EMISSIONS FROM THE MANUFACTURING PROCESSES AND ON-SITE STEAM & POWER GENERATION IN THE U.S. CHEMICAL INDUSTRY

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ENERGY CONSUMPTION vs. CO_2 EMISSIONS IN THE U.S.

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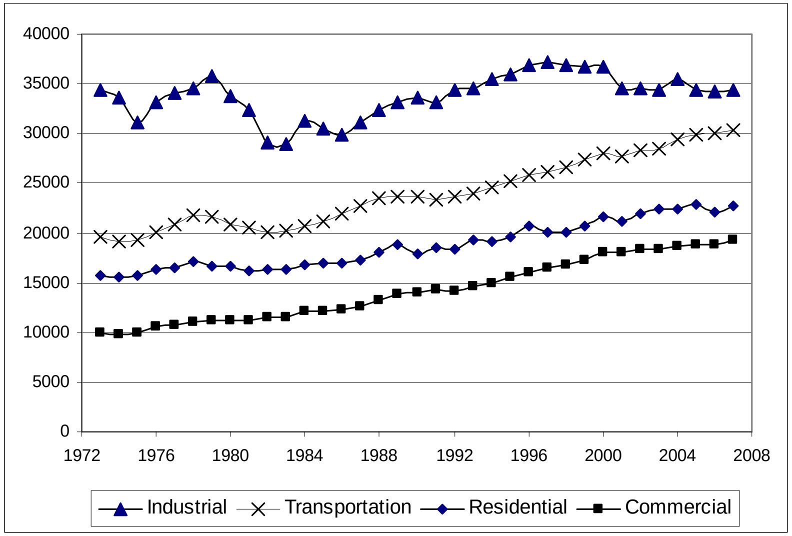
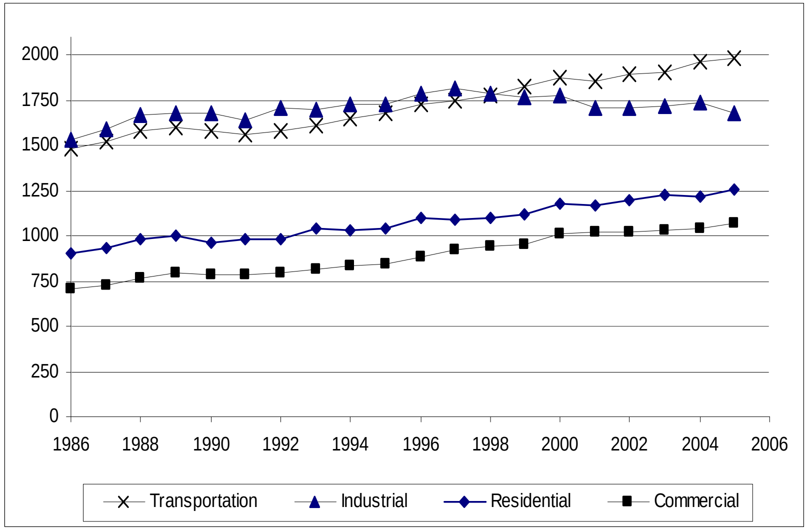
ENERGY CONSUMPTION AND CO_2 EMISSIONS IN THE INDUSTRIAL SECTOR HAS BEEN LARGER THAN ANY OF THE OTHER SECTORS OVER THE PAST THREE DECADES



ENERGY CONSUMPTION IN THE U.S. BY SECTOR, PJ



CO_2 EMISSIONS IN THE U.S. BY SECTOR, $mmtCO_2$

Source: U.S. Energy Information Administration database: http://www.eia.doe.gov/environment.html

ENERGY CONSUMPTION vs. CO_2 EMISSIONS BY SECTOR

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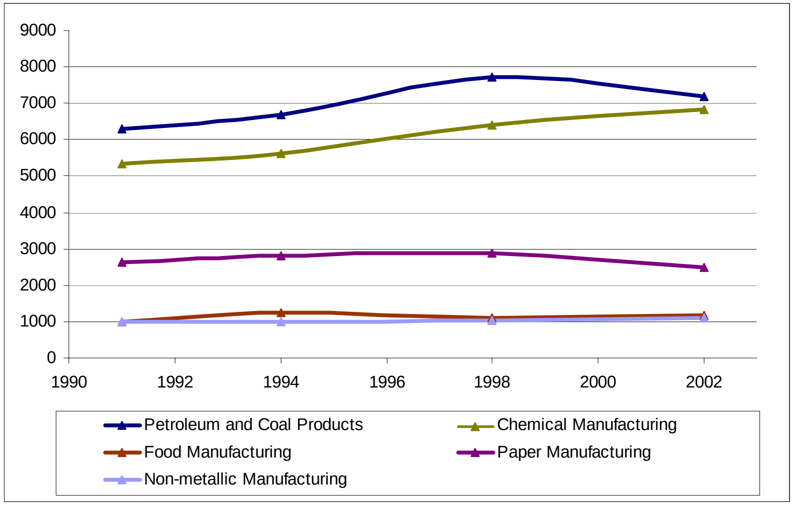
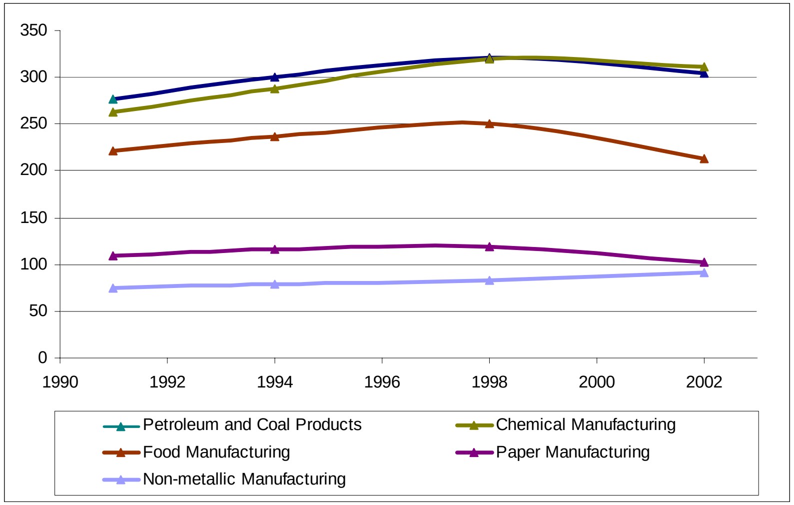
PETROLEUM AND CHEMICAL INDUSTRIES ARE THE LARGEST ENERGY CONSUMING AND CO_2 EMITTING SECTORS



ENERGY CONSUMPTION BY SECTOR, PJ



CO_2 EMISSIONS FROM MANUFACTURING, mmtCO_2

Source: U.S. Energy Information Administration database: http://www.eia.doe.gov/emeu/mecs/mecs2002/data02/shelltables.html

LET’S TAKE A CLOSER LOOK AT

THE U.S. CHEMICAL INDUSTRY

THE CHEMICAL INDUSTRY IS CALLED

THE KEYSTONE IN THE U.S. ECONOMY

BECAUSE OF ITS CAPACITY TO MANUFACTURE

MORE THAN 70,000 PRODUCTS

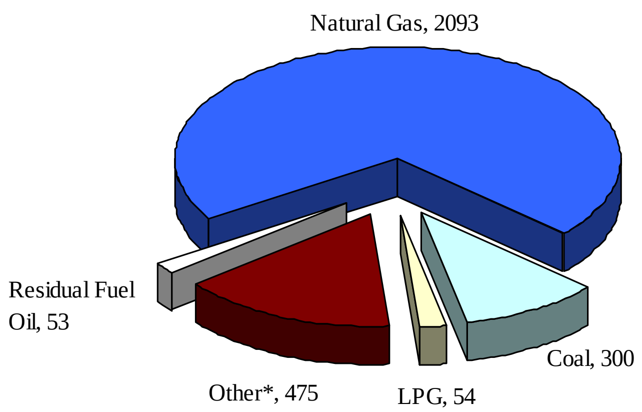
MAKING IT THE WORLD'S LARGEST CHEMICALS MANUFACTURER

