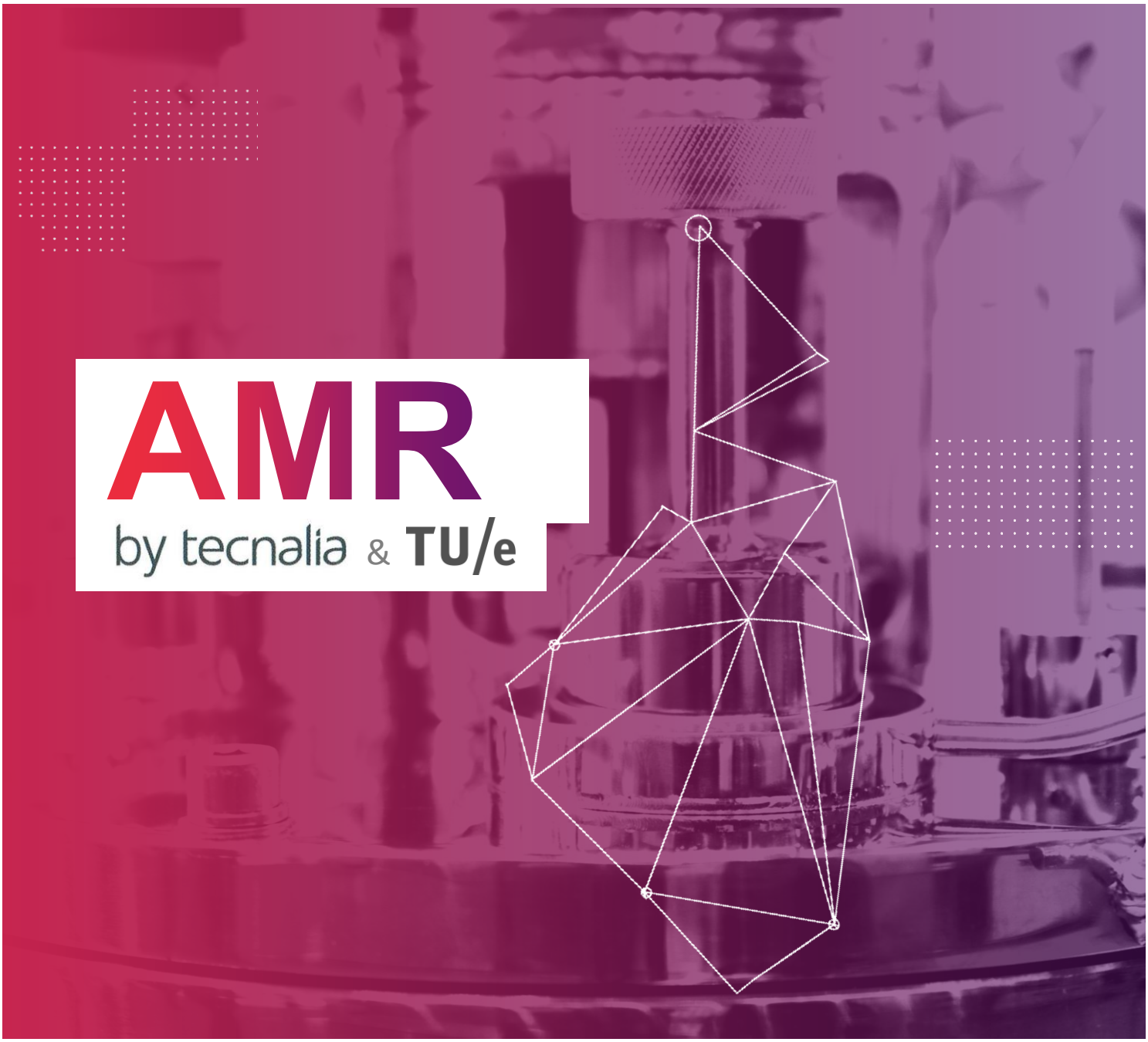


AMR

by tecnalia & TU/e

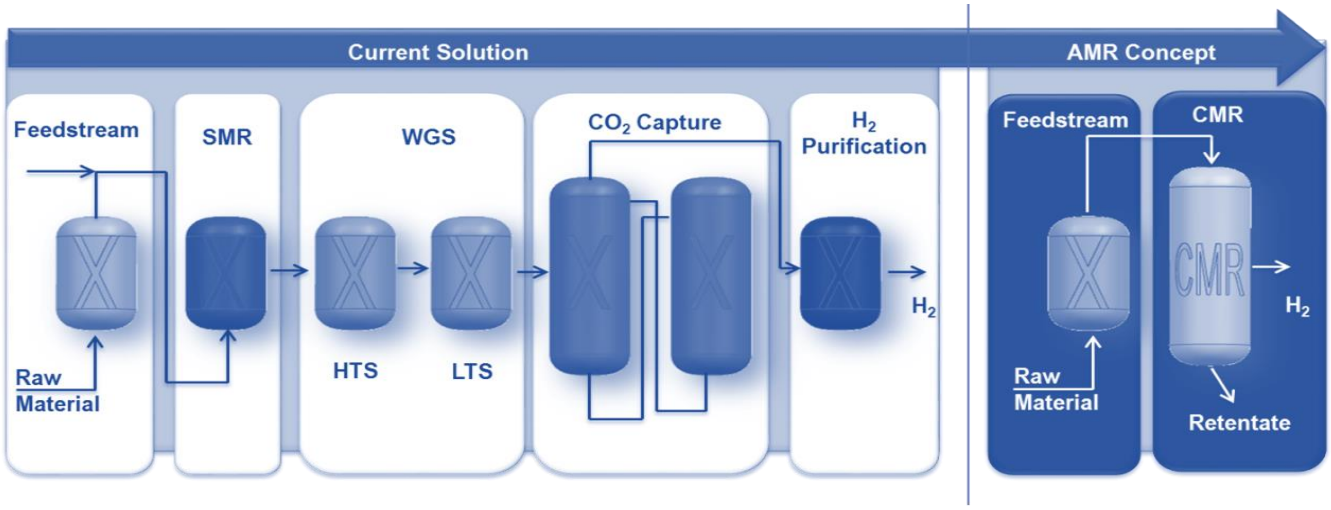
HYDROGEN PRODUCTION THROUGH ADVANCED MEMBRANE REACTORS

tecnalia Inspiring Business

TU/e Technische Universiteit Eindhoven University of Technology

www.tecnalia.com

HYDROGEN PRODUCTION THROUGH ADVANCED MEMBRANE REACTORS



This Advanced Membrane Reactor has been developed for pure hydrogen production at small to medium scale. **AMR integrates in catalytic membrane reactors, reaction and separation in a single stage,** separating the H_2 while it is produced thus shifting the equilibrium towards the products allowing the reduction of process temperature down to less than 600ºC.

Thanks to the properties of the membranes integrated, high purity hydrogen in one single step is obtained. The traditional 4 stages (Steam Methane Reforming, HT-Water Gas Shift, LT-Water Gas shift and PSA) are replaced by a single unit.