THE 2nd LARGEST

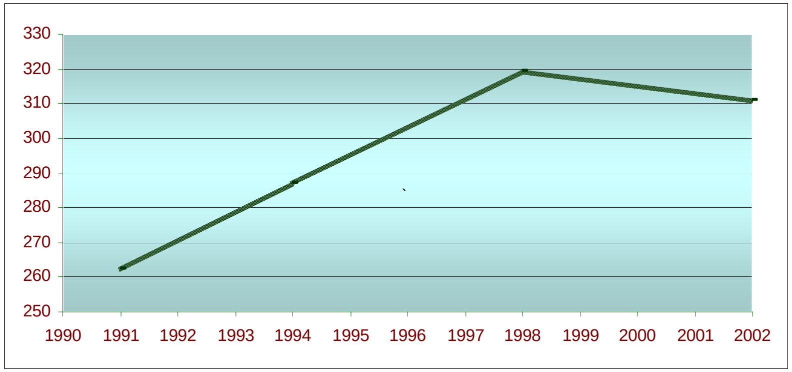
ENERGY CONSUMING MANUFACTURING SECTOR

IN THE U.S.

ENERGY CONSUMPTION vs. CO_2 EMISSIONS IN THE U.S. CHEMICAL INDUSTRY



FUEL CONSUMPTION IN THE U.S. CHEMICAL INDUSTRY, PJ



CO_2 EMISSIONS IN THE U.S. CHEMICAL INDUSTRY, mmtCO_2

Share of total manufacturing emissions (%)	Aggregate CO_2 Emission Coefficient (mmt per Quadrillion Btu of Energy Consumed)
% of [C]	[C] / [E]
22.2	41.5

Source: U.S. Energy Information Administration database: http://www.eia.doe.gov/environment.html

WHAT ARE THE SOURCES OF CO_2 EMISSIONS IN THE CHEMICAL INDUSTRY?

- ✓ MANUFACTURING PROCESSES
- ✓ ON-SITE STEAM GENERATION
- ✓ ON-SITE POWER GENERATION

WHAT ARE THE ENERGY CONSUMING PROCESSES IN THE CHEMICAL INDUSTRY?

- ✓ MANUFACTURING PROCESSES
- ✓ ON-SITE STEAM GENERATION
- ✓ ON-SITE POWER GENERATION

HOW CAN WE RELATE AND DESCRIBE THE CONNECTION IN ENERGY CONSUMPTION AND CO_2 EMISSIONS BY THE

MANUFACTURING PROCESSES,

ON-SITE STEAM GENERATION

AND

ON-SITE POWER GENERATION?

A COMPREHENSIVE DESCRIPTION OF INDUSTRIAL ENERGY USAGE AND EMISSIONS PATTERNS CAN PROVIDE INFORMATION ON THE POTENTIAL EFFECT OF

- → **TECHNOLOGICAL**
- → **ECONOMICAL**
- → **PUBLIC POLICY CHANGES**

LET'S CHOOSE AN EXAMPLE TO SEE THE COMPREHENSIVE DESCRIPTION OF INDUSTRIAL ENERGY USAGE AND EMISSIONS PATTERNS ON A NATIONAL SCALE

LET’S TAKE

HYDROGEN PRODUCTION

AS AN EXAMPLE MANUFACTURING PROCESS

HYDROGEN PRODUCTION IN THE CHEMICAL INDUSTRY CAN BE CHARACTERIZED BY CONSTRUCTING

MATERIAL, ENERGY AND EMISSION FLOWS MODELS

FOR THIS INDUSTRY

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HYDROGEN IS AN "INDUSTRIAL GAS"

LET'S SEE WHICH SUBSECTORS OF THE CHEMICAL INDUSTRY PRODUCES "INDUSTRIAL GASES"

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SUBSECTORS PRODUCING INDUSTRIAL GASES, M$

Industry	***Value***	% in total
Industrial Gas Manufacturing	4,791	92%
Plastics Material and Resin Manufacturing	162	3%
Other Basic Organic Chemical Manufacturing	135	3%
Petrochemicals	89	2%
Nitrogenous Fertilizer Manufacturing	26	<1%
TOTAL	**5,203**	**100%**

Source: U.S. Census Bureau, Current Industrial Reports: http://www.census.gov/industry/1/mq325c045.pdf

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HYDROGEN PRODUCTION AND SHIPMENT BY THE CHEMICAL INDUSTRY

2003		2004	
Production	Shipment	Production	Shipment
1.21×10^9 kg	8.43×10^8 kg	1.48×10^9 kg	1.14×10^9 kg

Source: U.S. Census Bureau, Current Industrial Reports: http://www.census.gov/industry/1/mq325c045.pdf

THE MAJOR HYDROGEN PRODUCTION TECHNIQUE IN THE CHEMICAL INDUSTRY IS

THE STEAM REFORMING OF NATURAL GAS

Material Flow Model of Hydrogen Production

A MATERIAL FLOW MODEL REPRESENTS

MASS INPUTS AND OUTPUTS

FOR AN INDUSTRIAL PROCESS.

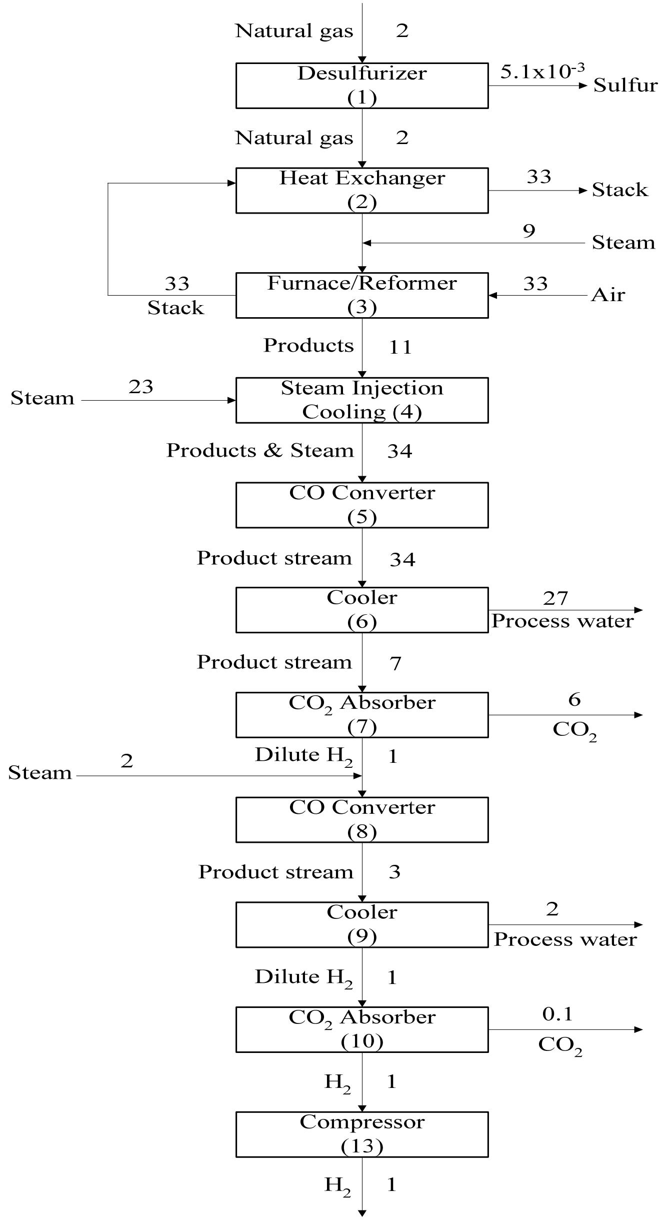
IT IS CREATED BASED ON A MASS BALANCE FOR EACH STEP OF AN INDUSTRIAL PROCESS.

Material Flow Model of Hydrogen Production

ONCE A MATERIAL FLOW FOR EACH PROCESS STEP IS CREATED FOR AN INDUSTRIAL PROCESS BASED ON UNIT MASS, THAT MATERIAL FLOW MODEL CAN BE SCALED AGAINST NATIONAL DATA BY USING NATIONAL DATA ON PRODUCT OUTPUT.

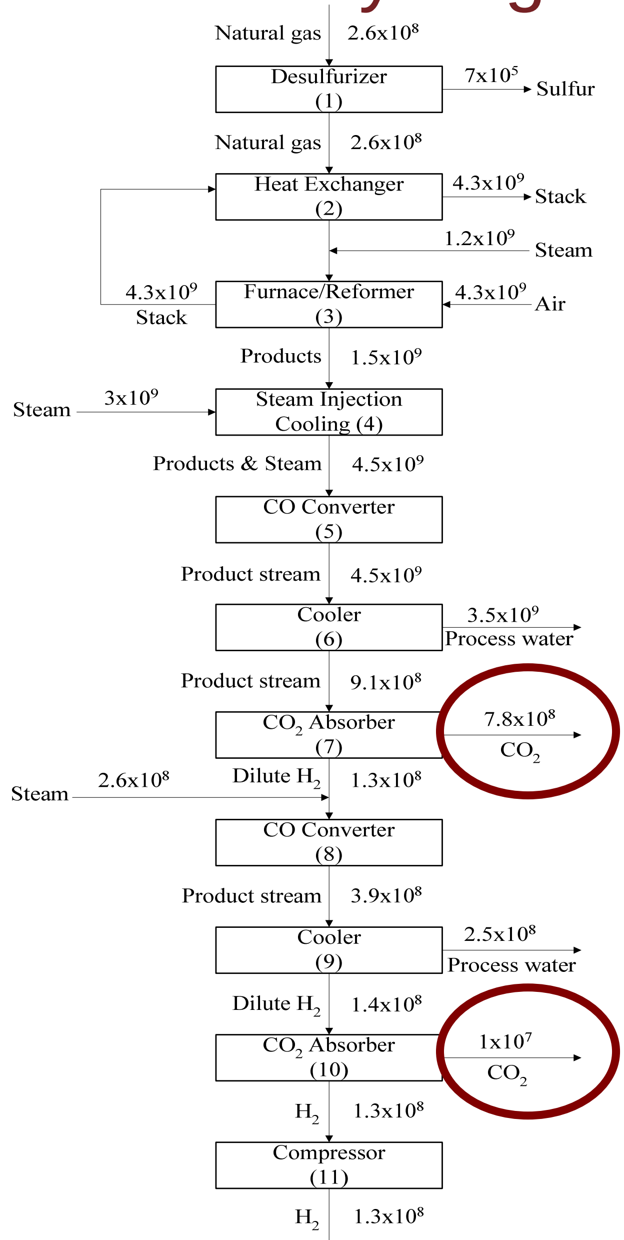
THIS PROVIDES AN OVERALL NATIONAL PICTURE OF MATERIAL INPUTS AND OUTPUTS FOR AN INDUSTRIAL PROCESS.

Material Flow Model of Hydrogen Production



Source: Brown, H.L., Hamel, B.B., Hedman, B.A. (1996). Energy Analysis of 108 Industrial Processes. Fairmont Press, Atlanta, GA.

Material Flow Model of Hydrogen Production



THE NEXT STEP IS TO CHARACTERIZE THE ENERGY CONSUMPTION OF THIS PROCESS, SO THAT WE RELATE THIS MANUFACTURING PROCESS WITH ENERGY CONSUMPTION

TWO ENERGY FLOW MODELS ARE REQUIRED TO ASSOCIATE MANUFACTURING PROCESSES WITH ENERGY CONSUMPTION:

ENERGY END-USE MODEL

ENERGY PROCESS-STEP MODEL

ENERGY END-USE MODEL :

DESCRIBES THE RELATIONSHIP BETWEEN

ENERGY AND END-USES

GENERIC RELATIONSHIP BETWEEN ENERGY AND END-USES

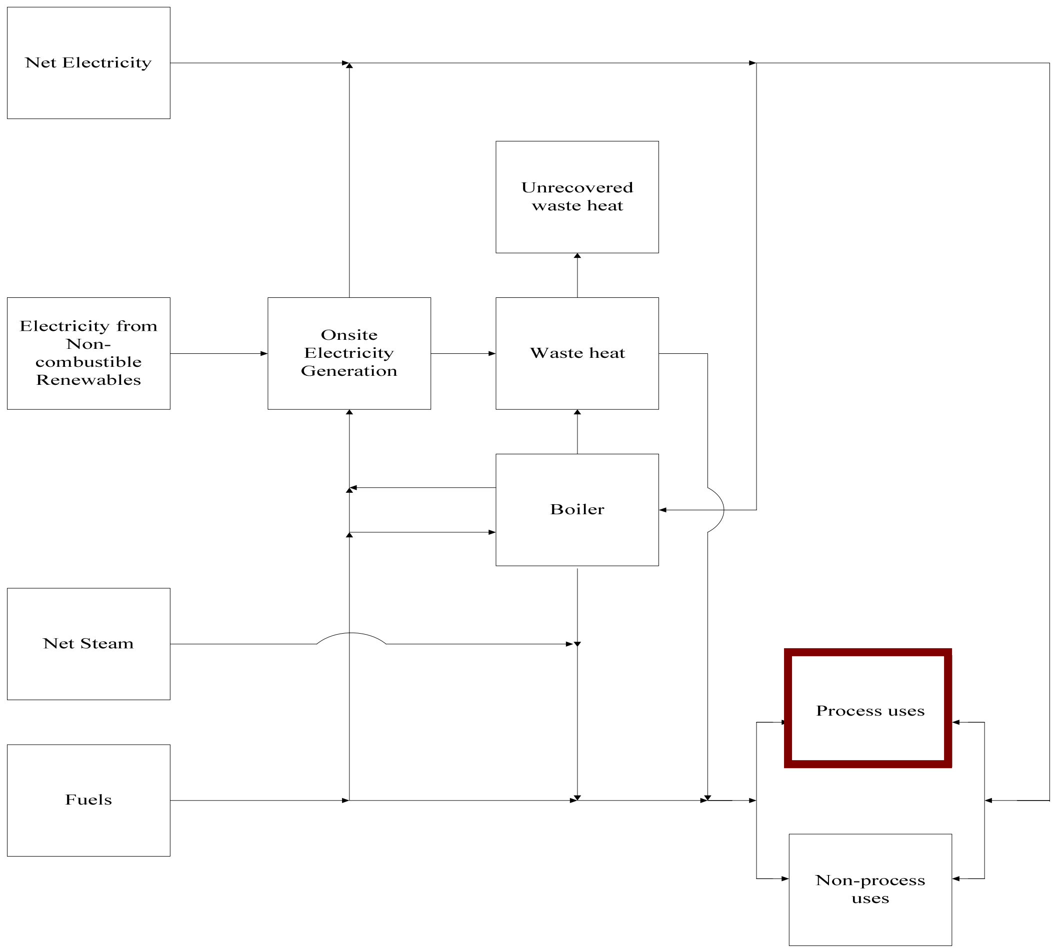
PROCESS AND NON-PROCESS END-USES CONSUME ENERGY IN THE FORM OF:

→ STEAM

→ FUEL

→ ELECTRICITY

→ WASTE HEAT



PROCESS END-USES

→ PROCESS HEATING
→ PROCESS COOLING & REFRIGERATION
→ MACHINE DRIVE
→ ELECTROCHEMICAL PROCESSES
→ OTHER

NON-PROCESS END-USES

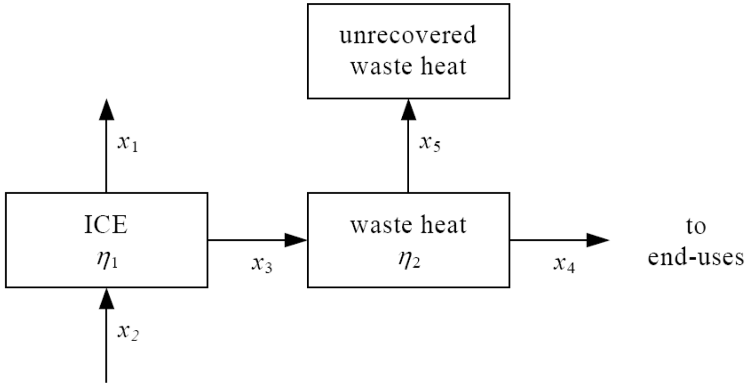
→ FACILITY HVAC
→ FACILITY LIGHTING
→ FACILITY SUPPORT
→ ONSITE TRANSPORTATION
→ OTHER

HOW TO DEVELOP AN ENERGY END-USE MODEL

THERE ARE 6 MODES OF POWER AND STEAM GENERATION IN THE CHEMICAL INDUSTRY:

1. INTERNAL COMBUSTION ENGINE WITH HEAT RECOVERY
2. GAS TURBINE WITH HEAT RECOVERY
3. STEAM TURBINE WITH HEAT RECOVERY
4. COMBINED CYCLE
5. STEAM GENERATION IN FUEL FIRED BOILER
6. STEAM GENERATION IN ELECTRIC BOILER

HOW TO DEVELOP AN ENERGY END-USE MODEL



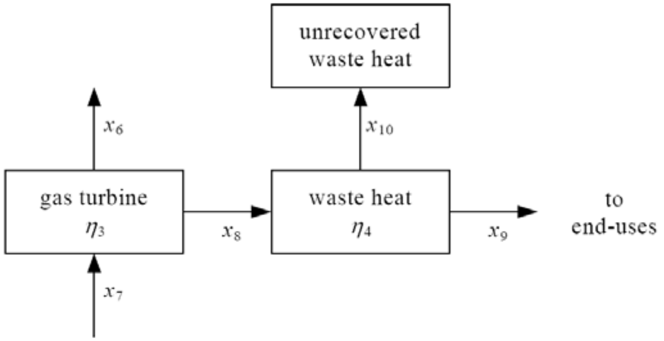
Internal combustion engine with heat recovery

$$x_1 = \eta_1 x_2$$

$$x_2 = x_1 + x_3$$

$$x_4 = \eta_2 x_3$$

$$x_3 = x_4 + x_5$$



Gas turbine with heat recovery

$$x_6 = \eta_3 x_7$$

$$x_7 = x_6 + x_8$$

$$x_9 = \eta_4 x_8$$

$$x_8 = x_9 + x_{10}$$

HOW TO DEVELOP AN ENERGY END-USE MODEL

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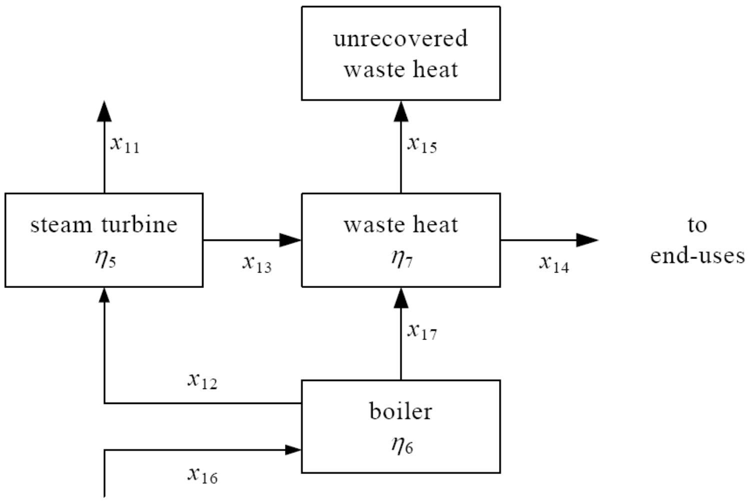


Steam turbine with heat recovery

$$x_{11} = \eta_5 x_{12}$$

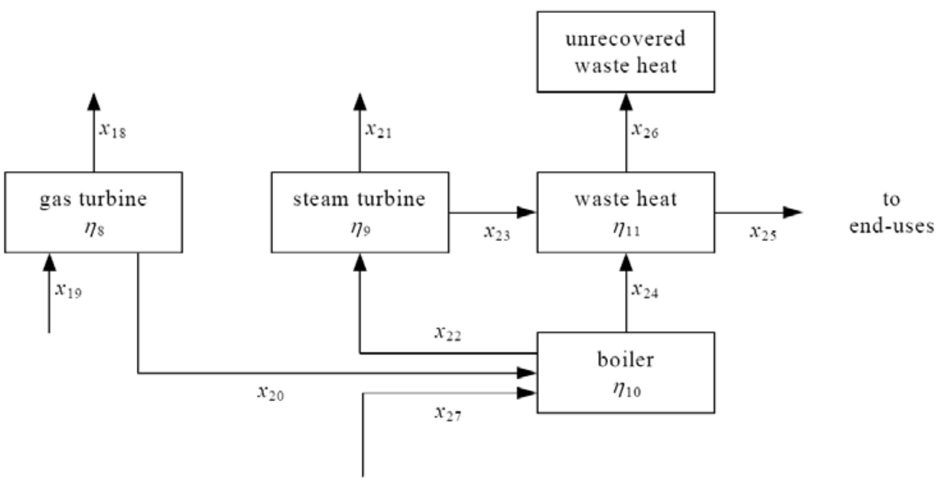
$$x_{12} = x_{11} + x_{13}$$

$$x_{12} = \eta_6 x_{16}$$

$$x_{16} = x_{12} + x_{17}$$

$$x_{14} = \eta_7 (x_{13} + x_{17})$$

$$x_{13} + x_{17} = x_{14} + x_{15}$$



Combined cycle

$$x_{18} = \eta_8 x_{19}$$

$$x_{19} = x_{18} + x_{20}$$

$$x_{21} = \eta_9 x_{22}$$

$$x_{22} = x_{21} + x_{23}$$

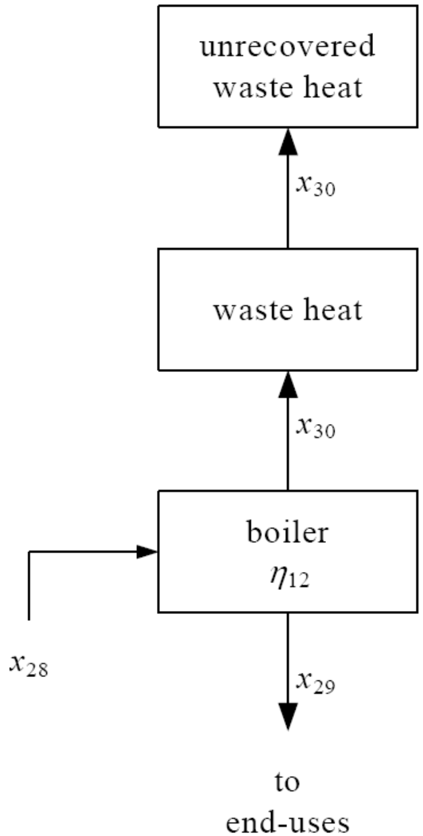
$$x_{22} = \eta_{10} (x_{20} + x_{27})$$