This reactor is later integrated together with its Balance of Plant to produce a Plug and Play system for distributed generation of pure hydrogen (>99.9%).

AMR provides an overall efficiency increase of the process and a reduction of the investment and the operation costs. AMR technology can produce high purity H_2 in situ at a cost lower than 0.4 € / m^3

AMR will supply hydrogen in the most affordable and reliable way, by using a flexible on-site production system based on proprietary membrane reactor technology.

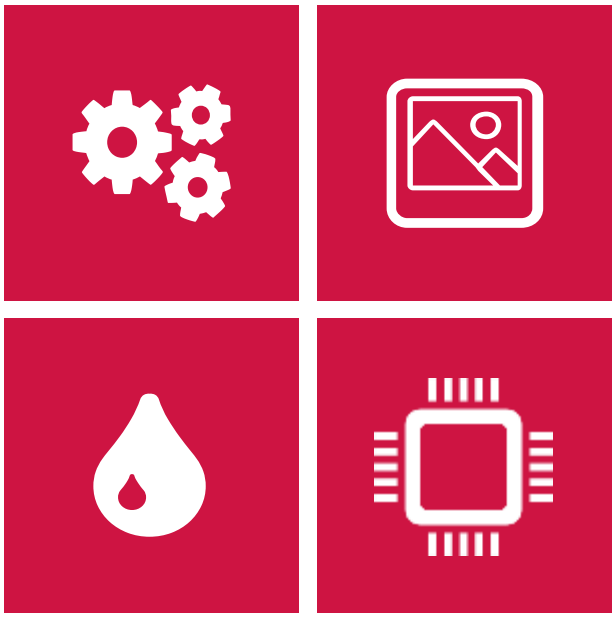
Based on the required quantity, quality and location of the end-user, AMR will provide the most cost-effective solution for the customer.

WHOM THE AMR IS ADDRESSED TO

The hydrogen obtained through our AMR technology can be applied in various industries, processes and applications, such as **float glass production, metal treatment, semiconductor production, food hydrogenation, chemical processes and fuel cell cars**.

Key benefits are:

- Cost-effective system
- Energy efficient
- Reliability of supply
- Independent on-site production
- Pay per use



On-site hydrogen generation vs centralized

The most implemented alternative for **providing industrial H_2 of high purity at small to medium scale (up to 100 Nm^3/h)** is the supply through compressed gas cylinders, containers or trucks, previously generated in large generation plants.

In this case, 60-65% of the final cost derives from transport and compression (in addition, 12% of the generated H_2 is lost in this operation).

With AMR this 65% of the current cost would be the minimum savings, with pay-backs from very short the AMR systems.

AMR vs competiting on-site reforming systems

Compared to on-site SMR systems, AMR is **much more compact** (single-stage process), **more efficient** (lower temperature and fluidized bed conditions), with **less environmental impact and more secure**. AMR has a much **lower cost both in CAPEX and in OPEX**.

- Membranes are protected by patent application specially focused on fluidized bed operating conditions. This allows achieving process efficiencies higher than 80%
- Expert design and integration of membrane reactor.
- Manufacture of Pd membranes of very low thickness (<< 10 um), with permeation levels higher than commercial membranes.
- Technology is protected by patent applications, for membrane recycling in the event of deterioration or end of life.

HYDROGEN PRODUCTION THROUGH ADVANCED MEMBRANE REACTORS

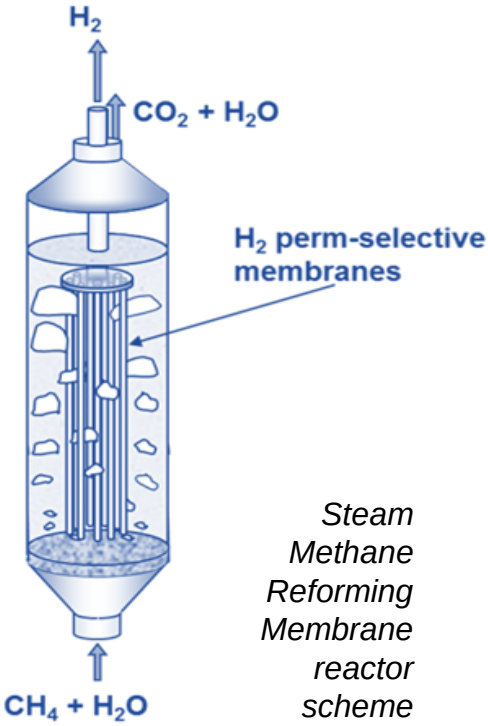
THE PRODUCT

The application with which it is proposed to access the market in a first step, by volume and short feasibility, is the supply of H_2 in industrial applications that demand it in high purity.

Natural gas is the starting **raw material** because gas networks exist throughout the developed countries.

Anyway, AMR systems can be applied to **other types of raw materials** such **as methanol or ethanol** (or their "bio-alternatives" for **renewable generation**), for example, in distributed applications.

However, with the same technology it could be addressed other types of applications such as the markets based on **fuel cells** (domestic and tertiary applications with CHP and mobility solutions with full electric vehicles with fuel cells), applications in the **petrochemical sector** and related (including **chemical**), processes for **hydrogenation** and **selective dehydrogenation** or applications where the purification of low purity gases in mixtures with H_2 is necessary.



Steam Methane Reforming Membrane reactor scheme

STATUS OF THE PRODUCT & TECHNOLOGY

AMR will reach TRL 6 before the end of 2018, with a reactor of 2 m^3_{H2} / h of installed generation capacity.