$$x_{20} + x_{27} = x_{22} + x_{24}$$

$$x_{25} = \eta_{11} (x_{23} + x_{24})$$

$$x_{23} + x_{24} = x_{25} + x_{26}$$

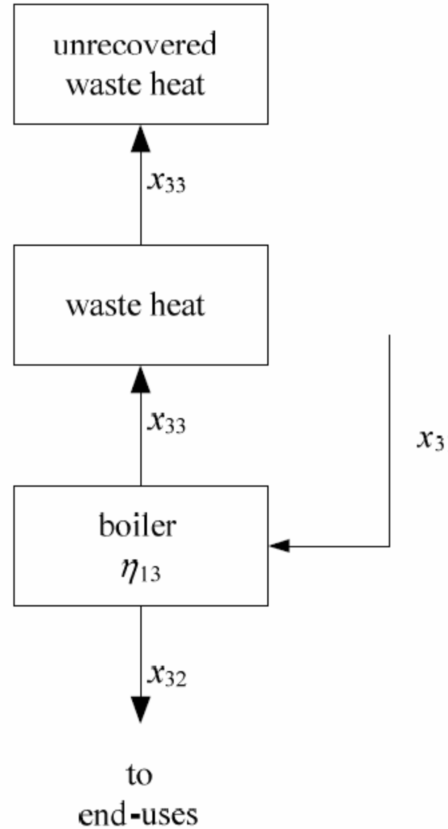
HOW TO DEVELOP AN ENERGY END-USE MODEL



Steam generation in fuel fired boiler

$$x_{29} = \eta_{12} x_{28}$$

$$x_{28} = x_{29} + x_{30}$$



Steam generation in electric boiler

$$x_{32} = \eta_{13} x_{31}$$

$$x_{32} + x_{33} = x_{31}$$

HOW TO DEVELOP AN ENERGY END-USE MODEL

Description of the inputs and outputs

Inputs		Outputs	
		x_1	Internal combustion engine electricity output
x_2	Internal combustion engine energy input	x_3	Internal combustion engine waste heat output
		x_4	Internal combustion engine recovered waste heat output
		x_5	Internal combustion engine unrecovered waste heat output
		x_6	Gas turbine electricity output
x_7	Gas turbine energy input	x_8	Gas turbine waste heat output
		x_9	Gas turbine recovered waste heat output
		x_{10}	Gas turbine unrecovered waste heat output
		x_{11}	Steam turbine electricity output
x_{12}	Steam turbine energy input	x_{13}	Steam turbine waste heat output
		x_{14}	Steam turbine recovered waste heat output
		x_{15}	Steam turbine unrecovered waste heat output
x_{16}	Steam turbine boiler energy input	x_{17}	Steam turbine boiler waste heat output
		x_{18}	Combined cycle–gas turbine electricity output
x_{19}	Combined cycle–gas turbine energy input	x_{20}	Combined cycle–gas turbine waste heat output
x_{27}	Combined cycle–boiler energy input	x_{21}	Combined cycle–steam turbine electricity output
x_{22}	Combined cycle–steam turbine energy input	x_{23}	Combined cycle–steam turbine waste heat output
		x_{24}	Combined cycle–boiler waste heat output
		x_{25}	Combined cycle–recovered waste heat
		x_{26}	Combined cycle–unrecovered waste heat
x_{28}	Fuel-fired boiler energy input	x_{29}	Fuel-fired boiler steam output
		x_{30}	Fuel-fired boiler recovered/unrecovered waste heat
x_{31}	Electric boiler energy input	x_{32}	Electric boiler steam output
		x_{33}	Electric boiler recovered/unrecovered waste heat

WHAT RELIABLE DATABASE PROVIDES THIS MUCH DETAILED INFORMATION ON ENERGY CONSUMPTION FOR EACH INDUSTRY?

U.S. DEPARTMENT OF ENERGY (DOE) ENERGY INFORMATION ADMINISTRATION (EIA) DATABASE

MANUFACTURING ENERGY CONSUMPTION SURVEY (MECS)

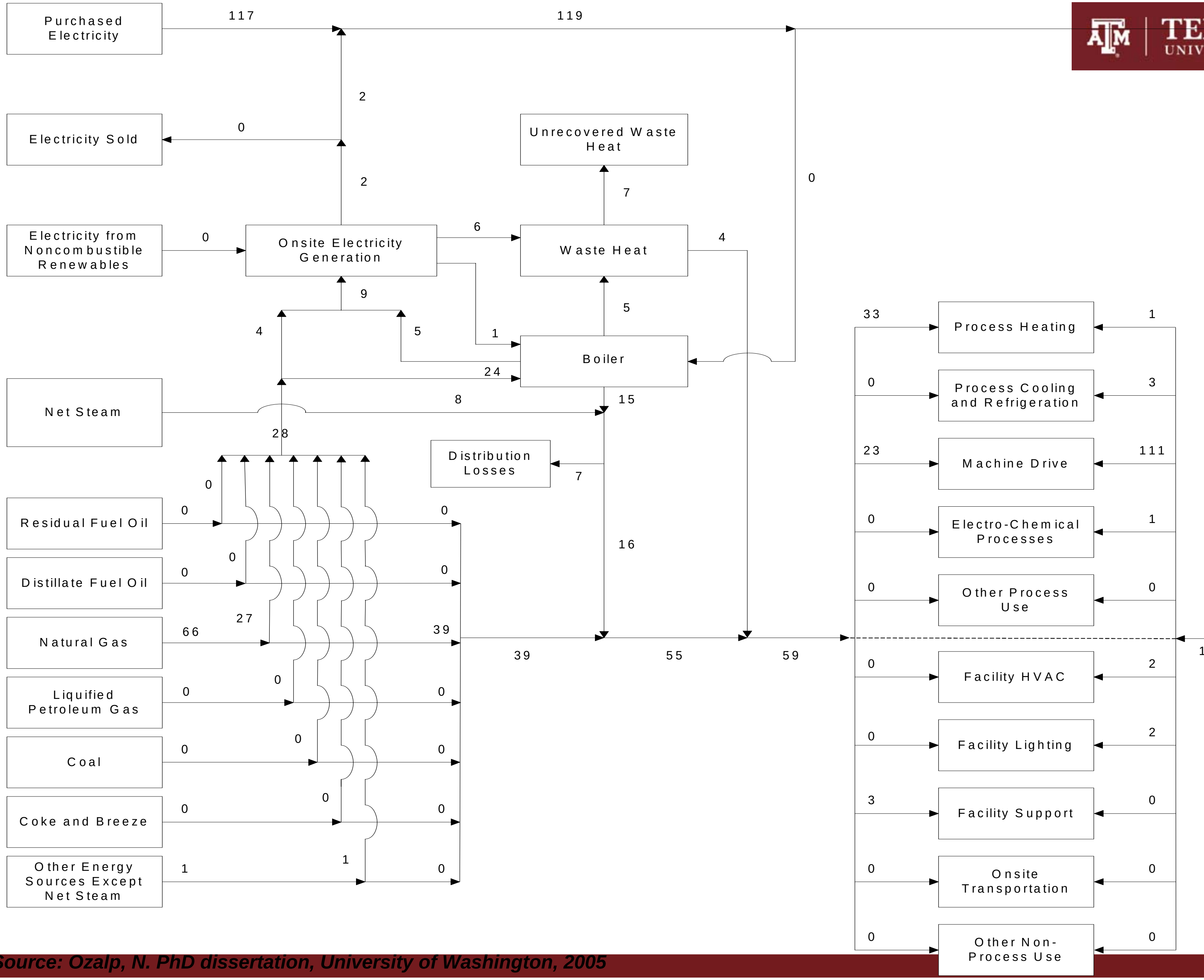
Source: http://www.eia.doe.gov/emeu/mecs/

EIA 860B:

ANNUAL ELECTRIC GENERATOR REPORT FOR NON-UTILITY

Source: http://www.eia.doe.gov/cneaf/electricity/page/eia860b.html

Energy End-use Model of the U.S. Industrial Gas Manufacturing Sector, PJ



Source: Ozalp, N. PhD dissertation, University of Washington, 2005

ENERGY PROCESS-STEP MODEL :

ALLOCATES THE ENERGY CONSUMPTION AMONG EACH PROCESS STEP

HOW TO DEVELOP AN ENERGY PROCESS-STEP MODEL

FIRST,

THE KEY ENERGY CONSUMING PROCESS STEPS

NEED TO BE IDENTIFIED.