- → The 2 m^3_{H2} / h reactor has been constructed and assembled and is under testing in the laboratories of TUE.
- → The system will already be a commercial unit and in the catalog the aim is to have reactors with capacities of 2, 20 and 50 Nm^3_{H2} / h.
- → The 20 Nm^3_{H2} / h reactor is being built at this time and will be completed at the beginning of 2019. For the 20 Nm^3_{H2} / h the design and some of the components have been purchased and the installation will de completed during 2018.

DEVELOPERS AND OWNERS OF AMR

In the development of the Advanced Membrane Reactor (AMR) following entities have participated

- University of Eindhoven: Focused on process and membrane reactor design and modeling
- TECNALIA: In charge of membrane development and manufacturing

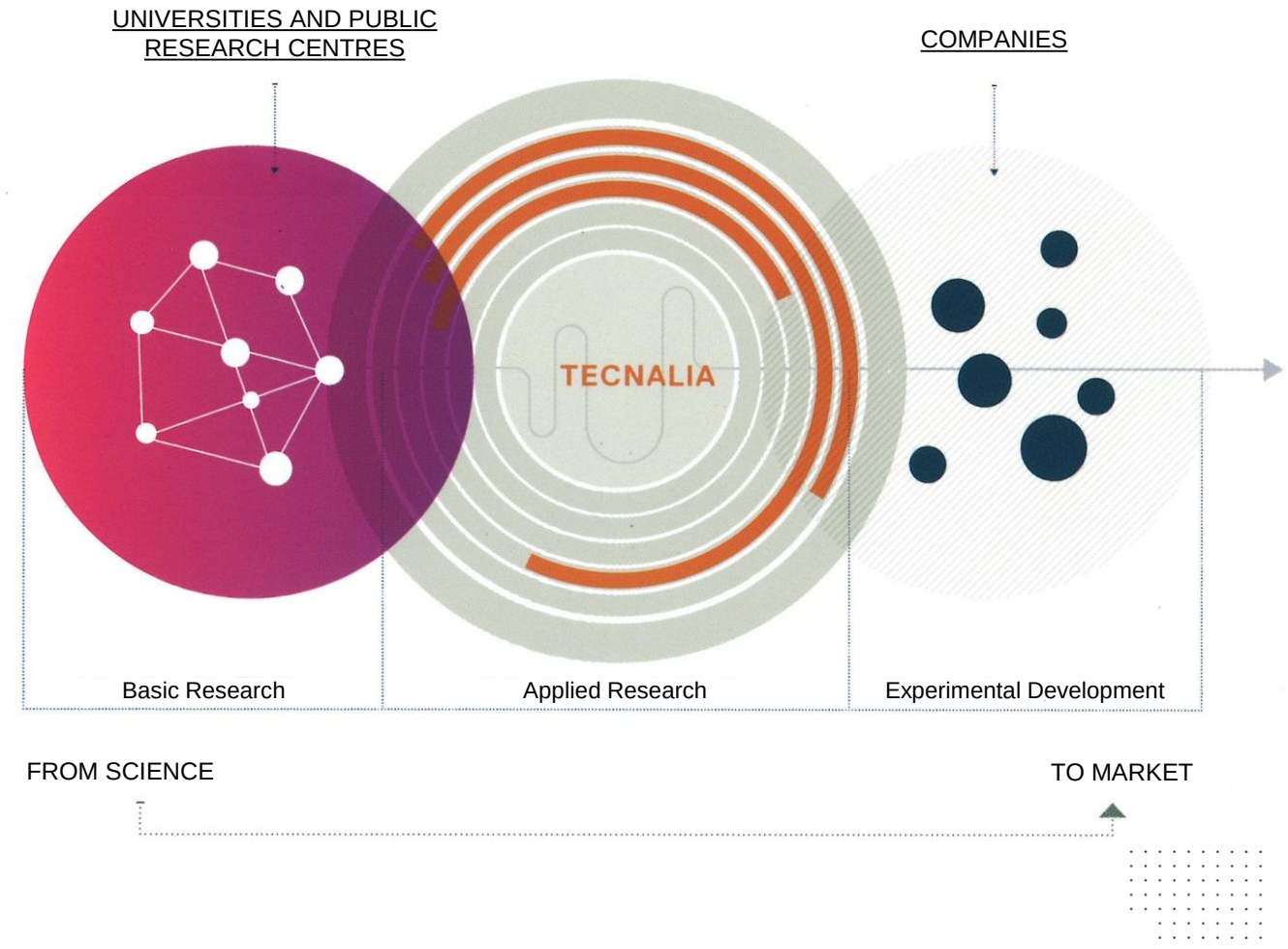
University of Eindhoven and TECNALIA are de owners of the technology.