THEN,

ENERGY USAGE IN EACH STEP

SHOULD BE ALLOCATED AS “FUEL”, “STEAM”, “WASTE HEAT” AND “ELECTRICTY”

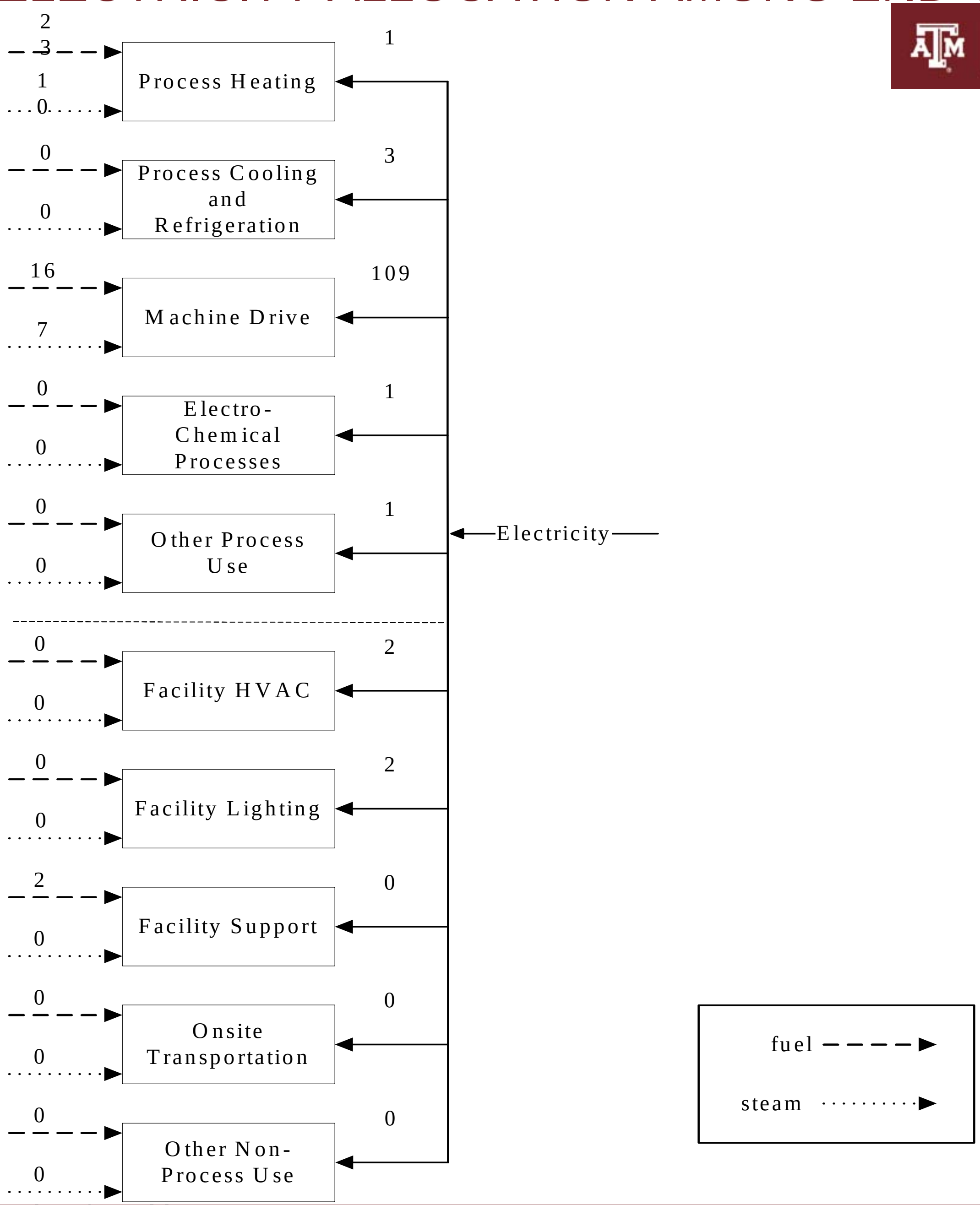
THE KEY ENERGY CONSUMING PROCESS STEPS

CAN BE IDENTIFIED BY REFERRING TO THE MATERIAL FLOW MODEL.

ENERGY USAGE IN EACH STEP

CAN BE ALLOCATED BY REFERRING TO THE ENERGY END-USE MODEL

FUEL, STEAM, AND ELECTRICITY ALLOCATION AMONG END-USES



Source: Ozalp, N. PhD dissertation, University of Washington, 2005

FUEL, STEAM AND ELECTRICITY ALLOCATION GIVEN IN THE "PROCESS END-USES" PART OF THE END-USE MODEL NOW CAN BE ALLOCATED AMONG THE PROCESS STEPS DESCRIBED IN THE MATERIAL FLOW MODEL

Energy process-step Model of Hydrogen Production

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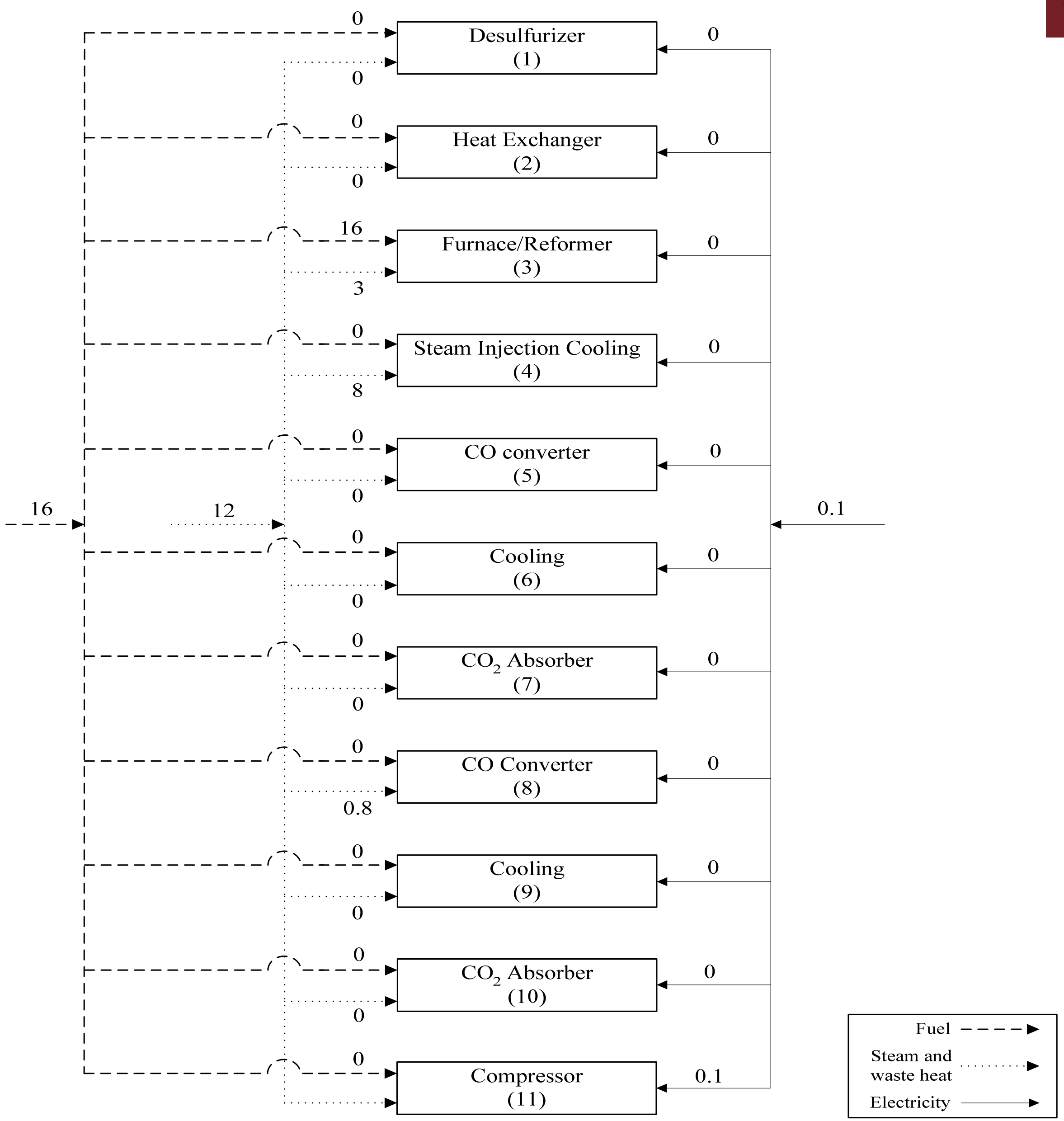