A co-ownership agreement has been signed among them.

A new company will be created for the exploitation of the Advanced Membrane Reactors

The project will last up to 3 years and the aim is to develop the 20Nm^3/h during 2019 and its scale up to the 50Nm^3/h during 2020

TECNALIA
IS A RESEARCH AND TECHNOLOGICAL DEVELOPMENT CENTRE

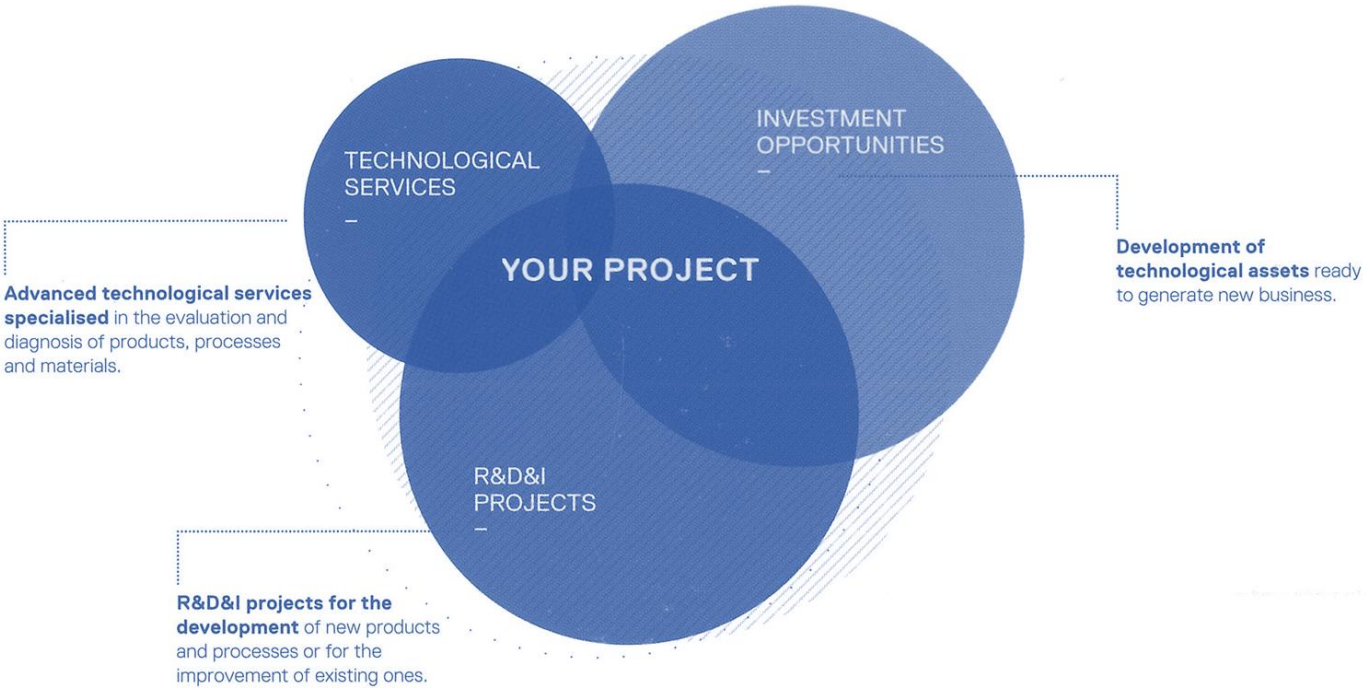


MISSION

We transform Technology into GDP

We transform technology into wealth to obtain beneficial visible results for companies, society, our environment and in short, for people.

OUR **OFFER**



WE CAN DO SO MUCH **TOGETHER**

Our work cannot be understood without yours; we would Like to work together so your company can compete better. Because together, we can develop technologies which will transform the present

The future is technological,
Let's share it!

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