Source: Ozalp, N. PhD dissertation, University of Washington, 2005

THE SAME METHODOLOGY CAN BE

APPLIED TO OTHER PRODUCTS OF

THE CHEMICAL INDUSTRY

TO CREATE SIMILAR

MATERIAL AND ENERGY FLOW MODELS

IF THE "**<u>REPRESENTATIVE</u> PRODUCTION TECHNIQUE AND THE PROCESS STEPS**" ARE CORRECTLY CHOSEN, THEN THE END-USE MODEL AND THE PROCESS-STEP MODELS RESULTS SHOULD BE IN AGREEMENT

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LET'S SEE WHAT WE GET IF WE CREATE ENERGY-PROCESS STEP MODELS FOR ALL PRODUCTS OF THE INDUSTRIAL GAS MANUFACTURING SECTOR

ENERGY END-USE DATA vs. ENERGY PROCESS-STEP MODEL DATA

	End-use model	Process-step Model	C_2H_2	CO_2	$N_{2\text{-}C}$	$N_{2\text{-}NC}$	$O_{2\text{-}C}$	$O_{2\text{-}NC}$	Ar	H_2	F.
Fuel total	**37**	**20**	**4**	**0**	**NA**	**NA**	**NA**	**NA**	**0**	**16**	**NA**
Process Heating	22	20	4	0	-	-	-	-	0	16	-
Process C&R	0	0	0	0	-	-	-	-	0	0	-
Machine Drive	15	0	0	0	-	-	-	-	0	0	-
Electroch. Proc.	0	0	0	0	-	-	-	-	0	0	-
Other proc. uses	0	0	0	0	-	-	-	-	0	0	-
Steam & w.h. total	**19**	**16.5**	**2**	**3.5**	**NA**	**NA**	**NA**	**NA**	**0**	**11**	**NA**
Process Heating	11	3	0	0	-	-	-	-	0	3	-
Process C&R	0	8	0	0	-	-	-	-	0	8	-
Machine Drive	8	0	0	0	-	-	-	-	0	0	-
Electroch. Proc.	0	0	0	0	-	-	-	-	0	0	-
Other proc. uses	0	5.5	2	3.5	-	-	-	-	0	<1	-
Electricity total	**116**	**124**	**<1**	**2**	**NA**	**NA**	**NA**	**48**	**74**	**<1**	**NA**
Process Heating	1	0	0	0	-	-	-	0	0	0	-
Process C&R	3	2	0	0	-	-	-	0	2	0	-
Machine Drive	111	71	<1	2	-	-	-	0	69	<1	-
Electroch. Proc.	1	<1	<1	0	-	-	-	0	0	0	-
Other proc. uses	0	51	<1	0	-	-	-	48	3	0	-
Grand total	**172**	**169.5**	**5.8**	**5.5**	**6.5**	**<0.1**	**1.2**	**48**	**74**	**28**	**0.4**

F: fluorocarbon, NA: not available, C: cryogenic, NC: non-cryogenic

Source: Ozalp, N. PhD dissertation, University of Washington, 2005

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NOW LET'S COMPLETE RELATING

THE ENERGY USE AND THE EMISSIONS

IN THIS SECTOR BY GIVING

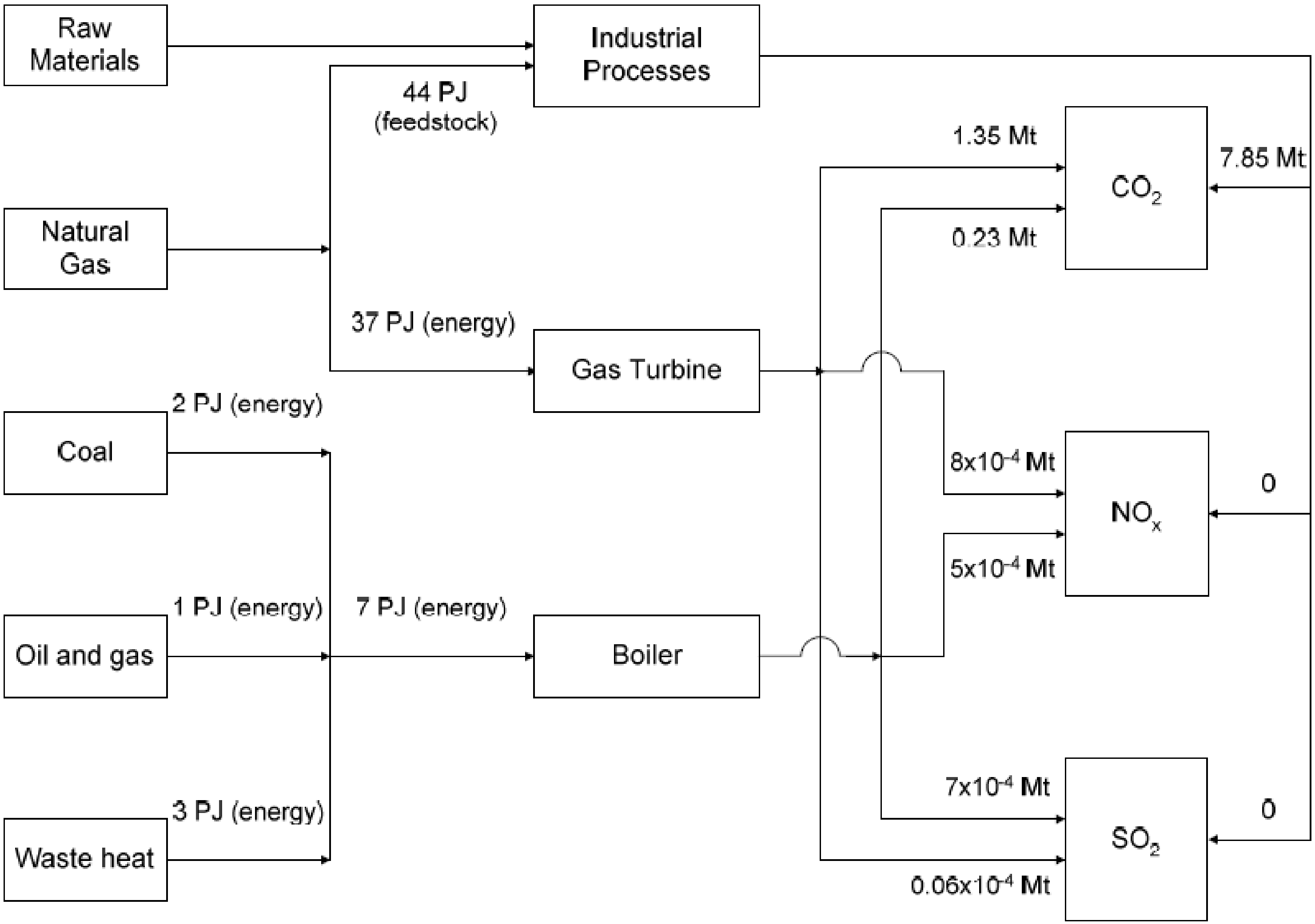
AN EMISSIONS FLOW MODEL

DEPICTING THE ENERGY CONSUMPTION AND

EMISSIONS FROM MANUFACTURING PROCESSES,

AND STEAM & POWER GENERATION

EMISSIONS FLOW MODEL OF THE INDUSTRIAL GAS MANUFACTURING SECTOR



Source: Ozalp, N. PhD dissertation, University of Washington, 2005

CONCLUSIONS

A COMPREHENSIVE AND CONSISTENT DESCRIPTION OF CURRENT MANUFACTURING ENERGY AND MATERIAL USAGE PATTERNS ALONG WITH EMISSIONS PATTERNS CAN PROVIDE INFORMATION ON THE POTENTIAL EFFECT OF TECHNOLOGICAL, ECONOMIC AND PUBLIC POLICY CHANGES IN ENERGY INTENSIVE MANUFACTURING SECTOR.

CONCLUSIONS

THEREFORE, IT IS IMPORTANT TO DEVELOP ENERGY, MATERIAL AND EMISSIONS FLOW MODEL FOR MAJOR ENERGY CONSUMING INDUSTRIES TO SEE THE CHARACTERISTICS OF THE CORELATION BETWEEN ENERGY CONSUMPTION AND EMISSIONS FROM THE MANUFACTURING PROCESSES, AND STEAM & POWER GENERATION.

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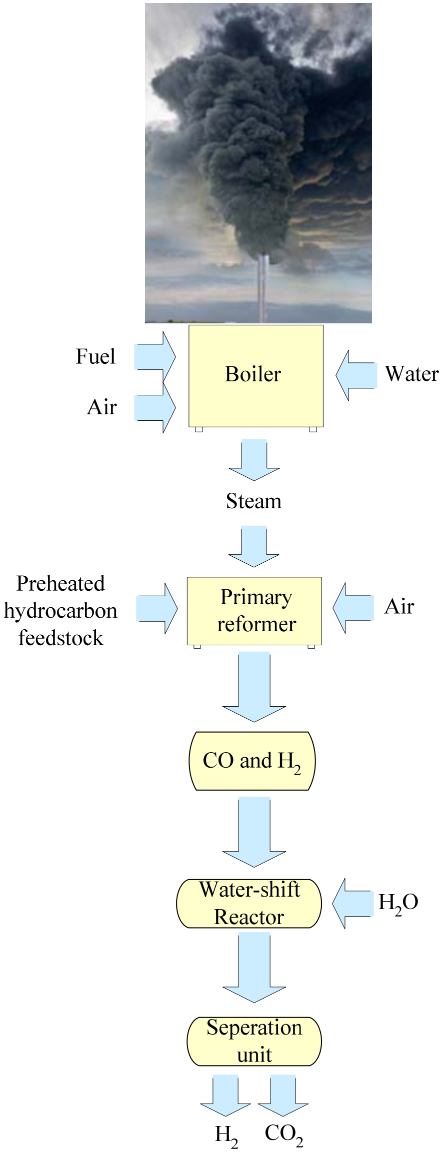
WHAT WOULD BE

AN ALTERNATIVE PROCESS

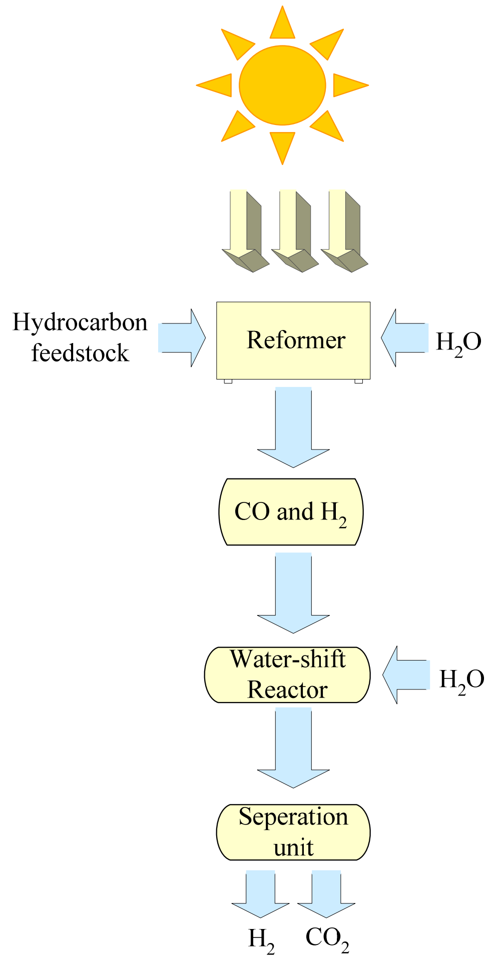
TO AVOID OR REDUCE CO_2 EMISSIONS

IN THE U.S. CHEMICAL INDUSTRY?

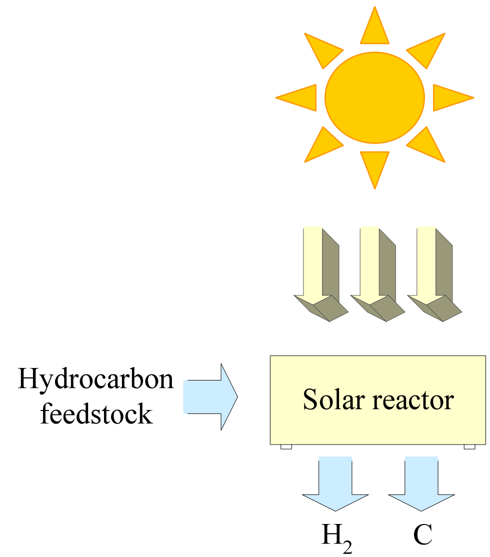
LET'S TAKE A LOOK AT OUR HYDROGEN PRODUCTION EXAMPLE AGAIN TO SUGGEST AN ALTERNATIVE PROCESS TO AVOID AND/OR REDUCE CO_2 EMISSIONS FROM MANUFACTURING



CONVENTIONAL REFORMING



SOLAR REFORMING



SOLAR CRACKING

CONCLUSIONS

THE U.S. CHEMICAL INDUSTRY WOULD HAVE THE FOLLOWING ADVANTAGES IF IT CHANGES ITS CURRENT HYDROGEN PRODUCTION PROCESS AND ON-SITE STEAM&POWER GENERATION FROM TRADITIONAL INTERNAL/EXTERNAL COMBUSTION TO SOLAR REFORMING/GASIFICATION :

→UPGRADED CALORIFIC VALUE OF FUEL

→NO CONTAMINATION OF PRODUCTIONS

→AVOIDING OF IRREVERSIBILITIES RESULTING IN LOWER THERMAL EFFICIENCY

→NO DISCHARGE OF POLLUTANTS

THANK YOU